Analyzing the stability level of organic waste by the static respiration index and dynamic respiration index

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Abstract. Stability is a parameter that reveals the extent of decomposition of biodegradable organic matter. Various methods are employed to measure the stability level of organic materials, including the static respiration index (SRI) and dynamic respiration index (DRI). In this study, the characteristics and stability of food waste, garden waste, municipal organic waste, fruit waste, tofu factory waste, and cow dung samples used in the study were identified and analyzed on the basis of the water content, volatile solids, C/N ratio, lignin content, and SRI and DRI values. In addition, an appropriate method for the further processing of unstable organic waste samples was determined. Organic waste samples were collected from nine places. Results revealed that the tofu factory waste samples exhibit the highest SRI and DRI values of 13.3995 mgO₂g⁻¹OM⁻¹h⁻¹ and 148.3747 mgO₂g⁻¹OM⁻¹h⁻¹, respectively. The composting results for tofu factory waste samples and cow dung with coconut shells as the bulking agent for 14 days revealed that the highest percentage of SRI decrease for tofu factory waste was 99.94% on the 3rd day of composting. On the other hand, the highest percentage of SRI decrease for the cow dung samples is 99.17% on the 7th day of composting.

Keywords: dynamic respiration index; organic waste; stability; static respiration index

1. Introduction
Each human activity generates waste. Hence, an increase in the population leads to an increase in the amount of the waste generated. Based on The Waste Management Act No. 18 year 2008, waste is defined as the residual of the daily activities of humans and/or natural processes in the form of solids. For example, 65 million tons of waste is generated daily in Indonesia, with an organic waste composition accounting to ~60% in 2018. Of the total waste available daily, 7% is recycled, 69% is disposed into landfills, and 24% cannot be managed appropriately [2].

Waste management that has not been maximized is affected by transportation systems and public behavior. In UU No. 18 of 2008 regarding waste management, the people and government can reduce waste by limiting the amount of accumulated waste, recycling waste, and reuse waste. Organic waste can be recycled using a composting system. As much as 0.53% of the households in Indonesia have implemented a composting system [3]. In addition to composting, mechanical-biological processing units and anaerobic digestion can be employed to recycle organic material to a stable level, thereby preventing the disposal of unstable organic waste [4]. One of the requirements for compost quality is that when employed, compost is stable and does not contain phytotoxic compounds [5]. Stability can
be defined by the extent of the decomposition of biodegradable organic material [6]. Ponsa et al. (2010) have reported that the stability of organic waste can be divided into the biodegradable level category as highly biodegradable wastes (SRI > 5 mgO$_2$.g$^{-1}$.DMh$^{-1}$); moderately biodegradable wastes (SRI = 2–5 mgO$_2$.g$^{-1}$.DMh$^{-1}$); and low biodegradable wastes (SRI < 2 mgO$_2$.g$^{-1}$.DMh$^{-1}$).

Various methods have been employed to measure the stability level of organic materials, such as the static respiration index (SRI) and dynamic respiration index (DRI). In this study, the stability of different organic wastes and their characteristics based on parameters of the water content, volatile solids, C/N ratio, lignin content, and SRI and DRI were analyzed, and an appropriate method to further manage unstable organic waste samples was determined.

2. Research Method
2.1 Research Procedure

In this study, organic waste samples are collected from different sources. As much as 1–2 kg of each sample is collected by the grab sampling method (Table 1). Cow dung is used as the feedstock for the anaerobic digester.

| Types of Waste          | Locations of Sample        | Age of Waste |
|-------------------------|----------------------------|--------------|
| Food waste              | Canteen A                  | 0 day        |
| Food waste              | Canteen B                  | 0 day        |
| Food waste              | Padang Restaurant, Depok   | 0 day        |
| Organic waste           | Kemiri Muka Market, Depok  | 1 day        |
| Fruit waste             | Merdeka 2 WMU, Depok       | 0 day        |
| City waste              | Merdeka 2 WMU, Depok       | 0 day        |
| Garden Waste            | FTUI WMU                   | 0 day        |
| Tofu factory waste      | Depok                      | 3 days       |
| Anaerobic digester feedstock | FTUI WMU               | 15 days      |

