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Quality monitoring for a water reclamation system in a mandarin orange canning factory

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ABSTRACT

To conserve water in the mandarin orange canning industry, a water reclamation system was designed for a production scale of 50 kL/h. The discharged water from mandarin transportation using a conveyor belt was collected in a pool, chlorinated, filtered by active carbon, and then UV-sterilized. This water was then reused for the processes of segmenting, transportation, and washing after alkaline solution treatment. The water quality had been monitored during the water reclamation. The results showed that the reused water quality was improved by the system and the main physicochemical properties and sensory index were conformed to the requirements of Chinese National Standard GB5749 except the index of chemical oxygen demand. The reused water contained about 0.4 ppm of chlorine and 10 μg/mL of pectin. The total bacterial count was $\leq$ 10 CFU/mL and no *Escherichia coli* was detected. The seasonal production monitoring results showed that the quality of disposed water from this system remained stable. This technology might be useful for water reclamation in other fruit processing plants.

Keywords: Mandarin orange canning; Water reclamation; Water quality monitoring

1. Introduction

Although water is ubiquitous, only about 0.4% is suitable for human consumption [1]. A report from the Committee of Environment and Development of the World in 1988 claims that water is replacing petroleum as a valuable commodity and is causing a worldwide crisis [2]. The World Health Organization (WHO) has estimated that 1,000 cubic meters per person per year is the benchmark level below which chronic water scarcity is considered to impede development and harm human health [3]. A few companies and research institutions had studied water reclamation technology and put into practice [4–6]. China consumes less than one-quarter of the world average per capita water usage, and has one of the 13 poorest water resources in the world [7]. The shortage of water is a serious problem in China. It was estimated that the water supplies fall short of 300–400 million cubic meters every

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year and 70% of the river systems are polluted to various extents [8]. For example, the Huang He is the second longest river in China and 73% of the sewage disposed into the river originates from industrial discharge. The direct economic loss caused by waste water has reached 1.8–2.5 billion USD per year [9]. It is well known that water shortage is one of the most important challenges to mankind in this century [10].

Water conservation contributes to sustainable development and market competitiveness of the food industry. Implementation of water conservation and reuse practices in the food industry faces a great challenge for limiting production costs and maintaining the environment and public health through knowledge, technical expertise, and documentation [11,12]. The Codex Committee on food hygiene proposed guidelines in 2001 for the hygienic processing of reclaimed water in food plants [13], which is a widely accepted standard for water reclamation in food industries. Richard evaluated the public health implications of water reclamation in the food and beverage industry [14], which found that conservative reuse of water had no negative effects on human health. Legislation has been enacted to address water quality, other than drinking water. The US Environment Protection Agency (EPA) in 2004 [15] described guidelines for water reuse. There has been a focus on water reuse technology in canned food factories in Thailand and South Africa. The water reuse rate is greater than 40% in these countries, which reduces production costs and environmental pollution [16,17].

Presently, China ranks first in total fruit canning production worldwide, with exports totaling approximately 1.1 million tons per year. China also ranks first in total canned orange output in the world, accounting for 60–70% of the world's trade volume [18]. Using current processing technologies, the water requirement is quite high, as up to 30–50 kL of water is required to produce a single metric ton of canned mandarin oranges. The environment could be seriously impacted if wastewater is not properly treated. To make matters even worse, wastewater from canning mandarin oranges contains large amounts of organic components, including carbohydrates, acids, pectin, pigments, and essential oils. The biochemical oxygen demand (BOD) is about 6.4 kg/ton and liquid suspensions account for approximately 1.3 ppt of water [19]. Treatment of this type of wastewater is both complex and difficult, and the cost is expected to be very high.

Since there is a higher standard for the safety of food products, water treatment in the food industry must address the potential toxicity of disinfectants and microbiological contamination [11]. Casani and Knøchel [20] proposed a Hazard Analysis and Critical Control Points (HACCP)-based approach for evaluating microbiological contamination to ensure acceptable water quality for different purposes when reusing water from the food industry.

To conserve water in the mandarin orange canning industry, a water reclamation system was designed using a production scale of 50,000 L of water per hour. This project commenced in 2008, some technological improvements and upgrades were introduced, they included the following: sump inlet located stainless steel mechanical grid, which used to intercept pollutants in suspension or floating state; parallel in the original bag filter on the basis of a set of bag filters, each set of bag filter was used in rotation every 12 h, then the bag filter can be cleaned regularly; between the bag filters and activated carbon filter, and between activated carbon filter and UV filter set pressure pump, then the water can be smoothly driven flow through the water treatment system. Its trial run over two production seasons indicated that the quality of reclaimed water met the designated requirements.

