Valorization of Concentrated Dairy White Wastewater by Reverse Osmosis in Model Cheese Production

Sabine Alalam 1, Julien Chamberland 1, Alexia Gravel 1, Véronique Perreault 1, Michel Britten 2, Yves Pouliot 1, Steve Labrie 1 and Alain Doyen 1,*

1 Department of Food Sciences, STELA Dairy Research Center, Institute of Nutrition and Functional Foods (INAF), Laval University, Quebec, QC G1V 0A6, Canada; sabine.alalam.1@ulaval.ca (S.A.); julien.chamberland@fsaa.ulaval.ca (J.C.); alexia.gravel.1@ulaval.ca (A.G.); veronique.perreault.5@ulaval.ca (V.P.); yves.pouliot@fsaa.ulaval.ca (Y.P.); steve.labrie@fsaa.ulaval.ca (S.L.)
2 Food Research and Development Centre (FRDC), Agriculture and Agri-Food Canada, Saint-Hyacinthe, QC J2S 8E3, Canada; michel.britten@agr.gc.ca
*
Correspondence: alain.doyen@fsaa.ulaval.ca

Abstract: Treatment of dairy white wastewater (WW) by reverse osmosis (RO) is usually performed to generate process water and to reclaim dairy components for their valorization. For this study, a mixture of pasteurized milk and WW from a dairy plant was concentrated by RO to achieve a protein concentration similar to that of skimmed milk. Retentates, which are concentrated WW, were used in the preparation of cheese milk. The effect of using model concentrated WW was evaluated on (1) the soluble–colloidal equilibrium between protein and salt, (2) the milk-coagulation kinetics, and (3) the cheese composition and yield. An economic assessment was also carried out to support the decision-making process for implementing a new RO system in a dairy plant for the valorization of dairy WW. The results showed that substituting more than 50% of the amount of cheese milk with model pasteurized WW concentrates decreased the moisture-adjusted cheese yield and impaired the coagulation kinetics. Excessive cheese moisture was observed in cheeses that were made from 50% and 100% model WW concentrates, correlating with a change in the soluble–colloidal equilibrium of salts, especially in calcium. To achieve sustainable and economic benefits, the ratio of added WW concentrates to cheese milk must be less than 50%. However, for such an investment to be profitable to a dairy plant within 0.54 years, a large-size plant must generate 200 m$^3$ of WW per day with at least 0.5% of total solids, as the economic analysis specific to our case suggests.

Keywords: dairy effluents; reverse osmosis; model cheese; rheology; salt equilibrium

1. Introduction

The dairy industry is one of the most important and fastest-growing economic sectors in the food industry, due to a significant increase in population and, consequently, in the demand for dairy products [1]. As a result, there is also a higher demand for resources, particularly water [2]. For example, up to 3.7 L of water to 1 L of processed milk are used in European cheese manufacturing [3]. This creates large volumes of dairy effluents [4] such as white wastewater (WW), whose chemical and bacterial composition is similar to that of diluted skimmed milk [5]. WW is generated as a result of the first rinse in pasteurizers, accounting for 1–3% of non-accidental processed-milk losses [6]. To respect the discharge limits of most developed countries’ current regulations, dairy wastewater must be treated before it is discharged into the environment, either discharged along with other wastewater into municipal wastewater-treatment plants or treated on site if dairy plants have their own equipment.

In dairy-processing plants, pressure-driven membrane-separation processes, especially reverse osmosis (RO), are widely used to limit the environmental impact of dairy effluents by generating process water that can be reused for a cleaning operation after the polishing
Several studies have shown that RO is an economically viable technology, and it is considered as an eco-friendly process, in terms of reducing water (by 35%) and energy consumption (by 36% and 10%, compared to natural gas and electricity) throughout the concentration of dairy by-products [9,11], and as a process that can be easily implemented in dairy plants [12]. Moreover, using RO on WW requires less energy than on other dairy products due to the lower solids content in WW [13].

Reverse-osmosis dairy-WW retentates are usually used as feed supplements [6,14], but little information is available regarding the possible valorization of this by-product in food, especially in dairy products. To our knowledge, only Bräo et al. (2019) have looked into this through evaluating the potential reuse of the milk-based stream in fermented milk beverages and dulce de leche [15]. They concentrated model and real WW by RO and nanofiltration (NF) and suggested using RO to produce process water on site and as a milk ingredient. Although they have shown the potential economic benefit of RO [15], no studies have focused on the use of RO WW concentrates as a dairy ingredient in cheese production.

Published works have highlighted the challenges of using RO skimmed-milk concentrates in the production of cheese, and challenges can also be expected with the use of RO WW concentrates. The microbial quality of WW concentrates was studied as part of a previous project [16]. Monitoring the RO filtration of WW concentrates based on their initial bacterial ecosystem, which is similar to that of pasteurized milk, and applying continuous RO for a maximum of 10 h at 50 °C was suggested to improve the microbiological and organoleptic quality of recovered food products. With respect to chemical quality, it is well known that skimmed-milk concentrates produced by RO are characterized by high contents of salts and lactose [17,18] and by high casein-micelle mineralization resulting from the shift of calcium, magnesium and phosphorus from the serum fraction to the colloidal fraction [19–21]. Changes in the milk salt balance may lead to changes in rennet coagulation of casein micelles that can be critical in the cheese-making process [22,23]. Variation in the milk composition could also affect the cutting time, curd moisture content, whey fat losses and curd yield [24,25], and such changes should be investigated.

This study aims to determine the possibility of using model RO WW concentrates as a dairy ingredient in the production of model cheeses. Different percentages (0%, 50% and 100%) of model RO WW concentrates were evaluated to identify the maximum possible WW substitution rate to be used in cheese production without negatively affecting the composition and properties of the cheese. The evaluation included how dilution and concentration cycles affected the cheese-making capabilities and the reversibility of mineral and protein balances in the recovered milk. Finally, the economic impact of implementing a RO system in a dairy plant to generate WW concentrates was estimated.

