Evaluation of Washing and Screening for Upgrading the Calcium Content of Oyster Shells Using a Simulated Wet-Type Trommel

Sang-Eun Lee and Seok-Hwi Kim *

Center for Bio-Resource Recycling, Institute for Advanced Engineering, Yongin 11780, Republic of Korea
* Correspondence: shkim5526@iae.re.kr

Abstract: The oyster shells produced at shucking sites contain various organic and inorganic impurities and are discharged without proper pretreatment. In the present study, we confirmed a process for removing organic/inorganic impurities and salts from abandoned shells using a wet type of trommel. A particle size analysis showed that the inorganic impurities in the studied shells were Si, Fe, Al, etc. derived from sediment, and their contents were relatively rich in fine particles. Dissolved ions (Cl\(^{-}\), SO\(_{4}\)\(^{2-}\), and NO\(_{3}\)\(^{-}\)) and organic matter (carbon, nitrogen, and phosphorus) can be removed concurrently for a short period (<5 min) by a trommel. The higher removal efficiencies for total organic carbon (TOC, ~93.4%), total nitrogen (TN, ~59.9%), and total phosphorous (TP, ~92.9%) in the washing wastewaters after filtration not only indicate increased organic matter in the fine particles derived from crushed shells during trommel operation, but also that a certain portion could be removed by precipitation. However, considering that a small amount of salt compounds (Na and Cl) still remains in the shell even after calcination followed by washing, the scope of shell use must be considered.

Keywords: oyster shell; recycling; impurities; washing and screening; trommel

1. Introduction

Oyster shell waste is a byproduct generated in oyster farming, and about 90% of the total weight is discharged as waste in the shucking process. Recent regulations and strategies on waste in Europe, Korea, and Japan have opened up new opportunities for sustainable development through the management and treatment of aquaculture materials [1–3]. In this regard, recent trends in shell waste applications have been reviewed, such as novel ideas for the valorizing of shells to achieve both ecological and economic perspectives [1,4–6]. The main component of these shells is calcium carbonate (CaCO\(_{3}\)), which is a highly valuable resource as an alternative to limestone [1,6]. As a potential substitute for limestone, shells have been studied for their usability as industrial and environmental materials, for example, in building materials [1,7–9], eutrophication inhibitors [10,11], filters [12], catalysts [13,14], plastic fillers [15–18], soil conditioners [19–21], CO\(_{2}\) absorbers [22,23], and desulfurization absorbents [24,25]. In fact, the oyster shells generated during the shucking process contain various impurities, such as organic residues and hanging ropes. However, research has not been conducted on how to remove the impurities through either screening or washing until now. Most of the studies conducted so far have only used washed shells for the confirmation of their reactivity rather than for mentioning the importance of their pretreatment [22–25].

Figure 1 illustrates the process of oyster shell generation. Oysters are sold in shells as products, but most are shipped out in flesh form after going through the shucking process. Therefore, unlike other shellfish, oysters produce a large amount of shellfish waste. As per the status of oyster shell management in Korea in 2017 [26,27], only about 53% of the shells separated during the shucking process are recycled as fertilizer or for seedling collection, and about 100,000 tons of shells are not utilized, but instead stored (75,000 tons, 26% of total total weight).
generated amount) or abandoned (24,000 tons, 8.4% of total generated amount). Moreover, the amount of shells recycled as fertilizer has decreased by about 58% compared with 2011, and the amount of abandoned shells is increasing every year [27]. Most shells that are not recycled are abandoned on the coast, which is the main culprit of environmental pollution in coastal areas. Thus, a proper management plan for oyster shells is urgently needed, with oyster generation increasing every year.

![Figure 1](image-url)  

**Figure 1.** Process of oyster shell generation using the hanging method in oyster cultivation.

Separation through a screening process is commonly used to remove impurities from waste, and the physical/chemical properties of the waste are very important factors for selecting an appropriate system. For this reason, particulate matters have been removed through screening. Considering the massive utilization aspect, shells are commonly used as raw materials for industrial products through washing or calcination. The impurities present in the shell function as a limiting factor for their usage as a limestone substitute. Thus, these impurities must be effectively pretreated in order to meet the calcium quality for the shell’s applications.