2. Materials and methods

2.1. Water reclamation treatment

The basic processing steps of mandarin orange canning factories were similar to typical canning operations, which included raw material selection, washing, peeling/preparation, blanching, sorting/grading, filling, sealing, retorting, cooling, labeling, or storage [21]. The discharged water from these different steps largely varied in quality and quantity. The processing of sorting/grading accounted for 55% of the total water consumption, but the other processing accounted, which include washing, peeling/preparation, blanching, filling, sealing, retorting, and cooling, only for 45% [19]. A conveyor belt was used to transport the fruit in the processing of sorting/grading. Great deal of the fresh water was emptied into the conveyor belt and discharged. This discharged water was selected for reclamation. As shown in Fig. 1, the discharged water from mandarin orange transportation over a conveyor belt was collected in a pool. After chlorination, active carbon filtering, and ultraviolet (UV) sterilization, water was reused for blanching, segmenting, transportation, and washing following alkaline solution treatment. The investment cost of this water reuse treatment system was about $460,000 and the operational cost was approximately $52,000 per production season. Six water quality monitoring points were selected in the system for research purposes.

Three 350 mL water samples were collected at each monitoring point every 4 h during each sampling date and conducted continually throughout the production

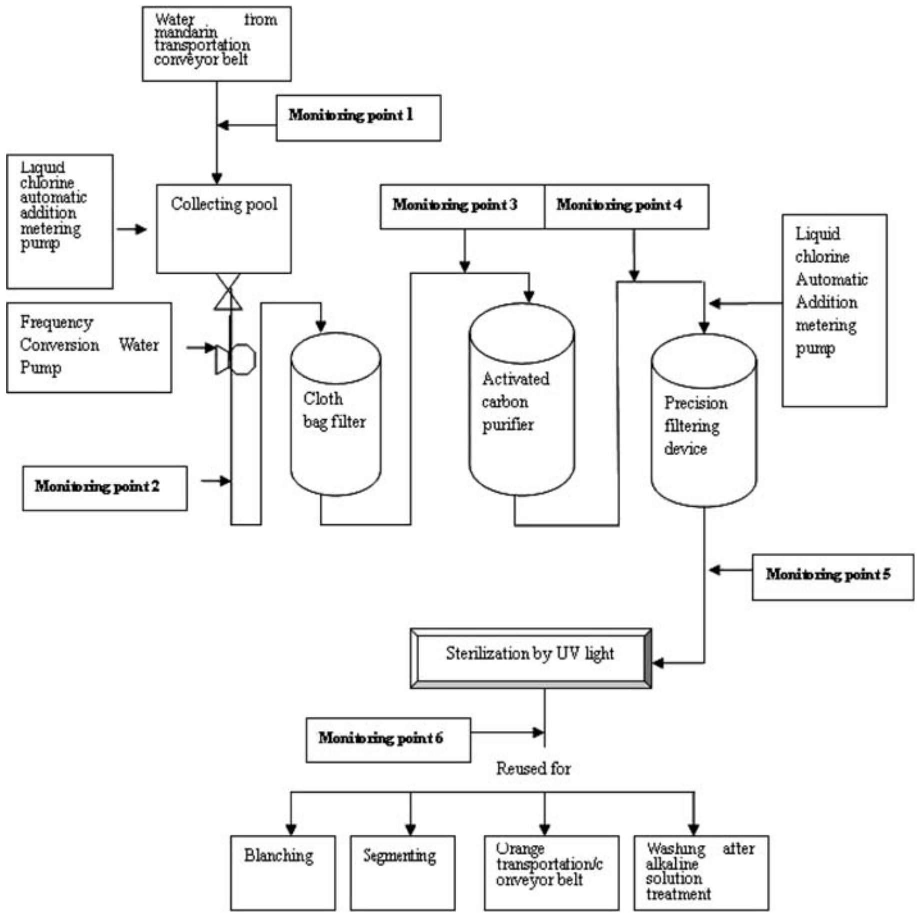

Fig. 1. The water reclamation system and monitoring points in a mandarin orange canning factory.

season. The samples were analyzed in the factory laboratory immediately after collection. The results were reported as means with standard deviations.

