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Softened Water and Steam Boiler Water Condensate Quality used in the Milk Production Line of a Private Dairy Unit Located in Bechar Province (South-West of Algeria): Physicochemical and Bacteriological Analysis

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ABSTRACT

Background: This study aimed at assessing the physicochemical and bacteriological parameters of the water at the softener outlet and the steam boiler water condensate of a dairy unit located in Bechar province (South-West of Algeria).

Methods: Some physicochemical and bacteriological parameters were analyzed based on standard methods given by the American Public Health Association (APHA).

Result: The obtained results showed that the parameters: pH, EC, salinity, TA, TAC, sulfate, nitrate, and fluoride ions of most analyzed water samples at the softener outlet (SW) were in agreement with national regulations. However, the steam boiler water condensate samples (BW) were out of specification except for TA, TAC, nitrate, and fluoride ions. The SW and BW samples were qualified as very hard exceeding the standard set at 15°f and 10,5 to 11,5°f, respectively, with high salinity and TDS values. The bacteriological analysis showed that most of the steam boiler water condensate samples complied with national regulations with the absence of fecal coliforms, knowing that the BW5 and BW8 samples were contaminated with spores of sulfite-reducing Clostridia at a load of 3 and 1 spore/50 mL, respectively. However, an average of 6/10 (*i.e.* 60%) of the softened water samples were contaminated with the opportunistic species '*Pseudomonas aeruginosa*', while the SW5, SW8 and SW10 samples were contaminated with spores of sulfite-reducing Clostridia (1 to 11 spores/50 mL). All samples were free from *Salmonella* spp. A high TH of the water at the softener outlet reveals a malfunction of the external treatment (softening). On the one hand, boiler scaling that may occur can reduce the steam flow (low efficiency of the heat treatment), which contributes to poor pasteurization of the milk, especially in the presence of bacterial contaminants, and on the other hand, increase the energy expenditure.

Key words: Bechar (Algeria), Physicochemical and bacteriological analysis, Private dairy unit, Process water, Softener, Steam boiler.

INTRODUCTION

Food safety has always been considered a challenge for manufacturers, and one of the means to ensure it within the production chain is that of water steam applied in agrifood industries as heat treatment (Benyagoub, 2011; Benyagoub *et al.* 2017). On an industrial scale, heating and cooking are done by moist heat, and the control of this operation, particularly during processing can contribute to the reduction of food loss, which was estimated at 750 billion dollars worldwide (Tremblay, 2015). Food loss has repercussions beyond the socioeconomic framework and can extend to health and environmental issues.

Water in the form of ice or steam is a possible vector and/or reservoir of microbiological and chemical hazards. These hazards may be present in the resource being used. They can also be generated during the treatment, storage and distribution of water within the company if appropriate measures for controlling its quality are not applied (ANSES, 2014).

To this end, the food industry must take all the measures to ensure the good quality of the steam used directly for the production and processing of food (Josse *et al.* 2011). The study's aim is then to focus on assessing the performance of the steam boiler and the softener of a dairy unit located in Bechar (South-West of Algeria) by analyzing some physicochemical and bacteriological parameters of the water at the softener outlet as well as the steam boiler water condensate.

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MATERIALS AND METHODS

All experiments were carried out at Mohammed Tahri University of Bechar (Algeria), for three months from April to June 2021.

Studied dairy unit

The dairy unit is located in Nif Errhaa-Ouakda 14 km north of Bechar **(**Southwest of Algeria), and specializes in the production of pasteurized partially skimmed milk, fermented milk, and lemonade. The production can go up to 40000 liters of milk as a maximum production per day (Benyagoub *et al*., 2018a; Benyagoub, 2019). The dairy unit under study has a steam production unit where the produced steam is mainly used for the pasteurization of milk (partially skimmed milk and milk used for the production of fermented milk 'Leben') and lemonade, as well as for the cleaning of the equipment. This system includes a water softener, a steam trap associated with the boiler (Fire tube boiler), a softened water tank, a feed water tank, and a condensate return (Fig 1), whose the produced steam is mainly used for heating water and milk pasteurization (Fig 2). The softener is composed of an R-SO_3Na cation exchange resin and a reservoir of saturated NaCl solution, which regenerates the resin (Josse *et al.* 2011; Benyagoub *et al.* 2018a; Benyagoub, 2019).