As shown in Figure 1, oyster shells discharged from shucking sites are primarily crushed and then dumped in designated areas. A hammer crusher with screening applied to oyster shucking site is the only method for removing the hanging ropes so far; however, the shells are discarded while containing organic/inorganic components that remain on the shell surface. Although these impurities themselves do not harmful effects, they are generally not preferred in terms of the recycling of the shells regarding the industrial purpose mentioned above. According to the studies by Sikes et al. [28] and Lee et al. [29], it has been reported that there is an organic matter layer in the shell containing up to a few percent of organic matter. Moreover, the hanging ropes are not completely removed when shells are crushed at shucking sites, and some are mixed into the crushed shells and eventually discharged together. According to the results from Ha et al. [30], most of the particles separated from the shell surface were identified as soil particles, although the particles depend on the growth environment of the shell.

In contrast to these particulate impurities, shells also contain seawater components with a high salt content on both the surface and in the lattice, as oysters are grown and collected in the sea [28,31]. Therefore, in terms of utilizing untreated shells as a resource, the aforementioned impurities and salt should be removed before the shells can be considered as an alternative for limestone. Salt, which is highly soluble, can be easily removed by washing with freshwater. Nevertheless, due to the challenges of treating the washing water generated, there have been no studies on salt removal so far. For this reason, shells have currently been stored and left outside for certain periods of time and then only used for low-grade purposes such as fertilizer.
In the present study, therefore, we conducted an impurity-removing experiment for recycling oyster shells into a high-quality material. Specifically, we applied a simulated trommel to remove salt from the shell as a calcium resource and observed the washing characteristics of a wet method. At the same time, we also analyzed the quality of wastewater from the washing process to study the wastewater quality management.

2. An Obstacle to Oyster Shell Recycling in Korea

Oyster shells remain a pressing issue for the local community, as they are often left abandoned on the coast despite having been studied as a potential source of calcium. Figure 2 shows photographs of shell generation during the shucking process. The shell is separated from the oyster flesh and discharged after crushing without washing. However, large amounts of particles with fishery byproducts are included in the oyster shells that are discharged from shucking sites (Figure 2b); short hanging ropes are also randomly discharged with the oyster shells (Figure 2c). In addition, organic substances that have not been completely removed and have a high salt content are the greatest obstacle to recycling. For this reason, in representative shell recycling plants, shells are used as a raw material for fertilizer after being left in yards for more than 6 months to remove the salt residue.

![Figure 2. Photographs of oyster shells (including impurities) during the shucking process. Shucked oyster shells were conveyed (a, b) to a crusher and then dumped in the shell yard (c). Aquatic debris such as kelp, seaweed, and soils are discarded together with oyster shells during the shucking process.](image)

3. Materials and Methods

3.1. Collection of Oyster Shell

In the present study, oyster shells (Crassostrea gigas) were obtained from each of the oyster shell storage sites in Tongyeong, Korea. Because the physicochemical characteristics of the shells depend on the storage period outside, two different oyster shell samples were used for this study according to the storage periods. Shells collected from shucking sites were generated in the current year and were thus considered to be relatively fresh (OSF), and shells obtained from fertilizer manufacturing plants (OSW), having been stored outside for more than six months, were considerably weathered.

A particle size analysis was performed using a wet method, as impurities were tangled and adhered to the surface of the shell. We placed approximately 300 g of dried shell into sieves, with particle sizes ranging from 75 μm to 5 mm, and washed them with tap water. We then measured the amount of recovered dried shell filtered through each sieve size. For the particle analysis, the average value was used by repeating the process twice for each shell sample.

3.2. A Wet-Type Trommel System

To observe the washing characteristics, a screening device was designed and manufactured as shown in Figure 3. We constructed this device by applying a simulated typical trommel with a 1 mm mesh net. The screen had an inside diameter of 150 mm, length of 300 mm, and effective volume of 7 L in total. In the washing process, about 1 kg of shell
was loaded into a trommel, and 4 L of washing water was poured into the water vessel so that about 15% of the total volume of the screen could be submerged. The trommel was operated at a speed of 20 rpm. In order to confirm the removal of impurities during the operation of the trommel, washed shell and water samples were collected from inside and outside the screen according to the washing time.

![Image](image_url)

**Figure 3.** A simulated trommel wrapped with a 1 mm screen. The rotating drum was filled with oyster shells immersed in tap water, accounting for approximately 15% of the total volume of the drum.