2. Materials and Methods
2.1. Wastewater Sampling and Preparation of Concentrates

Three different batches (200 L/batch) of dairy WW (pH 7.13 ± 0.14% and 0.05 ± 0.01% of total solids [TS]) were collected at a Canadian dairy plant directly after the first hydraulic flush of a cleaning-in-place (CIP) cycle for an industrial pasteurizer. This wastewater was composed only of remaining pasteurized milk diluted in tap rinse water and was free of CIP solutions. To minimize microbial development, the WW was transported in a refrigerated environment from the dairy plant to Laval University (a 2 h trip). The three WW batches were also kept refrigerated (maximum 3 days) until the RO concentration process. The concentration of milk solids in the WW continuously decreased upon rinsing the pasteurizer due to dilution with water as a function of rinsing time [7]. The late sampling during the first water-rinsing cycle of the CIP process could explain the low concentration of WW. Therefore, to avoid the discrepancy in the levels of low concentration in various samples, skimmed milk was added to the IWW in order to generate model WW with a composition similar to that of the initial WW (0.6% of TS) used in our previous study [5]. To constitute model WW, pasteurized skimmed milk obtained from a local milk supplier was added to the initial WW batches (200 L). Regarding the concentration
of model WW by RO, firstly, the RO membrane was conditioned through an alkaline cleaning cycle, and the pure-water fluxes were determined at 50 °C (TMP of 20 bars). Afterwards, model WW was preheated and concentrated by reverse osmosis (RO) at a constant temperature of 50 °C, as described in our previous work [16]. Filtrations were performed in triplicate using a filtration pilot plant (GEA-Niro, Hudson, WI, USA) equipped with a 2 m² spiral-wound polyamide RO membrane (RO22540, Parker Hannifin Corporation, Cleveland, OH, USA) characterized by a 98% average of salt rejection (Parker Hannifin Corporation, Cleveland, OH, USA). The volume concentration factor was chosen in order to reach a protein concentration of 3.2% (similar to that of skimmed milk) which was measured with the LactoScope Fourier-transform infrared spectroscopy (FTIR) Advanced (Delta Instruments B.V., Drachten, The Netherlands). After the concentration step, a cleaning procedure was carried out following the membrane manufacturer’s instructions, as described by Chamberland et al. [9]. Pasteurization (72 °C, 16 s) was then applied to concentrates using a UHT system (CFI-25, Chalinox, Sorel, QC, Canada). Samples from the initial WW, model WW and concentrated pasteurized WW were stored at −30 °C until chemical analysis.

2.2. Cheese-Milk Standardization

For cheese-milk standardization, raw cream (41–42% fat) obtained from a local milk facility (Agropur, Quebec City, QC, Canada) was pasteurized (63 °C for 30 min) using a double-jacket cooker (Stephan Universal Machine UMC 5, Stephan Food Service Equipment GmbH, Hamelin, Germany) under constant agitation. Pasteurized skimmed milk was purchased from a local milk supplier and stored at 4 °C, pending cheese production. Model pasteurized WW concentrates (CWW) were standardized by mixing pasteurized cream and skimmed milk prior to the pH adjustment to 6.2 at 32 °C [21]. Three different cheese-milk mixtures were tested: (1) cheese produced using pasteurized cream and skimmed milk only (0% CWW) (control sample), (2) cheese made from pasteurized cream, 50% skimmed milk and 50% CWW, and (3) cheese made from pasteurized cream and 100% CWW. All cheese milk used for cheese production was composed of 4% protein with a 0.7 protein-to-fat ratio.

2.3. Kinetics of Rennet Gel Formation and Model-Cheese Production

Dynamic low-amplitude oscillatory rheology was used to determine the coagulation kinetics, as described by Perreault et al. (2016) [26]. A stress-controlled rheometer (ARES-G2; TA instruments, New Castle, DE, USA) equipped with concentric cylinders (27.7 and 30 mm in diameter; TA instruments) was monitored to determine the viscoelastic properties of model cheeses. In short, 25 mL of a mixture of cheese milk (0%, 50% and 100% of standardized CWW) was used. The pH of all cheese milk was adjusted to 6.2 by adding lactic acid (21% w/w). The temperature was set to 32 °C and maintained with a Peltier thermal-control system (C-PTD 200; TA instruments). Then, the cheese milk was renneted to achieve a final concentration of 0.01%. A constant strain of 0.1% and a frequency of 1 Hz were fixed in order to record the storage modulus (G’) [21]. The period until G’ increased by 1 Pa is defined as the rennet coagulation time (RCT) [20]. However, to obtain the same gel firmness, the curd was cut when G’ reached 100 Pa. Model cheeses were then produced, and the cheese curds and whey were sampled using the method described by [21]. All were renneted with ChymO-PLUS 1200PRE031 (Fromagex, Rimouski, Quebec, Canada) to achieve a final concentration of 0.01% (0.065 IMCU/mL), as reported in many other studies [20,27,28]. The curd-cutting time was determined from the coagulation kinetics and corresponds to the time required to reach a G’ value of 100 Pa. Cheese milk containing 0%, 50% and 100% of standardized fresh CWW as well as whey samples were stored at −30 °C until chemical analysis. Model cheeses were kept refrigerated at 4 °C after production.

2.4. Determination of Proximate Composition

Initial-white-wastewater (IWW), MWW, CWW, and SM samples were characterized by their contents of total solids, ash, total proteins, total caseins, non-protein nitrogen (NPN),
lactose and fat. The total mineral content, concentrations of Ca, K, Mg, Na and P, and protein and casein contents in the soluble phase (serum) and colloidal phases were analyzed. The pH of all samples was also measured. The same analyses were performed on cheese-milk mixtures (containing 50% and 100% of standardized CWW) and on whey samples, except for NPN, soluble and colloidal salts, proteins, and caseins. To separate the soluble phase (serum proteins and minerals) from the colloidal phase, samples were ultracentrifuged at 100,000 $\times$ g for 1 h at 32 °C (Ultracentrifuge Optima XE-90, Beckman Coulter, Brea, CA, USA). The thin layer of fat was removed, and the supernatants (soluble phases) were collected with a syringe, stored at −30 °C and analyzed for their true-protein, casein and salt contents [29]. The true-protein, casein and salt contents in the colloidal phases were obtained by the difference between the content of those components in the control skimmed milk, CWW and various mixtures of cheese milk and the different soluble phases of each sample. However, different white-wastewater, skimmed-milk, cheese-milk mixtures and whey samples were thawed overnight at 4 °C prior to the analysis. The total solids and ash contents were determined by air-drying methods (AOAC International 990.20 and 945.46, respectively). Ashes were then collected in 3 mL of 20% w/v trichloroacetic acid glacial (TCA; Anachemia, Radnor, PA, USA) and diluted to 50 g with HPLC-grade water prior to filtration by a 0.45 µm filter (Starstedt, Nümbrecht, Germany) to quantify their salt contents. The salts content (Ca, Mg, K, Na and P) was analyzed using an Inductively Coupled Plasma (ICP)—Optical Emission Photometer (OES) (Optima4300 DV, Perkin-Elmer, Waltham, MA, USA). True proteins, non-protein nitrogen (NPN) and caseins were calculated after measurement of total nitrogen (TN), non-protein nitrogen (NPN) and non-casein nitrogen (NCN) by micro-Kjeldahl methods, with a protein-to-nitrogen factor of 6.38 (AOAC International 991.20, 998.05, and 991.21). Lactose concentrations were determined by high-performance liquid chromatography (HPLC) using the ISO 22662 IDF 198 (2007) method [30]. Lipid content was measured using an adaptation of the Mojonnier method (AOAC International 1990, 989.05).

2.5. Cheese Yield and Recovery

The content of proteins, fat, other solids, ash, and calcium in the model cheese was obtained through mass balance calculations of the whey and cheese milk, containing 0%, 50% and 100% CWW. It was analyzed using the methods previously described (Section 2.4).