Sampling conditions

Water sampling was done according to the method described by Rodier *et al*. (2009), in sterile glass flasks (Fig 3). Softened water and steam boiler water condensate samples were collected, ten of each (Table 1). While the various analyses were done at Mohammed Tahri University of Bechar (Algeria).

Physicochemical and bacteriological analysis

All analyzed parameters were carried out based on standard methods given by the American Public Health Association (Lipps *et al*. 2022). The collected water samples have undergone physicochemical analysis by measuring the following parameters: pH, temperature, electrical conductivity (EC), salinity, total dissolved solids (TDS), sulfate, phosphate, nitrate, fluoride, oxidizable organic matter (OOM), total suspended solids (TSS), total hardness (TH), alkalimetric title (TA) and the complete alkalimetric title (TAC). However, bacteriological analysis was based on the detection and enumeration of the following bacterial parameters (JORA n.39, 2017): Total aerobic mesophilic flora (TAMF at 22 and 30°C), total coliforms, fecal coliforms, fecal streptococci (Enterococci), sulfite-reducing Clostridia, *Salmonella* spp, and *Pseudomonas* spp, if any, suspected pathogenic bacteria have undergone differential biochemical tests according to standard microbiological methods as described by Tille (2018); Benyagoub *et al.* (2018b).

RESULTS AND DISCUSSION

Bacteriological analysis

The bacteriological analysis results of softened water and steam boiler water condensate samples are shown in Table 2.

The bacteriological analysis showed that the steam boiler water condensate samples complied with national regulations except for the BW7 sample (*i.e*. 1/10) which had a high TAMF load at 22 and 30°C (3,41 and 2,9 Log_{10} CFU/mL, respectively). In addition, both BW5 and BW8 samples revealed contamination with spores of sulfite-reducing

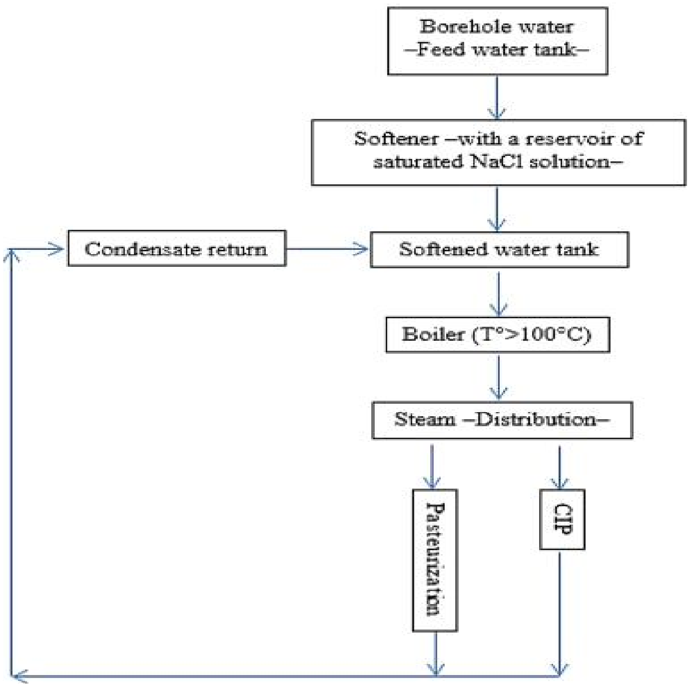

Fig 1: Steam production diagram (Source: Private dairy unit). CIP: Cleaning in place.

Clostridia (3 and 1 spore/50 mL, respectively). The compliance of almost all the steam boiler water condensate samples was due to both the high temperature and the pressure generated by the steam boiler (Zerouali, 2020).

An average of 6/10 (*i.e.* 60%) of the water samples at the softener outlet were contaminated with *Pseudomonas* spp and four samples, namely SW2, SW3, SW5, and SW10 had TAMF loads ranging from 2,11 to 3,98 Log_{10} CFU/mL exceeding the standard for drinking water set at 2 Log_{10} CFU/mL. Bacteriological analysis revealed that the SW9 sample was contaminated with total coliforms, while the SW5, SW8 and SW10 samples had a sulfite-reducing Clostridia spores load of 11; 6; and 1 spore/50 mL, respectively. However, all samples were *Salmonella* spp-free.

Table 1: Frequency and dates for collection of softened water and steam boiler water condensate samples.