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The water, carbon, and nitrogen content and volatile solids of the collected samples are tested. The water content is tested according to ASTM D 2974-87. Volatile solids are tested by the gravimetric method according to the Standard Method 2540 G. The total carbon is tested by the HACH Method 420 by using a DR 5000 spectrophotometer at a wavelength of 425 nm. Furthermore, the dissolved oxygen (DO) content of the sample is measured. First, each sample is mashed using a food blender. Then, 15 g of the sample is mixed with 500 mL of distilled water, 15 mL of a phosphate buffer solution, as well as 5 mL each of CaCl$_2$, FeCl$_3$, and a MgSO$_4$ solution. The addition of a phosphate buffer solution without NH$_4$Cl as nutrient serves to inhibit the formation of nitrogenous oxygen demand [6].

Then, the sample is aerated for 15 min, and incubation is continued for 45 min. This step is repeated five times. Next, the sample is incubated for 18 h. Before testing, the sample is aerated for 20 min. Then, the DO of the sample is measured each minute by using a DO meter every 2 h. The measurement of each organic sample is carried out by using the Triplo method or three times replications.

2.2 Data Analysis

The DO level determined by triploid is used to calculate the oxygen saturation percentage of the sample according to the following formula. In this study, a DO of 6.71 mg/L at 37°C is attained.

\[
\% \text{ O}_2 \text{ Saturation} = \frac{\text{DO (mg/L)}}{6.71 \text{mg/L}} \times 100\% \tag{1}
\]

Then, a chart of the percentage of O$_2$ saturation as a function of time in minutes is constructed to calculate the slope. According to Gomez et al. (2004), the slope used in the formula is calculated from
the linear trendline. Based on the study by Rahmah (2018) using the SRI method, types of sample used, and required variables, SRI can be expressed by the following formula.

\[
SRI \text{ (mgO}_2\text{g}^{-1}\text{OM}^{-1}\text{h}^{-1}) = \frac{V \times P \times 32 \times m \times 60}{R \times T \times X \times DM \times OM}
\]  

(2)

where, \(V\) is the volume of air in the Erlenmeyer flask (mL), \(P\) is the atmospheric pressure (atm), 32 is the molecular weight of oxygen, \(m\) is the chart slope per 100, 60 is the conversion value of minutes to hours, \(R\) is the ideal gas constant \((0.08206 \text{ L atm} \text{ mol}^{-1} \text{K}^{-1})\), \(T\) is the temperature (K), \(X\) is the wet sample weight (g), \(DM\) is the dry matter \((\text{gDM/} \text{gX})\), and \(OM\) is the organic matter \((\text{gOM/} \text{gDM})\).

The DRI can be calculated by the following formula. This formula is used because the SRI and DRI values are related to different percentages, which are constant, and the correlation factor \((R^2)\) is greater than those in other formulas, which is equal to 0.98 \((p < 0.01)\) [9].

\[
DRI = 2.643RI + 113
\]  

(3)

2.3 **Continuation of Management**

Continuation of management (or Continuous management indicates the knowledge of the time required to increase the stability of samples. Composting was employed herein, with cow dung and tofu factory waste as examples. The Takakura composting method is employed for mixing organic waste with coconut shells. Each of the organic wastes is mixed with coconut shell in a ratio of 2:3. The fiber and shell of coconuts serve as a bulking agent that can soak moisture from the sample, increase the organic stability, and deactivate parasites and pathogens in the sample [10]. Composting is carried out in a medium-sized basin, with high walls, and the basin is covered using a trash bag. Then, the compost is tightly covered using fabric. Composting is carried out for 14 days, and the parameters are measured at days 3, 7, 10, and 14. The DO, water content, volatile solids, and carbon and nitrogen content are retested.