The final masses (g) of cheese and whey were recorded to calculate the actual yield (%) of model cheese with the following Equation (1):

$$\text{Actual yield} \% = \left( \frac{\text{Mass of curd (g)}}{\text{Mass of cheese milk (g)}} \right) \times 100$$

Following the AOAC International 2005, 948.12 method, gravimetry was used in a forced-air oven at 100 °C for 5 h to dehydrate the shredded cheese curds in order to analyze the moisture content of the cheese 7 days after production. Moisture-adjusted yield (50%) was also calculated using the following Equation (2):

$$\text{Moisture – adjusted yield} \% = \text{actual yield} \times \left[ \frac{1 - \text{Cheese moisture} \%}{1 - \text{Whey moisture} \%} \right] \times \left[ \frac{1 - \text{Whey moisture} \%}{50} \right]$$

The protein retention (%) was calculated using the following Equation (3):

$$\text{True protein retention} \% = \left( 1 - \frac{\text{True protein in the whey} \%}{\text{True protein in the cheese milk} \%} \right)$$

and the fat retention (%) was determined using the following Equation (4):

$$\text{Fat retention} \% = \left( 1 - \frac{\text{Fat in the whey} \%}{\text{Fat in the cheese milk} \%} \right)$$
2.6. Economic Evaluation

To evaluate the economic impact of implementing an RO system for WW valorization in a dairy plant, an economic predictive analysis was performed. The economic assessment was studied to compare four different scenarios. The first scenario consisted of a discharge of WW effluents into municipal drains. The other three scenarios took into consideration a valorization of concentrated WW by RO used as a milk ingredient. More specifically, and according to their initial total-solid contents (0.05%, 0.1% and 0.5%), the concentrated WW by RO could be reintroduced into the unpasteurized fresh milk that was received and that was destined to be used in the production of model cheeses.

According to the Canadian Dairy Commission “all milk utilization must be declared as per their final end-use. The Harmonized Milk Classification System (HMCS) defines under which class milk components used in the manufacture of a finished dairy product must be declared in order to comply with this policy”. Therefore, we considered that the use of WW concentrated by RO will be classified as Class 3 (a) 1, intended for use in “cheese with a minimum casein content of 95%, derived from fluid milks not mentioned elsewhere”.

The values of 0.05% and 0.1% TS were respectively chosen in relation to TS content in WW used in the present work and in our previous study [5]. The value of 0.5% TS was chosen to reflect the higher potential TS content in dairy WW. In these three scenarios, water reclamation using RO was also considered. For the different simulations, we considered that 1000 m$^3$ of milk per day would be processed in a dairy company that generates 200 m$^3$ of WW, as described by Brão et al. (2019) [15]. In all scenarios, filtration was fixed to 10 h with a cleaning frequency of 4 h per day in these virtual plants, a permeate flux of 17 L/m$^2$ h and a feed pressure of 1300 kPa [12,15].

The feed rate ($Q$, m$^3$/h) was calculated using the equation below (5) as a function of permeate volumes ($V_p$, 198.75, 197.51, 187.53 m$^3$) generated after the concentration of the initial WW (0.05%, 0.1% and 0.05% TS, respectively) to reach approximate total solids equal to that of skimmed milk (8%), during 10 h ($\Delta t$, h).

$$Q \left(\text{m}^3/\text{h}\right) = \frac{V_p \left(\text{m}^3\right)}{\Delta t \left(\text{h}\right)} \quad (5)$$

The required membrane area was calculated according to the equation below (6), where $A$ is the required area (m$^2$), $Q$ is the flow rate (L/h), and $J$ is the permeate flux (L/h m$^2$).

$$A \left(\text{m}^2\right) = \frac{Q \left(\text{L/h}\right)}{J \left(\text{L/h m}^2\right)} \quad (6)$$

The active power required for the pump ($P$, W) of the RO systems was calculated according to the equation below (7), where $Q$ is the flow rate of the fluid (m$^3$/s), $p$ is the feed pressure (Pa) for 85% of the pump performance.

$$P \left(\text{W}\right) = \frac{Q \left(\text{m}^2/\text{s}\right) \times p \left(\text{Pa}\right)}{0.85} \quad (7)$$

The pumping energy ($E$, kWh) was calculated using the equation below (8). It is a function of the active power ($P$, kW) over time ($\Delta t$, h).

$$E \left(\text{kWh}\right) = P \left(\text{kW}\right) \times \Delta t \left(\text{h}\right) \quad (8)$$

The theoretical thermal energy ($ET$, kWh) was estimated using the equation below (9), as described by Méthot-Hains et al. (2016) [31]. Since our WW samples were not water or milk, we decided to fix an approximate specific heat capacity of milk ($C_m$, 0.92 kcal/kg, °C) in Equation (7), with the mass of WW ($M$, kg), and the difference between the initial temperature (4 °C) and the processing temperature of WW (50 °C) ($\Delta T$, °C).

$$ET \left(\text{kWh}\right) = C_m \left(\text{kcal/kg, °C}\right) \times M \left(\text{Kg}\right) \times \Delta T \left(\text{°C}\right) \quad (9)$$
Finally, the total energy consumption of the RO system \((E_{\text{total}}, \text{kWh})\) was the sum of the pumping energy and the thermal energy, calculated using the following Equation (10), as also described by Méthot-Hains et al. (2016) [31].

\[
E_{\text{total}} \text{ (kWh)} = E \text{ (kWh)} + ET \text{(kWh)}
\]  

(10)

Table 1 below details all the unit prices of the basic economic-assumption calculations.

| Units                                | Unit Price  | References                                                                 |
|--------------------------------------|-------------|-----------------------------------------------------------------------------|
| Electricity                          | 0.03306 CA$/kWh | Hydro-Quebec in 2021 for business customers with a contract power of more than 5000 kW (rate L) |
| Electrical power                     | 0.433 CA$/kW day | [31]                                                                       |
| Water used for membrane cleaning and rinsing | 0.10 m³/m² of membrane | [9]                                                                 |
| Cleaning solutions                   | 0.97 CA$/m³ (per employee) | [9]                                                                    |
| Human resources (3 employees per shift of 8 h) | 15.54 CA$/h | [32]                                                                    |
| Fresh water                          | 0.75 CA$/m³ | [33]                                                                       |
| Production of drinking water         | 0.69 CA$/m³ | [33]                                                                       |
| Effluent collection                  | 0.58 CA$/m³ | [33]                                                                       |
| Effluent treatment                   | 0.39 CA$/m³ | [33]                                                                       |
| Membrane capital cost                | 398.54 CA$ | [11]                                                                       |
| Euro conversion                      | 1.47 CA$/Euro | [33]                                                                      |

Value of pasteurized white-wastewater concentrates (Milk Class 3(a)1)

| Fat                                  | 10.8069 CA$/kg | Quebec and Ontario Class Prices (1 February 2022) |
| Proteins                             | 15.0190 CA$/kg | Quebec and Ontario Class Prices (1 February 2022) |
| Other solids                         | 0.9009 CA$/kg | Quebec and Ontario Class Prices (1 February 2022) |

2.7. Statistical Analysis

All experiments were performed in triplicate (with three different WW batches). Significant differences were evaluated using one-way ANOVA with the Tukey test for the overall composition of skimmed milk and WW as well as for the cheese composition (95% confidence level), and a Student’s t-test was conducted to detect any significant difference between the contents of salts \((\alpha = 0.05)\) using SAS software (SAS Institute Inc., Cary, NC, USA). Mean values and standard deviations are reported.