### 3.3. Analytical Methods and Procedures

All the shell samples in this experiment, whether they were washed or not, were dried in a drying oven (HB-501M, Hanbaek Science Co., Bucheon, Korea) at 80 °C before the analysis was performed. An X-ray diffraction (XRD-6100, Shimadzu Co., Kyoto, Japan) analysis was conducted to identify the mineral species with Ni-filtered Cu-Kα radiation at 40 kV and 30 mA. Data were collected in the 2θ range from 5° to 60° at 0.02° intervals and a counting time of 1 s per step. X-ray fluorescence (XRF-1800, Shimadzu Co., Japan) was used to investigate the chemical compositions of the shells. The wastewater generated during the trommel operation was analyzed for chemical oxygen demand (COD), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), suspended solid (SS), and ions (Cl−, NO3−, SO42−). The samples for the ion analyses were filtered using syringe filters with a 0.45 μm cellulose membrane; then, an ion chromatograph (930 Compact IC Flex, Metrohm Co., Herisau, Switzerland) was used. Based on the experiment and considering the water-to-shell ratio, the dissolution amount of each ion from the shell was quantified. The COD, TOC, TN, and TP values of the obtained wastewater were measured using a spectrophotometer (Spectroquant prove 100, Merck, Darmstadt, Germany) before and after filtration.

In addition, the shells were calcined for 1 h by raising the temperature up to 900 °C at a heating rate of 10 °C/min using an electric muffle furnace. To compare the calcination effects on the removed salt and organic residues, a leaching experiment was performed on each shell sample after washing and calcination. About 2.5 g of shell was prepared with 40 mL of distilled water for each sample. The mixture was then stirred at 100 rpm for 2 h. The supernatant was filtered using a syringe filter with a 0.45 μm cellulose membrane and analyzed for Cl−, NO3−, and SO42− contents.

### 4. Results and Discussion

#### 4.1. Particle Size and Chemical Composition

Analyzing the results of the particle size distribution for the shells collected from the two different sites, it was found that the contents of the coarse granules (>5 mm) were not different (Figure 4). However, the fine particles with sizes less than 75 μm from OSW were characterized by a 30% or higher content compared with those from OSF. The shells separated in this way also showed visually different characteristics (photographs shown in Figure 4). The colors of the particles that ranged 300 μm or less were dark, and they were not easy to distinguish from soil particles; in particular, at a particle size of 150 μm or less, they were observed to have a dark gray color very similar to marine sediment. However,
the results of the XRD analysis by particle size showed that calcite (CaCO₃) was observed to be a major constituent regardless of the particle size (Figure 5). This indicates that the shells stored outdoors partly turned into fine grains as a result of weathering. However, quartz (SiO₂) was also observed in the relatively finer particles (Figure 5). This was also consistent with the changes in chemical compositions observed by the XRF analysis according to the particle sizes (Table 1). The Ca content significantly increased as the particles became coarser, while the Si, Fe, and Al contents significantly increased as the particles became finer. As shown in the inserted photo images in Figure 4, a particle size more than 600 µm seemed to be composed of fragments of the oyster shell. On the other hand, small particles appeared to contain impurities other than calcium, considering their gray color. Ha et al. [31] conducted a mineral analysis by separating the impurities attached to the shell surface. As a result, clay minerals such as quartz, albite, smectite, and illite were identified. From these minerals, it was confirmed that CaO, SiO₂, and Al₂O₃ existed in relatively large amounts. In addition, Fe₂O₃ was also observed in a large quantity, even though iron oxides and hydroxides were not identified by the XRD analysis [32]. This shows a distinct difference from the observation of only calcite in the washed shell. Because these elements are more enriched in soil, the marine sediments that are mixed in with the oyster could be effectively removed with a simple particle size sorting method.

Figure 4. Particle size distribution of oyster shells recovered from two different sites according to the period of open storage. OSF samples were collected from a shucking site, while OSW samples were collected from a fertilizer manufacturing plant. Numbers are the recovery yield in wt.%.  