Samples	Dates of collection
SW-BW (1)	April 22, 2021
SW-BW (2)	April 25, 2021
SW-BW (3)	April 29, 2021
SW-BW (4)	May 4, 2021
SW-BW (5)	May 10, 2021
SW-BW (6)	May 15, 2021
SW-BW (7)	May 24, 2021
SW-BW (8)	May 27, 2021
SW-BW (9)	May 31, 2021
SW-BW (10)	June 5, 2021

SW (1 to 10): Softened water samples; BW (1 to 10): Steam boiler water condensate samples.

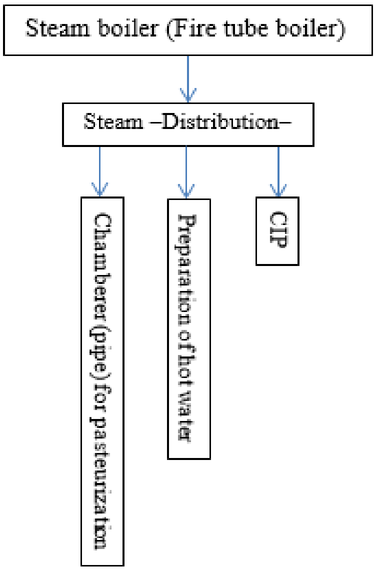

Fig 2: Steam distribution (Source: Private dairy unit). CIP: Cleaning in place.

The identification results of the strains isolated during the search for pathogenic bacteria are given in Table 3 and Fig 4.

The isolated bacterial strains were identified as follows: *Pantoea* spp, *Aeromonas hydrophila* and *Enterobacter cloacae.*

The microbiological and physicochemical quality of softened water depends on the quality of the feed water tank (Ouadi and Remili, 2021). A recent study on the feed water tank quality for the studied dairy unit revealed that it had the same bacteriological characteristic as the water at the softener outlet which was *Salmonella* spp-free and contaminated with the opportunist species *'P. aeruginosa'* (Ouadi and Remili, 2021). This opportunistic pathogen has significant capacities for adaptation, resistance and persistence in the environment, particularly in the form of biofilms (Pessereau, 2015), where the complexation of iron with mineral elements present in the water such as Cl^-, SO_4^{2}, OH^-, PO_4^{3} and HCO_3^- is likely to affect the biofilm-forming capacities of *P. aeruginosa* (Imperi and Visca, 2013).

Physicochemical analysis

The physicochemical analysis results of softened water and steam boiler water condensate samples are shown in Table 4.

The physicochemical parameters of the analyzed water samples, namely: pH, TA, TAC, chloride, phosphate, nitrate and fluoride contents were in accordance with national regulations, except for the following steam boiler water condensate samples, namely BW5, BW7, BW8 and BW9, which have exceeded the threshold set for nitrate ions. However, the TDS and consequently EC, salinity and TH parameters had values exceeding the limits established by the legislator where according to Josse *et al.* (2011), the high concentration of dissolved solids in the boiler decreases the heat transfer which reduces boiler efficiency. For this reason, the water that is used must not only allow continuous heat exchange and protection against corrosion by removing

(a) (b)

(A): Steam boiler water condensate; (B): Softened water.

Fig 3: Water samples (Original, 2021).

oxygen from the water and ensuring sufficient alkalinity for this purpose, but it must also minimize the scaling and ensure high-quality steam production.

Concerning the scaling, the external treatment here consisted of softening the feed water where the carried-out analyses revealed that the hardness of the water at the softener outlet was high throughout the study period. A previous study conducted by Ouadi and Remili, (2021) focused on the feed water tank of the studied private dairy unit showed a total hardness ranging from 30 to 115°f, a level promoting the creation of calcium and magnesium scale on the boiler compartments.