3. Results and Discussion

3.1. White-Wastewater Composition

3.1.1. Overall Composition of WW Concentrates

Table 2 presents the pH values and overall chemical composition of skimmed milk (SM), initial (IWW), model (MWW) and concentrated WW used in the cheese-making process. A very low content of milk solids was obtained for IWW (average of 0.05% TS), which is lower than the levels previously published for similar dairy effluents (vs. 0.5–3.12% TS) [5,7]. The pH value measured for IWW (7.13 \(\pm\) 0.14) was greater than that of SM (6.65 \(\pm\) 0.06). This could be explained by the significant dilution of SM with the treated industrial water used in the pasteurizer during the rinsing step (pH close to 7) [2], and the solubilization of colloidal calcium phosphate causing the release phosphates that can capture protons in the fluid [29]. The composition of CWW was significantly \((p > 0.05)\) similar to that of SM in terms of total solids (8.02–8.43%), true-proteins (3.18–3.12%), casein (2.7–2.63%), NPN (0.02%), lactose (4.96–4.98%), fat (0.23% vs. 0.09%) and total phosphorus content (0.10–0.11%). However, the total calcium contents (0.15% vs. 0.12%), and consequently the ash contents, correlated directly to the salt contents (0.86% vs. 0.74%) and were significantly higher \((p < 0.05)\) in CWW compared to those in SM. Since almost
200 L of IWW was used, RO concentration resulted in the accumulation of salts and their increased quantity in CWW (the RO membrane used was associated with a salt rejection of 98%), especially in total calcium (0.15%), which is found in tap water [5]. In fact, the quality of water used in an industrial context may be treated and contains chemicals that can increase minerals in this water and consequently in sampled WW, as reported by Boguniewicz-Zablocka et al. (2019) [2]. In the same vein, adding calcium to retentates through the concentration of the IWW containing high amounts of minerals (via tap water) could explain the significantly higher (p < 0.05) colloidal calcium (41.59 vs. 29.71 mg/g colloidal casein) and phosphorus (27.26 vs. 14.73 mg/g colloidal casein) in CWW compared to those in skimmed milk. Consequently, soluble casein concentrations were lower in CWW than in the SM (0.25% vs. 0.10%). This was the case for SM affected by an increase in colloidal calcium, which decreased their solubilization [34], the protein and casein equilibrium in milk phases, and the filtration temperature (50°C) used to avoid the migration of casein from the micelle into the serum phase [35].

### Table 2. Overall chemical composition of skim milk and white wastewater used for cheese-making.

| Parameters       | SM   | IWW  | MWW  | CWW  |
|------------------|------|------|------|------|
| Initial pH       | 6.65 ± 0.06 b | 7.13 ± 0.14 a | 6.90 ± 0.16 a | 6.95 ± 0.06 a |
| Total solids (%) | 8.02 ± 0.14 a | 0.05 ± 0.01 c  | 0.67 ± 0.03 b  | 8.43 ± 0.04 a  |
| Ash (%)          | 0.74 ± 0.03 b | 0.01 ± 0.00 c  | 0.07 ± 0.00 c  | 0.86 ± 0.06 a  |
| Total true protein (%) | 3.18 ± 0.12 a | 0.01 ± 0.00 c  | 0.25 ± 0.02 b  | 3.12 ± 0.03 a  |
| Soluble protein (%) | 0.72 ± 0.04 a | 0.00 ± 0.00 b  | ND              | 0.58 ± 0.04 b  |
| Total casein (%) | 2.71 ± 0.09 a  | ** N/D       | 0.19 ± 0.03 b  | 2.63 ± 0.01 a  |
| Soluble casein (%) | 0.25 ± 0.06 a  | ND              | ND              | 0.10 ± 0.04 b  |
| NPN (%)          | 0.02 ± 0.01 a  | N/D            | N/D            | 0.02 ± 0.00 a  |
| Lactose (%)      | 4.96 ± 0.13 a  | 0.01 ± 0.00 c  | 0.38 ± 0.03 b  | 4.98 ± 0.20 a  |
| Fat (%)          | 0.09 ± 0.01 ab | N/D            | N/D            | 0.23 ± 0.08 a  |
| Total calcium (%) | 0.12 ± 0.00 b  | N/D            | N/D            | 0.15 ± 0.01 a  |
| Total phosphorus (%) | 0.10 ± 0.00 a  | N/D            | N/D            | 0.11 ± 0.02 a  |
| Colloidal Ca (mg/g colloidal casein) | 29.71 ± 1.57 b | ND              | ND          | 41.59 ± 2.37 a |
| Colloidal P (mg/g colloidal casein) | 14.73 ± 5.57 b | ND              | ND            | 27.26 ± 5.36 a |

SM = skim milk; IWW = initial white wastewater; MWW = model white wastewater, CWW = pasteurized white-wastewater concentrates, NPN = non-protein nitrogen. Values are means of three separate experiments (mean ± SD); the same letters in the same row indicate no significant difference (Tukey, p > 0.05). * ND = not determined. ** N/D: not detected.

#### 3.1.2. Salts Equilibrium

The partitioning of salt in SM and CWW as well as their distribution between the soluble (serum) and the colloidal (micellar) fractions are presented in Table 3. In our study, 29.84, 27.50, 4.59, 25.38 and 32.39 mM of total Ca, K, Mg, Na and P, respectively, were measured in the SM, which is consistent with previous works [20,35]. Similar total salt contents were calculated in CWW, except for the divalent ions Ca (37.12 vs. 29.84 mM) and Mg (6.14 vs. 4.59 mM), which were significantly higher (p < 0.05) than those in SM (Table 3). As reported previously, high calcium and mineral concentrations may be due to their initial presence in the used rinse water. The same tendency was observed for the majority of colloidal salts (Ca, K, Mg, P), for which the contents were significantly higher (p < 0.05) in CWW than they were in SM: respectively, (26.23 vs. 18.21 mM), (1.18 vs. 0.00), (2.50 vs. 1.20) and (22.28 vs. 11.84). The concentration by RO induced a transfer of these ions, especially calcium, phosphorus and magnesium to the colloidal phase [19,36]. The soluble-salt contents were similar for SM and CWW, except the soluble calcium, which was significantly lower in CWW than in SM (10.90 vs. 11.68 mM, respectively). This shift of soluble calcium from the serum to the micelles can be explained by multiple factors such as the neutral pH, the higher total calcium concentration in tap water and the decrease in solubility of calcium and phosphorus when water is removed [37,38]. As previously mentioned, the temperature of the filtration (50 °C) can also lower the solubility of salts, whereas increasing the mineralization of casein micelles induces the retention of micellar
structure by promoting casein–casein interactions [39,40]. Furthermore, some studies reported that high salt contents in RO retentates can reduce the heat stability of milk [41], while a change in the salt equilibrium could modify the cheese-making properties of the milk, which we will discuss below [42].