<table>
<thead>
<tr>
<th>Particle size (µm)</th>
<th>Recovery Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;75</td>
<td>70.2</td>
</tr>
<tr>
<td>75-150</td>
<td>33.2</td>
</tr>
<tr>
<td>150-300</td>
<td>15.1</td>
</tr>
<tr>
<td>300-600</td>
<td>2.82</td>
</tr>
<tr>
<td>600-1000</td>
<td>0.54</td>
</tr>
<tr>
<td>1000-2000</td>
<td>0.82</td>
</tr>
<tr>
<td>2000-5000</td>
<td>1.92</td>
</tr>
<tr>
<td>&gt;5000</td>
<td>ND</td>
</tr>
</tbody>
</table>

Figure 5. X-ray diffraction patterns of the oyster shells collected from fertilizer manufacturing plant (OSW) with different particle sizes.

C : Calcite (CaCO₃)  
A : Aragonite (CaCO₃)  
Q : Quartz (SiO₂)
Table 1. XRF results of the oyster shells with different particle sizes. Each shell sample is the same as the ones used in Figure 5.

<table>
<thead>
<tr>
<th>Component (%)</th>
<th>Particle Size (µm)</th>
<th>75–150</th>
<th>150–300</th>
<th>300–600</th>
<th>600–1000</th>
<th>&gt;1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td></td>
<td>87.28</td>
<td>92.16</td>
<td>91.56</td>
<td>94.06</td>
<td>95.97</td>
</tr>
<tr>
<td>SiO₂</td>
<td></td>
<td>6.869</td>
<td>3.811</td>
<td>4.189</td>
<td>2.398</td>
<td>1.581</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td></td>
<td>2.162</td>
<td>1.347</td>
<td>1.506</td>
<td>1.234</td>
<td>0.708</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td></td>
<td>1.022</td>
<td>0.641</td>
<td>0.703</td>
<td>0.433</td>
<td>0.421</td>
</tr>
<tr>
<td>SO₃</td>
<td></td>
<td>0.944</td>
<td>0.901</td>
<td>0.892</td>
<td>1.083</td>
<td>0.773</td>
</tr>
<tr>
<td>K₂O</td>
<td></td>
<td>0.482</td>
<td>0.264</td>
<td>0.251</td>
<td>0.094</td>
<td>0.000</td>
</tr>
<tr>
<td>P₂O₅</td>
<td></td>
<td>0.417</td>
<td>0.362</td>
<td>0.393</td>
<td>0.292</td>
<td>0.218</td>
</tr>
<tr>
<td>SrO</td>
<td></td>
<td>0.385</td>
<td>0.321</td>
<td>0.330</td>
<td>0.320</td>
<td>0.267</td>
</tr>
<tr>
<td>MnO</td>
<td></td>
<td>0.177</td>
<td>0.136</td>
<td>0.110</td>
<td>0.073</td>
<td>0.059</td>
</tr>
<tr>
<td>Cl</td>
<td></td>
<td>0.175</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>ZnO</td>
<td></td>
<td>0.087</td>
<td>0.056</td>
<td>0.063</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

(1) Particle sizes were analyzed using a wet method. ND, Not detected.

4.2. Washing Characteristics of Oyster Shell Applied to a Simulated Trommel

Unlike particulate matters, salts such as Na⁺, Cl⁻, and SO₄²⁻ derived from seawater are very difficult to remove via particle separation. In addition, because the shell has an organic matter layer corresponding to several percent inside the tissue, this needs be effectively removed to realize high-quality calcium.

Figure 6 shows the concentration of Cl⁻, SO₄²⁻, and NO₃⁻ in the oyster shells along with the washing duration by applying the wet trommel. The leaching of these ions from the shell reached equilibrium in a very short period of time (<5 min). The total amounts of leached Cl⁻, SO₄²⁻, and NO₃⁻ in the OSF shells were 10.1 ± 0.3, 2.90 ± 0.27, and 5.55 ± 0.21 times higher than those observed in the OSW shells, respectively. The relatively low ion content in the OSW shells is related to salt removal by rainwater when they are stored outside. Compared with the concentrations of Cl⁻, however, the relatively low SO₄²⁻ and NO₃⁻ differences between the two samples are believed to have resulted from the increase in concentration in the washing water, as the residual organic matter in the shell was partially decomposed while being stored. These results are also clearly shown in the COD concentrations of the washing water. When comparing the COD levels at the beginning of the reaction (5 min), the concentration of the OSW shells was 20 mg/L, which was about 1.9 times higher than that of the OSF shells.