2.2. Analytical methods

The water quality parameters of chloride content, pectin content, total bacterial count, *Escherichia coli* and coliform bacteria, and physicochemical parameters of turbidity, chemical oxygen demand (COD), color, perceivable material, total soluble solids, and pH were selected for the analysis.

The chloride content in the samples was determined using a waterproof ExStik CL200 Chlorine Meter (Shanghai San-Xin Instrumentation, Inc. Shanghai, China). The total bacterial count was determined according to the plate count method and the *E. coli* and coliform bacteria contents were determined using the Petrifilm™ method, as described in the literatures of China's Ministry of Public Health GB/T4789.2 and GB/T4789.3 [22].

The pectin content in the water samples was determined by the carbazole and sulfuric acid spectrophotometric method [23] using a ShimadzuUV2550 spectrophotometer (Shimadzu Scientific Instruments, Columbia, MD, USA).

The physicochemical wastewater parameters of turbidity, color, perceivable material, total soluble solids, and pH were determined according to the National Standard Method of Drinking Water Standard Test Methods, Sensory Characteristics, and Physical Indicators (Chinese National Accreditation Service for Conformity Assessment, GB/T 5750.44) [24]. The COD was determined according to the Standard Examination Methods for Drinking Water (Chinese National Accreditation Service for Conformity Assessment, GB/T 5750.7) [24].

3. Results and discussion

3.1. The residual chloride content in the water reclamation system

The residual chloride contents from monitoring points in the water reclamation system during the canning process are presented in Fig. 2. The water obtained from monitoring point 1 was polluted, whereas water at monitoring point 6 was cleaned following treatment. The former had a lower chloride concentration compared with the latter. The untreated water (monitoring point 1) was obtained from the conveyor belt, which was directly supplied to the factory through a long pipeline from the commercial water company, and the chloride content was less than 0.30 ppm. After treatment, the chloride content (monitoring point 6) ranged from 0.30 to 0.40 ppm, which met the free chlorine requirement on disinfectants as set by the Chinese National Standard [25]. The residual chloride content at monitoring point 2 was relatively high (1.5 ppm), mainly because of chlorination treatment. The cloth bag filter had little influence, and the chloride levels at monitoring point 3 were almost the same as that of monitoring point 2. When the water flowed through the activated carbon purifier (monitoring point 4), the level of residual chloride decreased sharply by approximately 70%. The activated carbon purifier's tank was 2,600 mm in diameter and 1,500 mm in height that stored 5 kL of filtration material of core absorbent carbon. It is designed for a production scale of 50 kL/h. The activated carbon had a good adsorption capacity for residual chloride in water, and its efficiency was primarily dependent on the residual chloride concentration [26]. To inhibit microbial growth, a second chlorination unit was added and the level of residual chloride remained at about 1.0 ppm (monitoring point 5). However, the chloride concentration decreased when the water flowed through the UV sterilization device at monitoring point 6, which reduced the remaining chloride by more than 60%. The UV sterilization device was made up of three ultraviolet sterilizers, all of them were in parallel. Each ultraviolet sterilizer was designed for a production scale of 1,620 kL/h, in which nominal capacity was 220 W. It was 219 mm in diameter and 1,200 mm in length, the input pipe diameter was 80 mm. The UV treatment is very effective for chloride degradation, which is dependent on light intensity and treatment duration [27].

3.2. Total bacterial count and E. coli in the water reclamation system

The total bacterial count and *E. coli* detected at various monitoring points in the water reclamation system during operation are presented in Figs. 3 and 4. Water samples obtained from monitoring point 1 contained between 10 and 100 CFU/mL, while the concentration of *E. coli* was less than 10 CFU/mL. Microbial contamination was virtually unavoidable, because the fruit was manually handled during transportation along the conveyor belt. Furthermore, considerable amounts of organic compounds from mandarin orange segments might have been dissolved in the water, which offered nutrients for micro-organism growth. Following the chlorination treatments, the total bacterial count and *E. coli* content of water samples at monitoring points 2 and 5 decreased to less than 1 CFU/mL, suggesting a good disinfection effect.