Table 3. Salt contents of skim milk and concentrated white wastewater used for cheese-making; distribution between serum and colloidal phases.

|                  | SM          | CWW         |
|------------------|-------------|-------------|
| **Total salts**  |             |             |
| Ca               | 29.84 ± 0.15 b | 37.12 ± 1.76 a |
| K                | 27.50 ± 1.78 a | 28.96 ± 2.59 a |
| Mg               | 4.59 ± 0.07 b | 6.14 ± 0.59 a |
| Na               | 25.38 ± 0.83 a | 27.51 ± 5.52 a |
| P                | 32.39 ± 0.49 a | 36.14 ± 5.38 a |
| Ca               | 11.68 ± 0.36 a | 10.90 ± 0.16 b |
| K                | 29.88 ± 2.8 a  | 27.78 ± 0.68 a |
| Mg               | 3.39 ± 0.21 a  | 3.63 ± 0.32 a |
| Na               | 22.00 ± 1.64 a | 23.59 ± 3.84 a |
| P                | 20.55 ± 4.92 a | 13.86 ± 5.83 a |
| **Soluble salts**|             |             |
| Ca               | 18.21 ± 0.36 b | 26.23 ± 1.91 a |
| K                | 0.00 ± 1.40 b  | 1.18 ± 2.03 a |
| Mg               | 1.20 ± 0.18 b  | 2.50 ± 0.51 a |
| Na               | 3.38 ± 2.15 a  | 3.92 ± 4.03 a |
| P                | 11.84 ± 4.87 b | 22.28 ± 4.74 a |

SM = skim milk; CWW = pasteurized white-wastewater concentrates. *Colloidal salts = Total salts—Soluble salts. Values are means of three separate experiments (mean ± SD); the same letters in the same row indicate no significant difference (Student’s t-test, \( p > 0.05 \)).

3.2. Cheese-Making Properties

3.2.1. Rennet-Coagulation Kinetics

Figure 1 shows the change in the storage and elastic-modulus (\( G' \)) values and the slopes of the curves all along the coagulation process of cheese milk made from CWW (50% and 100%) compared to skimmed cheese milk (control, 0% CWW) as a function of time after renneting. Typically, the increase in \( G' \) at a given time is due to the increased strength of the bonds between micelles, causing the rearrangement of casein micelles in the gel network [43]. Thus, the rennet coagulation time (RCT) and the rate of gel formation (slope) were also different according to the different types of cheese milk. The RCT consists simultaneously of two phases: the enzymatic and the aggregation phase. During the first phase, the rennet cleaves the \( \kappa \)-casein, and when a certain degree of hydrolysis has been reached, the second phase begins, leading to an increase of \( G' \) by 1 Pa [40,44]. The required time of the control cheese milk to reach the cutting firmness was the lowest, with a value of 100 Pa of \( G' \) at 20 min after renneting, followed by the 100% CWW and then the 50% CWW. Our results concerning the impact of using of RO WW concentrates in different percentages in milk agree with several studies that found a delay in gel coagulation over time using RO concentrates [20,28]. Many factors can impair or influence rennet-coagulation kinetics, such as pasteurization (double pasteurization in our case) [45], pH, temperature, the percentage of \( \kappa \)-casein, ionic strength, enzyme concentration, and ionic calcium and phosphate content [46]. Moreover, the presence of homogenized fat globules, the concentration of denatured whey proteins, and casein hydrolysis by proteinases can also change the chemical equilibria, the structure, and the functional properties of milk. It can also lead to an extended hydrolysis phase or to an extended aggregation phase of gel forming, or to both simultaneously [26,47–49]. However, the initial pH of the CWW had no effect on the casein-micelle structure since the narrow change in pH between 6.0 and 7.0 is reversible [34]. The pH and the total protein content were then adjusted to be similar in all the model cheeses. Therefore, we supposed that only salt contents, including the soluble-to-colloidal calcium ratio and the micellar-casein contents, were responsible for delaying...
the coagulation of model cheese made from RO concentrates (Table 1) [50]. As previously shown (Table 3), the micellar-calcium concentration in the CWW was significantly higher than in the control cheese milk. Moreover, the excessive content of micellar calcium could reduce the number of phosphate groups available for curd formation in the secondary phase of rennet coagulation and increase the number of bonds between casein micelles, which can contribute to reducing the curd-firming rate and increase the gel strength [27, 42, 51]. However, lowering the curd firming can represent an advantage for cheese manufacturers because it increases the cutting window or cutting time (the time between $G'$ values of 35 and 70 Pa) [52]. The cutting window was proportional to the percentage of added CWW (0.50% and 100%) as observed by Lauzin et al. (2019) [36].

Figure 1. Curves of rennet-coagulation kinetics followed by rheology for cheese milk made from control skimmed milk or 0% (full line), 50% (dashed line) and 100% (dotted line) of pasteurized white-wastewater concentrates (CWW): evolution of storage modulus ($G'$) as a function of time.

3.2.2. Cheese Composition, Yield and Recovery

Table 4 shows the composition, yield and milk-constituent recovery of the model cheeses made from 50% and 100% CWW. The initial pH of cheese milk made from 50% and 100% CWW was significantly higher ($p < 0.05$) than that of cheese milk made from 0% CWW, as previously discussed (Table 2). In fact, the pH values of the three types of cheese milk were preliminarily adjusted to 6.2 before the beginning of the cheese-making process. Protein-to-fat ratios required no adjustment since they were similar ($p < 0.05$) in all model cheeses, and model-cheese gels were cut at the same firmness to eliminate any of those modifying factors. All model cheeses had the same true-protein and fat contents and protein- and fat-retention values. However, the moisture contents of the model cheeses made from 50% and 100% CWW (59.57% and 62.18%, respectively) were higher than the control (54.80%) due to high levels of colloidal calcium in the cheese made from concentrates, correlating with the ash content (31.02 and 4.35% for 100% CWW model cheese, respectively). Our results are in line with those of Lauzin et al. (2018), who used RO milk concentrates for the production of model cheese [28]. They explained that the slower protein-network reorganization in CWW could be responsible for the abnormal syneresis of the curd during cooking, leading to water retention and higher moisture in cheeses made from CWW. Moreover, it has been shown that heated milk (double pasteurization in our case) tends to increase the moisture content in cheese and to increase denaturation of the serum proteins [45]. In view of the overall reported results on model-cheese characterization, using a maximum of 50% of CWW could be suitable to increase the yield. However, in contrast with model cheese made only from skimmed milk and cream, the higher moisture resulting from the use of 50% of CWW could be challenging and affect the cheese preservation and ripening, but this can be easily controlled with
changes during the cheese manufacturing, for example, by reducing the curd cut size or increasing the cooking temperature.

Table 4. Influence of concentrated-white-wastewater addition on model-cheese composition, yield and recovery.

| Item                          | 0% CWW       | 50% CWW       | 100% CWW      |
|-------------------------------|--------------|---------------|---------------|
| Cheese composition            |              |               |               |
| Initial milk pH               | 6.52 ± 0.02  b | 6.57 ± 0.04  ab | 6.67 ± 0.07  a |
| Moisture (%, w/w)             | 54.80 ± 1.77 b | 59.57 ± 0.78  ab | 62.18 ± 1.17  a |
| True protein (% dry matter)   | 35.53 ± 0.91  a | 33.46 ± 1.63  a | 33.33 ± 0.29  a |
| Fat (% dry matter)            | 56.25 ± 0.03  a | 56.72 ± 2.31  a | 56.18 ± 1.56  a |
| Protein/fat ratio             | 0.63 ± 0.02  a | 0.59 ± 0.05  a | 0.59 ± 0.02  a |
| Other solids (% dry matter)   | 8.43 ± 1.09  a | 9.72 ± 0.78  a | 10.81 ± 1.48  a |
| Ash (% dry matter)            | 3.37 ± 0.34  b | 3.54 ± 0.18  b | 4.35 ± 0.34  b |
| Ca (% dry matter)             | 1.01 ± 0.01  b | 1.07 ± 0.02  ab | 1.19 ± 0.07  a |
| Colloidal Ca (mg/g colloidal casein) | 24.04 ± 1.92  b | 27.38 ± 1.34  ab | 31.02 ± 1.01  a |

| Yield and recovery            |              |               |               |
| Actual yield (%)              | 20.47 ± 1.20  b | 24.56 ± 0.36  a | 24.64 ± 1.10  a |
| Moisture-adjusted yield (%)   | 17.68 ± 0.31  a | 17.85 ± 0.82  a | 16.01 ± 0.91  a |
| True-protein retention (%)    | 77.56 ± 0.48  a | 78.53 ± 0.48  a | 78.97 ± 0.66  a |
| Fat retention (%)             | 94.64 ± 0.92  a | 94.47 ± 3.12  a | 95.38 ± 2.78  a |

