

# Effect of Sewage Sludge Addition on the Completion of Aerobic Composting of Thermally Hydrolyzed Kitchen Biogas Residue

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The composting of thermal-hydrolyzed kitchen biogas residue, either with or without sewage sludge, was compared in this study. The addition of sewage sludge increased and prolonged the temperature to a sufficient level that met the requirements for aerobic composting. Moreover, after mixing the compost materials, oxygen, ammonia, and carbon dioxide levels reverted to those typical of aerobic composting. Finally, increased dewatering, organic matter degradation, and similar mature compost production were observed. Overall, the sewage sludge exhibits a potential synergistic effect to facilitate complete aerobic composting of thermal-hydrolyzed biogas residue.

*Keywords:* Biogas residue; Compost; Maturity; Sewage sludge

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## INTRODUCTION

Kitchen waste is an organic mixture that is rich in grease, salt, and potential fertilizer components such as organic matter and nitrogen. Currently, the main reclamation technology for kitchen waste is anaerobic digestion after pretreatment. Thermal-hydrolysis has been validated as an effective pretreatment measure to increase dewatering and biogas production (Qiao *et al.* 2011). However, the weight of the residue is one tenth to one eighth of the initial weight of the waste after completion of digestion. This residue is generally disposed of in landfills or applied to the soil as fertilizer (Odlare *et al.* 2011; Svensson *et al.* 2004). In one instance, application of fertilizer can lead to root rot in the presence of immature biogas residue due to a continual degradation of organic matter in the soil. Therefore, stabilization of the organic matter prior to fertilizer application is essential (Bustamante *et al.* 2012). Additionally, if the temperature of thermal-hydrolysis exceeds 100 °C, this can lead to the inactivation of most aerobic microorganisms that are responsible for the process of composting.

It is not clear whether thermal-hydrolyzed biogas residue can be successfully composted to produce stable and harmless organic fertilizer, or whether additional materials need to be added. It is well known that sewage sludge contains some amounts of heavy metals, such as As, Pb, Cu, and Cd. Uptake content of heavy metal increases along with the increase in the amendment dosage of the sludge compost (Zhou *et al.* 2010), but not to a threshold value indicating an adverse impact on soil quality (Singh and Agrawal 2008), let alone physiological disorder or injury, even bio-toxicity of seedling cultivated in amended soil (Hicklenton *et al.* 2001). Overall, therefore, heavy metals are not a critical worry under reasonable control on application dose and frequency. Additionally,

sewage sludge is physically and biochemically similar to biogas residue, and aerobically composted sewage sludge has the potential to produce organic fertilizer or growing media (Perez-Murcia *et al.* 2006; Cai *et al.* 2011). Therefore, the possible promotion of biogas residue composting with the addition of sewage sludge was investigated in this study.

## EXPERIMENTAL

### Materials

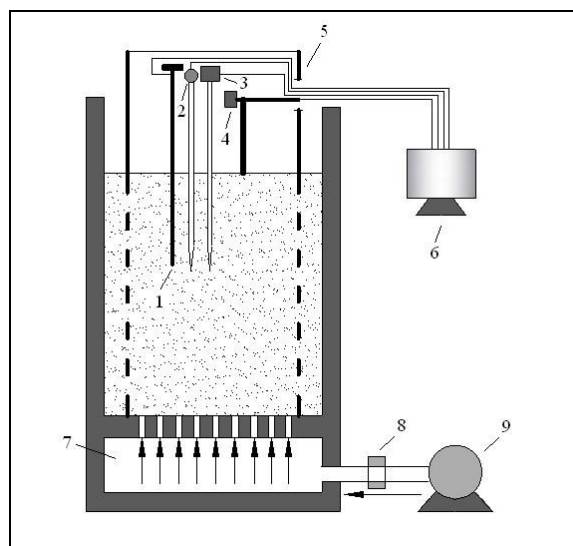
Kitchen biogas residue produced from digestion of kitchen waste, before which a thermal-hydrolysis (180 °C, 1.0 mbar, 60 min) procedure had been conducted, was collected from an anaerobic digestion station in the Haidian District of Beijing. Sewage sludge was collected from the Qinghuangdao Lv-gang sewage sludge treatment plant. Wood chips were used as an amendment during the composting process. The physicochemical properties of these three materials are shown in Table 1. The experiment was divided into two treatments: treatment 1, in which biogas residue and sewage sludge were mixed with wood chips at a weight proportion of 2:1:1; and treatment 2, in which biogas residue was mixed with wood chips at a weight proportion of 3:1.