The concentrations of TOC, TN, and TP in the washing water rapidly increased in the early stages of washing, having a relatively high concentration for the OSF shells. Because the trommel performed both washing and screening processes simultaneously, it crushed the shells during operation to induce increased suspended solids (1030 ± 264 mg/L for OSW, 6920 ± 1150 mg/L for OSF). However, both of these samples had significantly higher TOC (19 mg/L for OS-B, 10 mg/L for OSF) values in the washing water compared with COD (850 mg/L for OSW, 1720 mg/L for OSF). This indicates that most of the organic matter that washed out was not easily decomposed. Figure 7 shows the removal efficiencies for TOC, TN, and TP in the wastewater obtained via washing for 10 min after filtration. The removal efficiencies for TOC, TN, and TP for the OSF filtrates were 93.4%, 59.9%, and 92.3%, respectively, suggesting that most of these pollutants are particulate. Unlike nitrogen, the higher removal efficiency of TP after filtration seems to reflect its own chemical properties, which have a strong adsorption affinity onto the suspended particles [33,34].

The generation of a large amount of wastewater is essential when using a wet-type trommel for washing. However, the drastic reduction in TOC, TN, and TP concentration in washed water after filtration provides a wastewater management strategy for shell recycling, such as the precipitation of fine particles.
rastic reduction in TOC, TN, and TP concentration inside the chalk sample, while the OSW samples were collected from a fertilizer manufacturing plant.

Removal efficiency for total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) in the wastewater filtration. The removal efficiencies for TOC, TN, and TP for the OSF filtrates were 93.4%, 95.9%, and 92.3%, respectively, suggesting that most of these pollutants are particulate.

Figure 6. Leaching amounts of Cl\(^{-}\), SO\(_4\)^{2-}, and NO\(_3\)^{-}. OSF samples were collected from a shucking site, while OSW samples were collected from a fertilizer manufacturing plant.

Figure 7. Removal efficiency for total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) in the supernatant of washed water after filtration. The OSF samples were collected from a shucking site, while the OSW samples were collected from a fertilizer manufacturing plant.
Table 2 shows the comparative XRF results for the shells and whether or not they were washed. The loss on ignition (LOI) values for the shells that were not washed were 43.6% and 43.2% for the OSW and OSF shells, respectively. However, the LOI of the OSF shells after washing was increased from 43.6% to 44.1%. Considering that the theoretical weight change is 44% with decarbonization (CaCO$_3$→CaO + CO$_2$), the washed shells showed an LOI that was very similar to the theoretical value. In addition, impurities such as Si, Al, Fe, etc. were effectively removed after washing. Although there were differences for each elemental content, similar results were observed in the OSW shells. However, because Na, Cl, S, and P were still observed in both the OSF and OSW shells after washing, it appears difficult to completely remove these salts and organic matters through washing. This is the reason behind calcination being generally involved in the manufacture of high-quality calcium materials from limestone. In fact, oyster shells obtain organic matter in the process of growth and are known to contain a certain amount of organic matter in the lattice [28]. Oyster shells contain conchiolin as proteins between parts of the surface and particles of calcite [28, 31]—the protein layer, especially, contains sulfur inside the chalk and the nacreous layer—meaning that sulfur and phosphorus still remain, even when washing is thorough [31].

<table>
<thead>
<tr>
<th>Component (%)</th>
<th>OSW (1) Raw Shell (Unwashed)</th>
<th>Washed Shell</th>
<th>OSF (2) Raw Shell (Unwashed)</th>
<th>Washed Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>94.84</td>
<td>98.09</td>
<td>94.35</td>
<td>98.42</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>1.992</td>
<td>0.398</td>
<td>2.029</td>
<td>0.376</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.922</td>
<td>0.411</td>
<td>1.166</td>
<td>0.129</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>0.812</td>
<td>0.473</td>
<td>0.820</td>
<td>0.459</td>
</tr>
<tr>
<td>SrO</td>
<td>0.436</td>
<td>0.390</td>
<td>0.462</td>
<td>0.384</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.313</td>
<td>0.156</td>
<td>0.425</td>
<td>0.199</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>0.275</td>
<td>0.053</td>
<td>0.273</td>
<td>NA</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.105</td>
<td>NA</td>
<td>0.122</td>
<td>NA</td>
</tr>
<tr>
<td>MnO</td>
<td>0.091</td>
<td>NA</td>
<td>0.104</td>
<td>NA</td>
</tr>
<tr>
<td>ZnO</td>
<td>0.088</td>
<td>NA</td>
<td>0.115</td>
<td>NA</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.078</td>
<td>0.014</td>
<td>0.093</td>
<td>0.022</td>
</tr>
<tr>
<td>Cl</td>
<td>0.049</td>
<td>0.011</td>
<td>0.039</td>
<td>0.011</td>
</tr>
</tbody>
</table>

(1) Shells collected from oyster shell shucking site. (2) Shells collected from fertilizer manufacturing plant. NA, Not available.