0% CWW = model cheese made from 0% of concentrated white wastewater (control); 50% CWW = model cheese made from 50% of concentrated white wastewater; 100% CWW = model cheese made from 100% of concentrated WW. Cheese yield is adjusted to 50% of moisture. Values are means of three separate experiments (mean ± SD); the same letters in the same row indicate no significant difference (Tukey, p > 0.05).

3.3. Economic Impacts of Recovering Milk Constituents from WW

Table 5 provides an economic assessment of three different scenarios, in which WWs containing total solids of 0.05%, 0.1% and 0.5% are recovered after the implementation of a new RO system in virtual dairy plants generating 200 m³ of WW per day, compared to a non-valorization scenario (scenario 1), where WW is piped directly from the plant to the local municipal sewage-treatment system. The latter includes the cost of dairy processors to meet the Canadian regulatory requirement that all dairy industries should fully treat or pretreat their dairy effluents before releasing them into the drain or the environment [53,54]. The only difference between the three valorization scenarios is the quantity of recovered milk solids, the price of which is that of Class 3 (a) 1 milk, that is, milk used in the production of cheese in the Canadian milk-classification system. Only the scenario where WW contains 0.5% of total solids shows a profitable annual gain of CAD $820,000. With a 0.54-year payback, this scenario output could be worthwhile. In the other two valorization scenarios, the daily operational costs and the RO implementation cost exceed the income (Table 5). Furthermore, WW requires treatment through a dairy processor on site in order to avoid additional costs for transportation. It should be noted that this study was carried out based on a relatively large plant generating high amounts of dairy WW (200 m³) from pasteurizers. The profit would be considerably lower for most small- and medium-sized dairy plants producing less than 200 m³ of dairy effluents with less than 0.5% of total solids. While some have only examined the possibility of reclaiming water from dairy wastewater [7,8,55], Suárez et al. (2014) focused on the installation of an RO membrane with a 20 m³/h capacity for obtaining high-quality boiler water through the concentration of WW, an investment with an estimated 2.2-year payback [55]. Our economic assessment focused more specifically on the recovery of dairy milk solids, and not only on the reclaimed water that can be used for boiling or cleaning in a dairy plant. This study cannot be generalized to all dairy plants since each of them deals with specific WW compositions and economic charges related to WW treatment and operational costs. However, through comparing the scenario in which only process water is reclaimed from WW to those in which dairy effluents are concentrated by RO to a TS content of 20% and 22%, we can see that RO can reduce a plant’s natural-gas and electricity consumption by 36% and 10%, respectively [11], hence the importance of our experiment.
Table 5. Economic evaluation of white wastewaters recovered by implementing a new reverse-osmosis system in virtual dairy plants generating 200 m³ of white wastewaters per day compared to non-valorization scenario.

|                                | Non-Recovered WW | Recovered WW 0.05% of TS | Recovered WW 0.1% of TS | Recovered WW 0.5% of TS |
|--------------------------------|------------------|--------------------------|--------------------------|--------------------------|
| Membrane capital cost (CA$)    | 465,947.45       | 463,024.32               | 439,639.25               |
| Operational cost (CA$/day)     |                  |                          |                          |
| Membrane replacement           | 701.48           | 697.08                   | 661.87                   |
| Total energy consumption       | 3972.53          | 3972.53                  | 3972.53                  |
| Electrical power               | 3.68             | 3.68                     | 3.68                     |
| Water used for membrane cleaning | 87.07            | 86.53                    | 82.16                    |
| Cleaning solutions             | 112.61           | 111.91                   | 106.25                   |
| Human resources                | 745.92           | 745.92                   | 745.92                   |
| Effluent collection            | 116.00           |                          |                          |
| Effluent treatment             | 78.00            |                          |                          |
| Production of drinking water   |                  |                          |                          |
| Total                          | 194.00           | 5486.16                  | 5481.37                  | 5443.02                  |
| Incomes (CA$/day)              |                  |                          |                          |
| Retentate (Milk Class 3(a1))   | 768.92           | 1537.84                  | 7689.19                  |
| Balance per operating (CA$/day)| −194.00          | −4717.24                 | −3943.53                 | 2246.17                  |
| Balance per operating (CA$/year)| −70,810.00       | −1,721,792.72           | −1,439,387.80            | 819,851.57               |
| Pay back time (Year)           |                  |                          |                          | 0.54                     |

industry loss; + industry gain, WW = White wastewaters, TS = Total solids.

4. Conclusions

For the first time, the effect of substituting skimmed milk with CWW (50% or 100%) in the production of model cheese has been examined. Concentrating residual milk solids through RO is an interesting way to valorize WW. The higher salts content in milk cheese resulting from the use of CWW (50% or 100%) would most probably affect the cheese-coagulation kinetics while increasing moisture content in the cheese, thus resulting in a decreased yield of cheese. From an economical point of view, the valorization of WW with a TS content of 0.5% can be a good investment for dairy plants that generate more than 200 m³ of dairy WW per day in a country where the price of water and effluent treatment is significant; otherwise, the cost of implementing such a system would not be profitable. Finally, if the RO retentate of WW is considered as a dairy ingredient for cheese production, it is necessary to meet the regulatory requirements that apply to the countries or regions regarding its approval or not.

Author Contributions: Conceptualization, S.A. and A.D.; methodology, S.A., J.C., A.G., V.P., A.D.; software, S.A.; validation, S.A., J.C., M.B., Y.P., S.L. and A.D.; formal analysis, S.A.; investigation, S.A., J.C. and A.D.; resources, S.A., J.C., A.G., V.P., M.B., Y.P., S.L. and A.D.; data curation, S.A. and J.C.; writing—original draft preparation, S.A.; writing—review and editing, S.A., J.C., M.B., Y.P., S.L. and A.D.; visualization, S.A., J.C., M.B., Y.P., S.L. and A.D.; supervision, S.L. and A.D.; project administration, A.D.; funding acquisition, A.D. All authors have read and agreed to the published version of the manuscript.
Funding: This research was funded by Natural Sciences and Engineering Research Council of Canada (NSERC), grant number RDCPJ-500562-16, and the Consortium de recherche et innovations en bioprocédés industriels au Québec (CRIBIQ), grant number 2015-035-C16. Lactalis Canada and Saputo are thanked for their financial support.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: Lactalis Canada and Saputo are thanked for providing WW batches. Finally, the authors also thank Amélie Bérubé, Pascal Lavoie, Diane Gagnon and Véronique Richard (Laval University) for assistance with chemical analysis.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