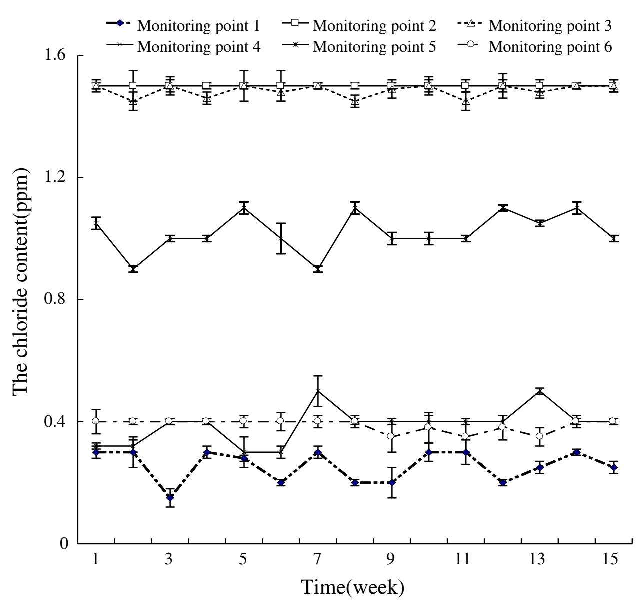

Fig. 2. Residual chloride contents at monitoring points in the water reclamation system.

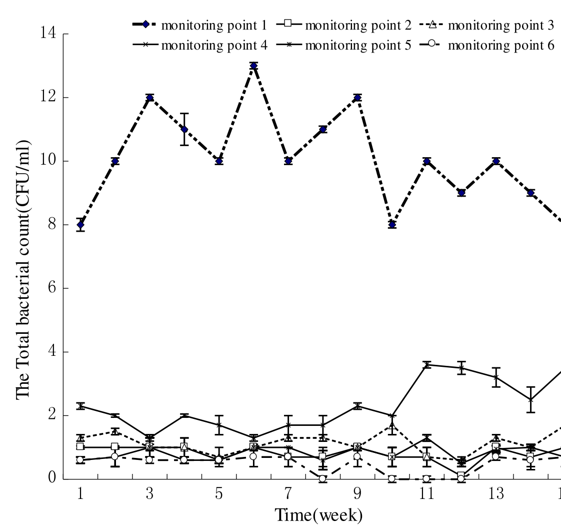

Fig. 3. The total bacterial count at six monitoring points in the water reclamation system of a mandarin orange canning factory.

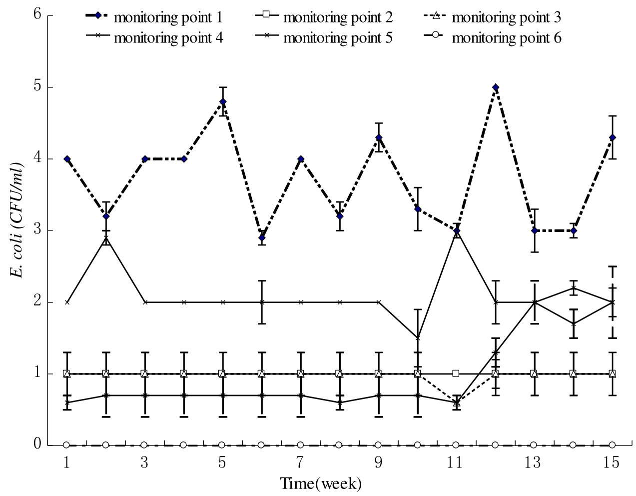

Fig. 4. *E. coli* detection at six monitoring points in the water reclamation system of a mandarin orange canning factory.

At monitoring point 6, the total bacterial count averaged less than 1 CFU/mL and the *E. coli* was not detected in the water after the reclamation process, which met the Chinese National Standard (Standards for Drinking Water Quality, [25], Table 1).

3.3. Changes in pectin content in the water reclamation system

The pectin content of water samples from the water reclamation system was presented in Fig. 5. Monitoring showed that water from the conveyor belt (monitoring point 1) contained the highest amount of pectin (27 ppm), and then gradually decreased as the water passed through the system. Following activated carbon adsorption, the pectin content was reduced to 13.36 ppm (monitoring point 4 in Fig. 5). The cleaned water (monitoring point 6) contained approximately 10 ppm of pectin, but did not induce cloudiness in the water and did not have any negative influences on processing the canned fruit.