3. Results and Discussion

3.1 **Organic Waste Before Composting Analysis**

| Sample                          | Water Content | Volatile Solids | C/N Ratio | Lignin Content |
|--------------------------------|---------------|-----------------|-----------|----------------|
| Padang Restaurant Waste        | 81.26%        | 57.82%          | 12.20     | 4.82%          |
| Garden Waste                   | 70.34%        | 89.66%          | 31.91     | 24.69%         |
| Canteen A Food Waste           | 89.73%        | 96.00%          | 1.92      | 8.27%          |
| Canteen B Food Waste           | 79.45%        | 72.36%          | 4.63      | 7.60%          |
| City WMU Waste                 | 76.23%        | 86.33%          | 8.90      | 16.07%         |
| Fruit Waste                    | 85.59%        | 96.73%          | 5.51      | 6.13%          |
| Cow Dung                       | 75.01%        | 64.00%          | 3.02      | 8.39%          |
| Tofu Factory Waste             | 89.46%        | 97.76%          | 13.97     | 4.30%          |
| Kemiri Muka Market Organic Waste | 70.63%        | 38.39%          | 1.23      | 10.57%         |

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The water content of five tested samples satisfied the range of water content for organic city waste, which is 50%–80%. However, the organic waste samples collected from the Padang restaurant, FTUI canteen, fruit residual, and tofu factory exhibited values above the existing range, related to the presence of a higher water content than that present in other samples. The volatile solids in the food waste samples collected from the Padang restaurant and organic waste collected from the market.
exhibited satisfactory values in the range of 40%–60%. The tofu factory sample exhibited the highest content of volatile solids (97.76%). The volatile solid content indicates the presence of organic compounds that can decompose biologically [11]. The C/N ratio that is sufficient to decompose organic waste ranges from 15 to 40 [12]. From the nine tested samples, only garden waste exhibited a C/N ratio that was in agreement with this range, which is 31.91. A low C/N ratio leads to the production of ammonia, which inhibits the biological activity and causes a pungent odor [12].

Figures 1 and 2 plot the oxygen saturation percentage as a function of time for the cow dung and tofu factory waste samples, respectively. The slope (m) obtained for each sample in these figures was used to calculate SRI. In this study, each sample exhibited a significantly decreased SRI from the first minute to ~10 min. Based on the DOCF value reported by Lee et al. (2017), food waste exhibited the highest range of DOCF values (0.36–0.92). DOCF value reveal the carbon fraction that is degraded and decomposed. At the start of testing, degradation was thought to occur rapidly. After that, the curve for each sample was stable. The curve in this study was divided into two, early minutes with a significant drop and the minute after that, respectively (Figures 1 and 2). The steep slope of the curve occurred at different minutes for different samples, such as the intersection of the curve on cow dung after 24 min and tofu factory after 5 min.

![Figure 1](image1.png)

**Figure 1.** Oxygen Saturation Percentage as a Function of Time for the Cow Dung Sample
Among the tested samples, tofu factory waste exhibited the highest SRI and DRI values of 13.3995 mgO$_2$.g$^{-1}$OM$^{-1}$.h$^{-1}$ and 148.3747 mgO$_2$.g$^{-1}$OM$^{-1}$.h$^{-1}$, respectively. The tofu factory waste exhibited the highest content of volatile solids (97.76%, Table 2) and the highest degradation of the oxygen saturation percentage, which was 89.97%, between the first minute till 120 min. In contrast, the cow dung sample exhibited the lowest SRI and DRI values of 0.4193 mgO$_2$.g$^{-1}$OM$^{-1}$.h$^{-1}$ and 114.1069 mgO$_2$.g$^{-1}$OM$^{-1}$.h$^{-1}$, respectively, caused by the slope of this sample. The cow dung sample exhibited the smallest slope. Table 4 summarizes the calculated unit conversion of the SRI value and biodegradation level classification based on the study by Ponsa et al. (2010).