CIP  Cleaning in place
CWW  Pasteurized white-wastewater concentrates
FTIR  Fourier-transform infrared spectroscopy
G'  Storage modulus
IWW  Initial white wastewater
MWW  Model white wastewater
NCN  Non-casein nitrogen
NF  Nanofiltration
NPN  Non-protein nitrogen
RCT  Rennet coagulation time
RO  Reverse osmosis
SM  Skimmed milk
TMP  Transmembrane pressure
TN  Total nitrogen
TS  Total solids
UHT  Ultra-high temperature
UF  Ultrafiltration
WW  White wastewater

References

1. Grout, L.; Baker, M.G.; French, N.; Hales, S. A review of potential public health impacts associated with the global dairy sector. GeoHealth 2020, 4, e2019GH000213. [CrossRef] [PubMed]
2. Boguniewicz-Zablocka, J.; Klosok-Bazan, L; Naddeo, V. Water quality and resource management in the dairy industry. Environ. Sci. Pollut. Res. 2019, 26, 1208–1216. [CrossRef] [PubMed]
3. Rad, S.J.; Lewis, M.J. Water utilisation, energy utilisation and waste water management in the dairy industry: A review. Int. J. Dairy Technol. 2014, 67, 1–20. [CrossRef]
4. Slavov, A.K. Dairy wastewaters–general characteristics and treatment possibilities–a review. Food Technol. Biotechnol. 2017, 55, 14–28. [CrossRef] [PubMed]
5. Alalam, S.; Ben-Souilah, F.; Lessard, M.-H.; Chamberland, J.; Perreault, V.; Pouliot, Y.; Labrie, S.; Doyen, A. Characterization of Chemical and Bacterial Compositions of Dairy Wastewaters. Dairy 2021, 2, 179–190. [CrossRef]
6. Balannec, B.; Géas-Guiziou, G.; Chaufer, B.; Rabbilier-Baudry, M.; Daufin, G. Treatment of dairy process waters by membrane operations for water reuse and milk constituents concentration. Desalination 2002, 147, 89–94. [CrossRef]
7. Vourch, M.; Balannec, B.; Chaufer, B.; Dorange, G. Treatment of dairy industry wastewater by reverse osmosis for water reuse. Desalination 2008, 219, 190–202. [CrossRef]
8. Suárez, A.; Riera, F.A. Production of high-quality water by reverse osmosis of milk dairy condensates. J. Irrig. Eng. Chem. 2015, 21, 1340–1349. [CrossRef]
9. Chamberland, J.; Bouyer, A.; Benoit, S.; Provault, C.; Bérubé, A.; Doyen, A.; Pouliot, Y. Efficiency assessment of water reclamation processes in milk protein concentrate manufacturing plants: A predictive analysis. J. Food Eng. 2020, 272, 109811. [CrossRef]
10. Deshwal, G.K.; Kadyan, S.; Sharma, H.; Singh, A.K.; Panjagari, N.R.; Meena, G.S. Applications of reverse osmosis in dairy processing: An Indian perspective. J. Food Sci. Technol. 2021, 58, 3676–3688. [CrossRef]
11. Chamberland, J.; Benoit, S.; Doyen, A.; Pouliot, Y. Integrating reverse osmosis to reduce water and energy consumption in dairy processing: A predictive analysis for Cheddar cheese manufacturing plants. J. Water Process Eng. 2020, 38, 101606. [CrossRef]
12. Suárez, A.; Fernández, P.; Iglesias, J.R.; Iglesias, E.; Riera, F.A. Cost assessment of membrane processes: A practical example in the dairy wastewater reclamation by reverse osmosis. J. Membr. Sci. 2015, 493, 389–402. [CrossRef]
13. Hernández, K.; Muro, C.; Ortega, R.E.; Velazquez, S.; Riera, F. Water recovery by treatment of food industry wastewater using membrane processes. Environ. Technol. 2021, 42, 775–788. [CrossRef] [PubMed]
14. Kirichuk, I.; Zmeievski, Y.; Mironchuk, V. Treatment of dairy effluent model solutions by nanofiltration and reverse osmosis. Ukrainian Food J. 2014, 3, 281–288.
15. Brião, V.B.; Salla, A.C.V.; Miorando, T.; Hemkemeier, M.; Favaretto, D.P.C. Water recovery from dairy rinse water by reverse osmosis: Giving value to water and milk solids. Resour. Consers. Recycl. 2019, 140, 313–323. [CrossRef]
16. Alalam, S.; Marciniak, A.; Lessard, M.-H.; Bouchard, C.; Pouliot, Y.; Labrie, S.; Doyen, A. Evolution of Bacterial Communities during the Concentration and Recirculation of Dairy White Wastewater by Reverse Osmosis. Int. Dairy J. 2021, 127, 105283. [CrossRef]
17. El-Gazzar, F.E.; Marth, E.H. Ultrafiltration and reverse osmosis in dairy technology: A review. J. Food Prot. 1991, 54, 801–809. [PubMed]
18. Lauzin, A.; Pouliot, Y.; Britten, M. Understanding the differences in cheese-making properties between reverse osmosis and ultrafiltration concentrates. J. Dairy Sci. 2020, 103, 201–209. [CrossRef]
19. Le Graet, Y.; Brulé, G. Effets de la concentration par évaporation et du séchage sur les équilibres minéraux dans le lait et les rétentrats. Le Lait 1982, 62, 113–125. [CrossRef]
20. Dussault-Chouinard, I.; Britten, M.; Pouliot, Y. Improving rennet coagulation and cheesemaking properties of reverse osmosis skim milk concentrates by pH adjustment. Int. Dairy J. 2019, 95, 6–14. [CrossRef]
21. Fournier, I.; Britten, M.; Pouliot, Y. Drainage and demineralisation of model cheeses made from reverse osmosis concentrates. Int. Dairy J. 2020, 103, 104628. [CrossRef]
22. Udabage, P.; McKinnon, I.R.; Augustin, M.-A. Mineral and casein equilibria in milk: Effects of added salts and calcium-chelating agents. J. Dairy Res. 2000, 67, 361–370. [CrossRef] [PubMed]
23. Augustin, M.A.; Udabage, P. Influence of processing on functionality of milk and dairy proteins. Adv. Food Nutr. Res. 2007, 53, 1–38. [PubMed]
24. Fagan, C.C.; Castillo, M.; Payne, F.; O’Donnell, C.; O’Callaghan, D. Effect of cutting time, temperature, and calcium on curd moisture, whey fat losses, and curd yield by response surface methodology. J. Dairy Sci. 2007, 90, 4499–4512. [CrossRef] [PubMed]
25. Gustavsson, F.; Glantz, M.; Buitenhuis, A.; Lindmark-Månsson, H.; Stålhammar, H.; André, A.; Paulsson, M. Factors influencing chymosin-induced gelation of milk from individual dairy cows: Major effects of casein micelle size and calcium. Int. Dairy J. 2014, 39, 201–208. [CrossRef]
26. Perreault, V.; Turcotte, O.; Morin, P.; Pouliot, Y.; Britten, M. Combined effect of denatured whey protein concentrate level and fat level in milk on rennet gel properties. Int. Dairy J. 2016, 55, 1–9. [PubMed]
27. Sandra, S.; Cooper, C.; Alexander, M.; Corredig, M. Coagulation properties of ultrafiltered milk retentates measured using rheology and diffuse wave spectroscopy. Food Res. Int. 2011, 44, 951–956. [CrossRef]
28. Lauzin, A.; Dussault-Chouinard, I.; Britten, M.; Pouliot, Y. Impact of membrane selectivity on the compositional characteristics and model cheese-making properties of liquid pre-cheese concentrates. Int. Dairy J. 2018, 83, 34–42. [CrossRef]
29. Gaucherfon, F. Milk salts: Distribution and analysis. In Encyclopedia of Dairy Sciences; Academic Press: Cambridge, MA, USA, 2011.
30. ISO 22662 IDF 198; Milk and Milk Products—Determination of Lactose Content by High Performance Liquid Chromatography. International Organization for Standardization: Geneva, Switzerland, 2007.
31. Méthot-Hains, S.; Benoit, S.; Bouchard, C.; Doyen, A.; Bazinet, L.; Pouliot, Y. Effect of transmembrane pressure control on energy efficiency during skim milk concentration by ultrafiltration at 10 and 50 °C. J. Dairy Sci. 2016, 99, 8655–8664. [CrossRef]
32. Chamberland, J.; Benoit, S.; Harel-Oger, M.; Pouliot, Y.; Jeantet, R.; Garric, G. Comparing economic and environmental performance of three industrial cheesemaking processes through a predictive analysis. J. Clean. Prod. 2019, 239, 118046. [CrossRef]
33. Gouvernement du Québec. Rapport sur le coût et les Sources de Revenu des Services d’eau. Juillet 2015. Québec, Canada. Available online: https://www.mamh.gouv.qc.ca/fileadmin/publications/grands_dossiers/strategie_eau/rapport_cout_et%2020_sources_revenus_services_eau.pdf (accessed on 24 March 2022).
34. Sinaga, H.; Bansal, N.; Bhandari, B. Effects of milk pH alteration on casein micelle size and gelation properties of milk. Int. J. Food Prop. 2017, 20, 179–197. [CrossRef]
35. Gaucherfon, F. The minerals of milk. Reprod. Nutr. Dev. 2005, 45, 473–483. [CrossRef] [PubMed]
36. Lauzin, A.; Bérubé, A.; Britten, M.; Pouliot, Y. Effect of pH adjustment on the composition and rennet-gelation properties of milk concentrates made from ultrafiltration and reverse osmosis. J. Dairy Sci. 2019, 102, 3939–3946. [CrossRef] [PubMed]
37. Holt, C. An equilibrium thermodynamic model of the sequestration of calcium phosphate by casein micelles and its application to the calculation of the partition of salts in milk. Eur. Biophys. J. 2004, 33, 421–434. [CrossRef]
38. Liu, D.Z.; Dunstan, D.E.; Martin, G.J. Evaporative concentration of skimmed milk: Effect on casein micelle hydration, composition, and size. Food Chem. 2012, 134, 1446–1452. [CrossRef]
39. Joshi, N.; Muthukumarappan, K.; Dave, R. Effect of calcium on microstructure and meltability of part skim Mozzarella cheese. J. Dairy Sci. 2004, 87, 1975–1983. [CrossRef]
40. Fox, P.F.; Guinee, T.P.; Cogan, T.M.; McSweeney, P.L. Fundamentals of Cheese Science; Springer: Boston, MA, USA, 2017.
41. Pouliot, Y.; Boulet, M.; Paquin, P. Observations on the heat-induced salt balance changes in milk II. Reversibility on cooling. J. Dairy Res. 1989, 56, 193–199. [CrossRef]