Due to the absence of filtration treatment as an authorized treatment for the food industries by using filtration materials namely flint sand, anthracite and/or activated carbon revealed by the high rates of TSS and OOM, as well as the malfunction of the softener, that the physicochemical parameters of the water at the softener outlet, namely: TH,

(a): Multitube-most probable number technique for total coliforms on Bromo Cresol Purple Broth w/Lactose (SW 9); (b): Multitube-most probable number technique for total coliforms on BCPL broth (BW5); (c): Mackenzie test for fecal coliforms on Buffered water and Bromo Cresol Purple Broth w/Lactose; (d): Coliform on Hektoen enteric agar (BW8); (e): *Pseudomonas* sp on Cetrimide-Nalidixic acid agar (SW7); (f): Search for *Salmonella* sp on Salmonella Shigella agar (BW3); (g): TAMF on TGEA medium (Tryptone Glucose Yeast Extract Agar) (SW3); (h): *Pseudomonas* sp on Cetrimide-Nalidixic acid agar (SW3); (i): Search for *Salmonella* sp on Salmonella Shigella agar (SW1); (j): API 20E test (SW3), (k): API 20E test (SW2); (l): Sulfite-reducing Clostridia (BW8); (m): Search for *Salmonella* sp on Salmonella Shigella agar (SW7); (n): Confirmation test for fecal streptococci on EVA Litsky medium (SW2); Source: Own study.

Fig 4: Illustration of the bacteriological analysis of softened water and steam boiler water condensate samples (Original, 2021).

Table 2: Bacteriological analysis results of softened water and steam boiler water condensate samples.

S	TAMF (n Log10 CFU/mL)		Coliforms (CFU/ 100 mL)		Enterococci (CFU/ 100 mL)	SRC (spore/ 50 mL)	*Salmonella* spp., (per 250 mL)	*Pseudomonas* spp., (per 250 mL)
	22°C	30°C	TC	FC				
SW1	0.3	1.38	<0.3	<0.3	<0.3	0	-ve	-ve
BW1	0.3	0.3	<0.3	<0.3	<0.3	0	-ve	-ve
SW2	2.08	1.34	<0.3	<0.3	<0.3	0	-ve	+ve
BW2	1.41	0.3	1.5	<0.3	<0.3	0	-ve	-ve
SW3	2.25	2.22	4	0.7	2.3	0	-ve	+ve
BW3	0.84	<0.3	0.7	<0.3	<0.3	0	-ve	-ve
SW4	0.3	0.3	0.4	<0.3	<0.3	0	-ve	-ve
BW4	0.3	0.48	2.3	<0.3	<0.3	0	-ve	-ve
SW5	1.79	2.11	4	0.9	0.4	11	-ve	+ve
BW5	1.4	0.3	<0.3	<0.3	<0.3	3	-ve	-ve
SW6	0.3	0.84	0.3	<0.3	<0.3	0	-ve	-ve
BW6	0.7	0.48	1.1	<0.3	<0.3	0	-ve	-ve
SW7	2.04	0.84	1.1	<0.3	<0.3	0	-ve	+ve
BW7	3.41	2.9	<0.3	<0.3	<0.3	0	-ve	-ve
SW8	0.3	2.07	2.3	<0.3	<0.3	6	-ve	+ve
BW8	0.3	0.3	<0.3	<0.3	<0.3	1	-ve	-ve
SW9	1.04	1.04	21	<0.3	<0.3	1	-ve	+ve
BW9	0.3	0.3	<0.3	<0.3	<0.3	0	-ve	-ve
SW10	2.98	3.25	1.1	0.3	0.4	1	-ve	-ve
BW10	0.9	<0.3	<0.3	<0.3	<0.3	0	-ve	-ve
A.S	/	/	10	<1	<1	<1	Abs	Abs
WHO (2017)	2	1.3	<1	<1	<1	0	/	Abs

S.: Samples; SW: Softened water samples; BW: Steam boiler water condensate samples; Sal: *Salmonella* spp; *P. aeruginosa*: *Pseudomonas aeruginosa*; TC: Total coliforms; FC: Fecal coliforms; TAMF: Total aerobic mesophilic flora; SRC: Sulfite-reducing Clostridia; CFU: Colony-forming unit; A.S: Algerian standard, Abs: Absence of bacterial pathogen; +ve: Positive; -ve: Negative; WHO (2017): World Health Organization guidelines (2017); A.S: Algerian Standard (JORA n.39, 2017); Source: Own study.

Table 3: Identification of presumed pathogenic bacteria isolated from softened water and steam boiler water condensate samples.