Table 3. Calculated SRI and DRI Values

| Sample                     | m   | DM (gDM/gX) | OM (gOM/gDM) | SRI (mgO$_2$.g$^{-1}$OM$^{-1}$.h$^{-1}$) | DRI (mgO$_2$.g$^{-1}$OM$^{-1}$.h$^{-1}$) |
|----------------------------|-----|-------------|--------------|----------------------------------------|----------------------------------------|
| Padang Restaurant Waste    | 0.0810 | 0.1874 | 1.00 | 2.1455 | 118.6642 |
| Garden Waste               | 0.2060 | 0.297  | 1.33 | 2.5855 | 119.8258 |
| Canteen A Food Waste       | 0.0474 | 0.103  | 2.02 | 1.1356 | 115.9980 |
| Canteen B Food Waste       | 0.1800 | 0.206  | 1.43 | 3.0520 | 121.0574 |
| City WMU Waste             | 0.1051 | 0.238  | 1.13 | 1.9360 | 118.1111 |
| Fruit Waste                | 0.1733 | 0.144  | 0.82 | 7.2702 | 132.1933 |
| Cow Dung                   | 0.0216 | 0.250  | 1.02 | 0.4193 | 114.1069 |
| Tofu Factory Waste         | 0.1686 | 0.105  | 0.59 | 13.3995 | 148.3747 |
| Kemiri Muka                | 0.1484 | 0.294  | 0.62 | 4.0471 | 123.6842 |

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Table 4. Conversion of the SRI Value and the Classification of the Biodegradation Level

| Sample         | SRI (mgO$_2$.g$^{-1}$DM$h^{-1}$) | Classification (Ponsa et al. (2010)) |
|----------------|----------------------------------|---------------------------------------|
| Fruit Waste    | 5.9717                           | Highly biodegradable wastes            |
organics. SNI 19-7034-2004 on compost specifications from organic waste ranging from 10 to 20 at the end of composting. The tofu factory wastewater content before composting was 89.46\%. On the 14th day, the water content decreased to 41.99\%, whereas the water content of the cow dung sample before composting was 75.01\%. After composting for 14 days, the water content of the cow dung sample became 40.62\%. The volatile solid content of the tofu factory waste sample was not considerably different from the initial conditions, which ranged from 94\% to 97\%. Meanwhile, the content of volatile solids in the cow dung sample increased from 64\% to 88.20\% on the 3rd day. The content of volatile solids in the cow dung sample increased until the 14th day to 93.29\%. The C/N ratio of the two samples still satisfied SNI 19-7034-2004 on compost specifications from organic waste ranging from 10 to 20 at the end of composting.

Scanning electron microscopy (SEM) images recorded just before and after composting of both samples revealed a smaller grain size after composting and a larger space between grains. SEM imaging aims to provide qualitative and quantitative information on the structure, texture, and surface morphological features of the material, such as shape, size, and others [14]. Both SEM images of the sample after composting revealed that composting using a bulking agent makes the sample bind with the bulking agent.
Figures 3 and 4 show the change in the oxygen saturation percentage as a function of time during composting carried out on the tofu factory waste and cow dung samples. The curve obtained with composting was more stable than that obtained before composting, where an extremely steep decline was observed. The decrease in the oxygen saturation percentage was less than that observed before composting. The highest decrease occurred on the 7th day for the tofu factory waste sample, which was 74.12%, while the lowest decrease for the tofu factory waste samples after composting for 14 days was 44.41%.
Figure 5. Change in the Oxygen Saturation Percentage as a Function of Time for the Tofu Factory Waste Sample

Figure 6. Change in the Oxygen Saturation Percentage as a Function of Time for the Cow Dung Sample

Table 6. Calculated SRI and DRI Values after Composting

| Sample          | Day | m   | DM (gDM/gX) | OM (gOM/gDM) | SRI (mgO₂g⁻¹OM⁻¹h⁻¹) | DRI (mgO₂g⁻¹OM⁻¹h⁻¹) |
|----------------|-----|-----|-------------|--------------|-----------------------|----------------------|
| Tofu Factory Waste | 3   | 0.0050 | 0.533 | 6.05 | 0.0077 | 113.0203 |
|                  | 7   | 0.0043 | 0.555 | 7.33 | 0.0052 | 113.0139 |
|                  | 10  | 0.0042 | 0.501 | 5.62 | 0.0074 | 113.0196 |
|                  | 14  | 0.0031 | 0.580 | 3.13 | 0.0085 | 113.0224 |
|                  | 3   | 0.0054 | 0.469 | 4.91 | 0.0116 | 113.0307 |
| Cow Dung         | 7   | 0.0041 | 0.693 | 8.42 | 0.0035 | 113.0092 |
|                  | 10  | 0.0037 | 0.610 | 7.27 | 0.0041 | 113.0109 |
|                  | 14  | 0.0033 | 0.594 | 5.29 | 0.0052 | 113.0138 |