42. Malacarne, M.; Franceschi, P.; Formaggioni, P.; Sandri, S.; Mariani, P.; Summer, A. Influence of micellar calcium and phosphorus on rennet coagulation properties of cows milk. J. Dairy Res. 2014, 81, 129–136. [CrossRef]

43. Panthi, R.R.; Kelly, A.L.; O’Callaghan, D.J.; Sheehan, J.J. Measurement of syneretic properties of rennet-induced curds and impact of factors such as concentration of milk: A review. Trends Food Sci. Technol. 2019, 91, 530–540. [CrossRef]

44. Bienvenue, A.; Jiménez-Flores, R.; Singh, H. Rheological properties of concentrated skim milk: Influence of heat treatment and genetic variants on the changes in viscosity during storage. J. Agric. Food Chem. 2003, 51, 6488–6494. [CrossRef]

45. Britten, M.; Giroux, H.J. Rennet coagulation of heated milk: A review. Int. Dairy J. 2022, 124, 105179. [CrossRef]

46. Giroux, H.J.; Bouchard, C.; Britten, M. Combined effect of renneting pH, cooking temperature, and dry salting on the contraction kinetics of rennet-induced milk gels. Int. Dairy J. 2014, 35, 70–74. [CrossRef]

47. Fox, P.F.; McSweeney, P.; Cogan, T.M.; Guinee, T.P. Cheese: Chemistry, Physics and Microbiology, Volume 1: General Aspects; Elsevier: London, UK, 2004.

48. Chandrapala, J.; McKinnon, I.; Augustin, M.A.; Udagave, P. The influence of milk composition on pH and calcium activity measured in situ during heat treatment of reconstituted skim milk. J. Dairy Res. 2010, 77, 257–264. [CrossRef] [PubMed]

49. Horne, D.S.; Lucey, J.A. Rennet-induced coagulation of milk. Cheese 2017, 115–143. [CrossRef]

50. McSweeney, P.L.; O’Mahony, J.A. Advanced Dairy Chemistry: Volume 1B: Proteins: Applied Aspects; Springer: New York, NY, USA, 2016.

51. Lucey, J.; Fox, P. Importance of calcium and phosphate in cheese manufacture: A review. J. Dairy Sci. 1993, 76, 1714–1724. [CrossRef]

52. Panthi, R.R.; Kelly, A.L.; Sheehan, J.J.; Bulbul, K.; Vollmer, A.H.; McMahon, D.J. Influence of protein concentration and coagulation temperature on rennet-induced gelation characteristics and curd microstructure. J. Dairy Sci. 2019, 102, 177–189. [CrossRef]

53. Canadian Water Network. Wastewater Treatment Practice and Regulations in Canada and Other Jurisdictions. 2018. Available online: https://cwn-rce.ca/wp-content/uploads/projects/other-files/Canadas-Challenges-and-Opportunities-to-Address-Contaminants-in-Wastewater/CWN-Report-on-Contaminants-in-WW-Supporting-Doc-2.pdf (accessed on 25 September 2020).

54. Government of Canada. Canada Wastewater Systems Effluent Regulations. 2020. Available online: https://laws-lois.justice.gc.ca/Collection/SOR-2012-139.pdf (accessed on 25 September 2020).

55. Suárez, A.; Fidalgo, T.; Riera, F.A. Recovery of dairy industry wastewaters by reverse osmosis. Prod. Boil. Water. Sep. Purif. Technol. 2014, 133, 204–211. [CrossRef]