S	*Salmonella* spp., (per 250 mL)	*Pseudomonas* spp., (per 250 mL)
SW1	-ve	-ve
BW1	-ve	-ve
SW2	-ve (*Pantoea* spp, *P. aeruginosa*)	+ve (*P. aeruginosa*)
BW2	-ve	-ve
SW3	-ve (*P. aeruginosa*)	+ve (*P. aeruginosa*)
BW3	-ve	-ve
SW4	-ve	-ve
BW4	-ve	-ve
SW5	-ve (*P. aeruginosa, Enterobacter sakazakii*)	+ve (*P. aeruginosa*)
BW5	-ve	-ve
SW6	-ve	-ve
BW6	-ve	-ve
SW7	-ve	+ve (*P. aeruginosa; P. horyzihabitans*)
BW7	-ve	-ve
SW8	-ve (*Enterobacter cloacae, Aeromonas hydrophila*)	+ve (*P. aeruginosa*)
BW8	-ve	-ve
SW9	-ve	+ve (*P. aeruginosa*)
BW9	-ve	-ve
SW10	-ve (*Aeromonas hydrophila*)	-ve
BW10	-ve	-ve

S. parameter: Suspected bacterial; Samp.: Water samples; *P. aeruginosa*: *Pseudomonas aeruginosa*; +ve: A positive culture for a presumed isolate; -ve: A negative culture for a presumed isolate; Source: Own study.

Table 4: Physicochemical analysis results of softened water and steam boiler water condensate samples.

S	pH	T (°C)	EC (µS/cm)	Salinity (‰)	TDS (mg/L)	TH (°f)	TA (°f)	TAC (°f)	Chloride (mg/L)	Sulfate (mg/L)	Phosphate (mg/L)	Nitrate (mg/L)	Fluoride (mg/L)	OOM (mgO_2/L)	TSS (%)
SW1	7.93	16.8	1050	0.5	518	60	0	20	35.5	64.1	0.28	8.26	0.35	11.2	0.011
BW1	8.52	18.3	6277	3.42	3033	70	0	0	106.5	85.4	0.57	54.1	0.48	16	0.019
SW2	7.62	20.8	4224	2.24	2198	275	0	0	284	64.1	0.28	18.2	0.11	6.4	43.81
BW2	8.28	21.2	4224	2.24	2198	100	0	0	35.5	85.4	0.28	38.9	0.33	16.8	35.96
SW3	8.05	16.1	1073	0.5	529	60	0	25	35.5	85.4	0.57	6.82	0.53	17.6	43.65
BW3	8.69	15.9	5270	2.84	2770	140	0	0	71	85.4	0.28	49.7	0.3	16	35.8
SW4	7.63	15.8	1380	0,6	687	115	0	12,5	35.5	85.4	0.57	8.02	0.31	22.4	43.81
BW4	8.69	18.2	5763	3.12	3050	230	0	0	53.25	64.1	0.57	54	0.32	12	35.96
SW5	7.77	29.5	1127	0.56	557	25	0	7,5	35.5	42.7	0.28	6.48	0.31	16.8	50.18
BW5	8.72	30.5	6451	3.52	3430	110	0	0	71	42.7	0,85	60.1	0.34	12.8	35.18
SW6	8.33	15.7	1085	0.5	535	15	0	0	35.5	64.1	0.57	7.64	0,3	13.6	43.81
BW6	8.57	15.8	6018	3.27	3019	90	0	0	177.5	42.7	0.57	58.5	0.27	9,6	35.96
SW7	7.57	13.4	25599	15.68	1513	2910	0	10	142	128.1	0.28	39.2	0.06	12.8	43.81
BW7	7.63	15.3	6875	3.78	3670	40	0	10	106.5	106.8	0.28	88.5	0.33	8.8	35.96
SW8	7.50	29.7	1122	0.55	554	95	0	0	53.25	42.7	0.57	11.3	0.32	12.8	43.81
BW8	8.11	23.1	6490	3.55	3450	365	0	0	124.25	42.7	0.28	80.5	0.45	12	75.44
SW9	7.86	21.3	1078	0.53	532	65	0	10	35.5	42.7	0.57	7.51	0.86	12	43.81
BW9	8.08	22.1	6584	3,6	3510	420	0	0	284	42.7	0.28	80.3	0.37	9.6	35.96
SW10	7.50	16.2	1059	0.52	522	90	0	25	71	85.4	0.28	7.66	0.66	9.6	43.81
BW10	6.95	17	5833	3.09	3160	260	0	0	177.5	64.1	0.28	68.2	0.34	13.6	35.97
A.Std. (S)	6.5-8.5	/	2800	1	1000	15	/	/	500	400	0.5	50	1.5	5	/
A.Std. (B)	/	/	/	2-2.5	/	10.5-11.5	40-50	70-90	/	/	20-30	/	/	/	/
Min value (S)	7.62	13.4	1050	0.5	518	15	0	0-0	35.5	42.7	0.28	7.51	0.06	6.4	0.011
Max value (S)	8.33	29.7	25599	15.68	2198	2910	0	25	284	128.1	0.57	39.2	0.86	22.4	50.18
Mean value (S)	7.776	19.53	3879.7	2.218	814.5	371	0	11	76.325	70.47	0.425	12.109	0.381	13.52	40.0511
Min value (B)	6.95	15.3	4224	2.24	2198	40	0	0	35.5	42.7	0.28	38.9	0.27	8.8	0.019
Max value (B)	8.72	30.5	6875	3.78	3670	420	0	10	177.5	106.8	0.85	88.5	0.48	16.8	75.44
Mean value (B)	8.224	19.79	5978.5	3.243	3129	182,5	0	1	120.7	66.2	0.424	63.28	0.353	12.72	36.2209