### 4.3. Comparisons with Pretreatment Methods on Impurities Removal Efficiency

Interestingly, Lv et al. [35] has pointed out that salt could be removed at a higher calcination temperature. Thus, the changes in the Cl$^-$, NO$_3^-$, and SO$_4^{2-}$ contents of the washed shells, depending on whether the shells were calcined, are shown in Figure 8. The contents of these ions tended to decrease after calcination. NO$_3^-$ and SO$_4^{2-}$ were greatly reduced by calcination (COS), and they were removed when shells were calcined followed by washing (WCOS), as shown in Figure 8b,c. This indirectly indicates that nitrogen and sulfur mainly originate from the organic matter. On the other hand, the Cl$^-$ content was reduced through calcination, but its reduction was not significant, as was the case for NO$_3^-$ and SO$_4^{2-}$. Generally, Cl$^-$ exists in the form of a compound that is mostly combined with salt on the shell surface. NaCl, which is representative of seawater salt, has melting and boiling points that are very high, at 800.7 °C and 1465 °C, respectively. The shells of this study were calcined at 900 °C, and thus this condition does not induce the complete decomposition of NaCl. Only part of the NaCl on the shell surface was removed through evaporation by means of phase transfer from solid to liquid. These results are well-supported by the relatively low Cl removal rate (36% for unwashed, 47.3% for washed) of calcination, regardless of washing. In other words, this suggests that it
is difficult to completely remove salt, even if the shell—which is a high-quality calcium source—is calcined.

![Graphs showing changes in Cl, SO$_4^{2-}$, NO$_3^-$, and Cl/SO$_4^{2-}$ molar ratio](image)

**Figure 8.** Changes in the Cl$^-$, SO$_4^{2-}$, and NO$_3^-$ contents and the Cl/SO$_4$ ratio with respect to the washing and calcination processes. "OS" represent oyster shells as-received without pretreatment, and the letters "C" and "W" in front of the "OS" indicate "Calcined" and "Washed", respectively.

**5. Conclusions and Implications**

In the present study, we confirmed the wet screening and washing characteristics by applying a simulated trommel to remove organic/inorganic impurities and salts to improve Ca purity. Considering that inorganic impurities (Si, Fe, Al, etc.) in the shell are relatively concentrated in fine granules, the purity of calcium in the shell can be upgraded through simple particle size screening. However, the salt and residual organic matter remaining in the shell cannot be effectively removed through washing. To upgrade Ca purity, calcination has been considered as a process to remove organic matter and salty compounds; nevertheless, salty compounds still remain in the shell to a certain extent. Therefore, for the shell to be utilized as a high-quality calcium resource, the effect of these residual salts should be considered.

The quality of calcium carbonate (CaCO$_3$) for industrial use should not be less than 90%, which is 50.4% in the form of lime (CaO). Among industrial applications, the required qualities for cement and fertilizer use are 90% and 92.9%, respectively, and limestone quality for steel/steel, alloys, and carbide is also required to be relatively high. Considering that the relatively higher purity of CaCO$_3$ in these applications is linked to the purity of the final product, it might not be possible to directly utilize the shell discharged from the shucking site. Therefore, the effective removal of impurities is required to efficiently use the shell as a limestone replacement material.

In this study on effective shell recycling, we identified screening/washing characteristics considering the residual salt. The results show the importance of pretreatment for securing high-quality calcium resources from oyster shells. In addition, we also observed changes in water qualities collected during the trommel operation. A drastic decrease in...
TOC, TN, and TP values after filtration would help to provide a wastewater management strategy for shell recycling.

**Author Contributions:** Conceptualization, S.-H.K.; methodology, S.-H.K.; investigation, S.-E.L.; data curation, S.-E.L. and S.-H.K.; writing—original draft preparation, S.-E.L.; writing—review and editing, S.-H.K. and S.-E.L.; project administration, S.-H.K. All authors have read and agreed to the published version of the manuscript.

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