Before composting, the SRI of the tofu factory waste was 13.3995 mgO₂g⁻¹OM⁻¹h⁻¹. After composting, the SRI of the tofu factory sample decreased to 0.0085 mgO₂g⁻¹OM⁻¹h⁻¹ on the 14th day of composting. On the 10th day, the SRI increased because of the increase in the water content of the
sample; hence, the DM decreases, and the OM is less than that on the 7th day. The SRI of the cow dung samples before composting was 0.4193 mgO₂/g·OM·h⁻¹. On the 10th day, the SRI of cow dung samples also increased because of the decrease in the DM and OM values. On the 14th day, cow dung samples exhibited an SRI of 0.0052 mgO₂/g·OM·h⁻¹. In addition, the DRI of both samples decreased from day 3 to day 14.

From this study, the percentage decrease in the SRI composting process ranged from 97% to 99%, indicating that composting with the Takakura method can be an alternative method for treating some organic wastes. Under the tofu factory waste condition, which exhibited a higher initial SRI value, the highest percentage of SRI decomposition decrease occurred on the 3rd day (99.94%), and until the 14th day of composting, the percentage decrease in the SRI value was the same. Therefore, the composting of the tofu factory waste samples by this method is sufficient for 3 days. On the other hand, for cow dung samples, the highest percentage of the SRI decrease occurred on the 7th day (99.17%). However, on the 10th day and 14th day, the percentage decrease of the SRI was less than that on the 7th day. This condition can be affected by the decrease in the oxygen saturation percentage, which was greater on the 10th day than on the 7th day.

Based on the 2001 California Compost Quality Council stability standard, composted samples are classified as extremely stable, which was related to the SRI of the composted sample being less than 0.5 mgO₂/g·VSh⁻¹ on each composting day. According to the US Department of Agriculture and the US Composting Council (2001), compost is declared stable when it has an SRI value of less than 0.125 mgO₂/g·VSh⁻¹. Based on this reference, the produced compost meets the standards. Based on the Canadian Council of the Environment documents (2005), compost stability is determined by an SRI value of less than or equal to 0.4 mgO₂/g·VSh⁻¹. The composting results revealed that the SRI of compost in both samples is less than 0.4 mgO₂/g·VSh⁻¹.

4. Conclusion

Based on this study, the following conclusions can be drawn:

1. Among the tested samples, tofu factory waste exhibits the highest SRI and DRI values of 13.3995 mgO₂/g·OM·h⁻¹ and 148.3747 mgO₂/g·OM·h⁻¹, respectively. In contrast, cow dung samples exhibit the lowest SRI and DRI values of 0.4193 mgO₂/g·OM·h⁻¹ and 114.1069 mgO₂/g·OM·h⁻¹, respectively.

2. The stability level of organic waste is divided into the category of biodegradation level. Fruit waste and tofu factory waste are categorized into highly biodegradable wastes (SRI > 5 mgO₂/g·DMh⁻¹). City WMU waste, garden waste, food waste, and organic waste from the market are categorized into moderately biodegradable waste (SRI = 2–5 mgO₂/g·DMh⁻¹). Cow dung samples are classified as low biodegradable wastes (SRI < 2 mgO₂/g·DMh⁻¹).

3. Composting is carried out on tofu factory waste samples and cow dung samples for 14 days by repeatedly checking each parameter on the 3rd, 7th, 10th, and 14th day. The SRI value for the two samples after composting becomes more stable. Composting by the Takakura method can be an alternative method for treating organic waste that is not yet stable.

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