S: Samples; SW: Softened water samples; BW: Steam boiler water condensate samples; T: Temperature (°C); TDS: Total dissolved solids; TH: total hardness or Hydrotimetric title; TA: Alkalimetric title; TAC: Complete alkalimetric title; TSS: Total suspended solids or suspended matter; T (°C): Temperature in degrees Celsius; °f: French degree; OOM: Oxidizable organic matter; EC: Electrical conductivity; AS. (S): Algerian Standard for softened water (SUDLAIT dairy unit, 1986); AS. (B): Algerian standard for steam boiler water condensate (SUDLAIT dairy unit, 1986); Min value: Minimum value; Max value: Maximum value; Source: Own study.

EC, salinity and TDS exceeded the threshold set by national regulations. Knowing that upstream, the physicochemical parameters result of the feed water reported in a previous study (Ouadi and Remili, 2021) complied with national regulations, except for the TSS parameter.

According to experts, the efficiency of the boiler is 80"92%, and heat losses in the system are often around 15%. Therefore, only 65 to 77% of the total thermal energy of the fuel can be used for steam production (Broutin and Goudiaby, 2021). To maintain this performance, the maintenance of the entire system is highly required. The treated water upstream of the boiler not only ensures a continuous heat exchange, but also protects it against corrosion, and therefore produces high-quality steam. Attention to boiler maintenance is extremely important, which can reduce operating costs and extend equipment life (Randriarivo and Rakotomalala, 2014).

The EC, salinity and TDS at the boiler level exceed that of the water at the softener outlet. This difference in salt levels is explained by the evaporation effect of the water in the boiler (Zerouali, 2020).

Given that the boiler is a device that allows the continuous transfer of thermal energy into a fluid that produces steam from heated water using fuel, industrial boiler water treatment is an essential step in the protection of steam production and distribution equipment (Bahadori, 2016). According to Some (2013); Randriarivo and Rakotomalala (2014), internal treatment by removal of impurities inside the boiler system is highly required. Its purpose is to react properly to water hardness, remove sludge, reduce oxygen, as well as prevent boiler water priming and foaming (Boiler water foaming means bubbles or foam that forms on the surface of the boiler water and comes out with the steam, while boiler water priming is the contamination of the steam with boiler-water solids).

In addition, an analytical monitoring plan for water quality comprising two programs must be respected; A self-monitoring program carried out by the manufacturer himself, and sanitary control carried out by the relevant state service, especially since the used process water does not come from a public distribution (Decree n. 2010-344, 2010; Benyagoub *et al.* 2018c).

CONCLUSION

Except for the opportunistic species ‘*P. aeruginosa*’, the bacteriological analysis results seem to comply with national regulations. While the physicochemical properties of the water at the softener outlet are not suitable for the production of steam because of its high TH values where the analyzed water was qualified as very hard. For this private dairy unit, managers should take the necessary corrective measures to restore the quality of the water intended for steam production by replacing the old softener with a new one or changing the old softener resin to respect the quality limits set by national regulations. On an industrial scale, the efficiency of the external and internal water treatment guarantees a good quality of the produced steam, and consequently, the applied heat treatment ensures the safety of foodstuffs. However, it is also necessary to improve and adapt steam production systems in food processing according to technical, financial, and geological conditions.

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