3.4. Changes in other physicochemical parameters in the water reclamation system

The changes of other physicochemical water parameters for the water reclamation system were presented in Table 1. Before treatment, the water at monitoring point 1 had a chroma value of 12 Hazen units (HU), turbidity of 6.3 Nephelometric turbidity unit (NTU), and total soluble solids of 157 mg/L. However, water after treatment (monitoring point 6)

Table 1
Changes in physicochemical water parameters during water reclamation

Parameters	Turbidity (NTU)	COD ($mg\ L^{-1}$)	Chroma(HU) (platinum – cobalt color)	Perceivable material	Odor	Total soluble solids ($mg\ L^{-1}$)	pH
Monitoring point							
1	6.3	298.73	12	Many	Slight odor	157	6.56
2	5.8	112.36	10	Little	Slight odor	96	6.85
3	5.5	91.07	8	Little	Slight odor	75	6.88
4	4.1	89.65	6	None	None	61	6.42
5	3.9	70.85	5	None	None	80	6.45
6	2.8	52.46	4	None	None	93	6.70
Chinese National Standard (maximum values) GB 5749-2006	3	3	15	None	None	1,000	6.5–8.5

Note: Turbidity, COD, chroma, total soluble solids, and pH were measured online.

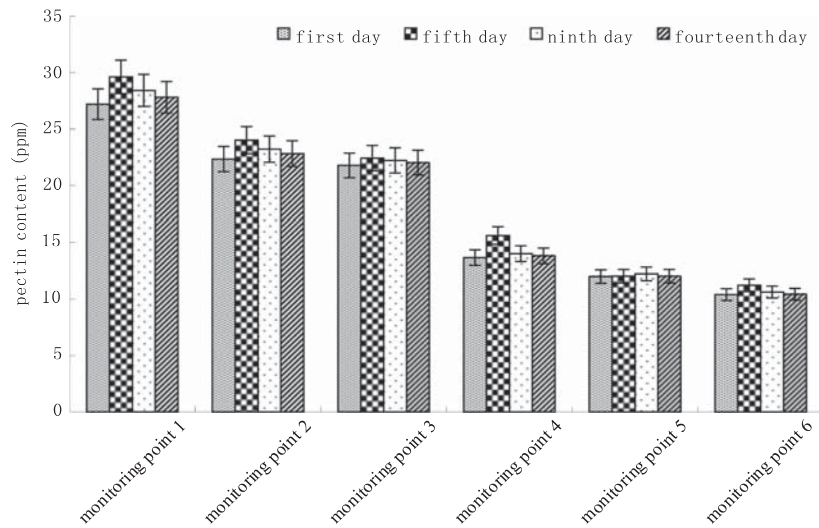

Fig. 5. Pectin content at six monitoring points in a water reclamation system in a mandarin orange canning factory.

had a chroma value of 4 HU, turbidity of 2.8 NTU, and total soluble solids of less than 100 mg/L. The data showed that the sensory index improved significantly after the water passed through the reclamation system. The pH values of the water were maintained within the range of 6.4–6.9, which met the Chinese National Standard (Table 1). The water was clear and no abnormal smell was detected. The processed water physicochemical parameters of turbidity, color, perceivable material, total soluble solids, and pH met the Chinese National Standard [25].

The COD value (52 mg/L) was notably higher than that of the Chinese National Standard, which may have been caused by dissolved pectin in the water [28,29]. Pectin is a constituent of oranges, therefore a high COD value might not be a concern for the safety and quality of the canned mandarin processing, providing that the micro-organisms were well controlled (Section 3.2). The COD values indicate the organic pollution levels in water. Many studies on organic pollution in water treatment have addressed biochemical treatments [30–33], while few have reported that the COD value was sufficiently controlled within the range of 100 mg/L, if the wastewater had not been biochemically treated. Soluble components of the raw material were easily dissolved in water during the production process. The water COD value of the present reclamation system reached about 52 mg/L, which illustrated its efficiency in water quality improvement.

4. Conclusions

A water reclamation system was designed for a mandarin orange canning factory with a production rate of 50,000 L/h. From the mandarin processing line, the water from a conveyor belt area was collected and treated by chlorination, active carbon filtration, and UV sterilization. The water after reclamation was clear, with most of the physicochemical parameters meeting the Chinese National Standard [25]. Reclaimed water could then be reused for mandarin grading, segmenting, conveying, and washing following alkaline treatment. This system can save 100,000 L of water per hour, which equates to 840,000,000 L of water that can be saved over one production season (8 h/day and 105 days/production season). As water is a very important, but scarce, resource in China and around the world, this water reclamation system could be a practical and economical approach in other fruit and vegetable canning factories.

Acknowledgments

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