**Table 1.** Physico-chemical Properties of Composting Materials

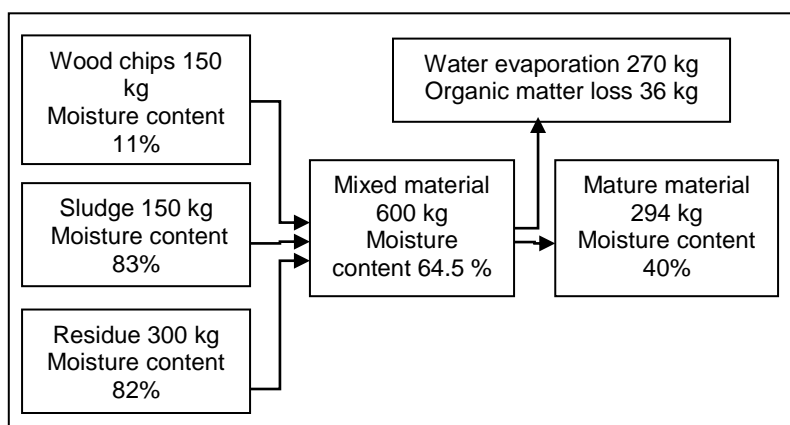
Material Types	Moisture (%)	Organic Matter (%)	Volatile Solids (%)	Total Organic Carbon (%)	Total Nitrogen (%)
Kitchen biogas residue	82	57	60	33	4.63
Sewage sludge	83	48	65	34	5.36
Wood chips	11	98	96	46	0.60

### Methods

The experiment was carried out in semi-open composting jars with a volume of 0.6 m<sup>3</sup> (Fig. 1). A mixture of sewage sludge and biogas residue with wood chips, or a mixture of biogas residue with wood chips were loaded into the jar. The mass balance for fresh matter of treatment 1 during composting is illustrated in Fig. 2. Air was supplied at 0.6 m<sup>3</sup>·min<sup>-1</sup>·kg<sup>-1</sup> from the bottom to the top by an air blower. The aeration was controlled using an innovative static forced-aeration process known as auto-control technology, which is based on a combination of temperature and oxygen concentration feedback by temperature and oxygen sensors (Chen *et al.* 2011; Luo *et al.* 2008). Notably, two temperature sensors were infixed inside jar. One was at the top position of the pile (the distance from sensor tip to pile surface was about 25 cm), and another was at the bottom position of the pile (the distance from sensor tip to pile bottom side was about 30 cm). The aeration parameters were adjusted at different stages based on the temperature and oxygen consumption rate (Chen *et al.* 2011; Shen *et al.* 2012). The aeration period lasted for 30 min, with aeration and unareation periods of 4 and 26 min, respectively, during the temperature elevation stage, 7 and 23 min, respectively, during the thermophilic stage, and 10 and 20 min, respectively, during the temperature decline stage. Temperature was measured using a PT100 thermal resistor (Pico Technology; China) temperature sensor connected to the control system.



**Fig. 1.** Structure of composting jar experiment: (1) temperature sensor; (2) CO<sub>2</sub> sensor; (3) NH<sub>3</sub> and O<sub>2</sub> integrative sensor; (4) vapor sensor; (5) cylindrical cover; (6) data logger; (7) air chamber; (8) flow meter; and (9) air blower



**Fig. 2.** Flow chart of fresh material mass balance for mixture composting of biogas residue, sludge and wood chips (weight proportion of 2:1:1)

The NH<sub>3</sub> and oxygen concentrations were detected by a custom-made detection device with a NH<sub>3</sub> online sensor (CR-200, UK) and oxygen automatic detector (A3, UK), which are connected to the control system. Carbon dioxide content was detected by a FGD10A (Status Scientific Controls; UK) sensor connected to the control system. A water vapor collection system was set up to collect the water vapor from the mixture pile. A gas duct linked to a guide slot was placed above the pile, and water vapor was pumped into a dehumidifier *via* the gas duct. After condensation, water was discharged, collected by the guide slot, and measured (Cai *et al.* 2012, 2013).

The biological maturity of the compost was indicated using the seed germination index as follows: 1 g of compost was soaked in 5 mL of deionized water to develop diluted samples (5 mL); then, it was spread on culture dishes covered with filter paper. Fifty seeds of radish were sown on the dishes, and they were transferred to a darkroom with a temperature of 30 °C and 35 to 60% relative humidity for germination. Finally, the

seed shoot length, germination percentage, and germination index (GI) were determined (*i.e.* (germination percentage of treatment) $\times$ (seed shoot length)/(germination percentage of control) $\times$ (seed shoot length of control) $\times$ 100%). Biological maturity data were analyzed by ANOVA at a significance level of  $P < 0.05$  using SPSS v13.0.

## RESULTS AND DISCUSSION

### Temperature Profile during Composting

Figures 3 and 4 display the temperature profile during the composting process for treatments 1 and 2, respectively. For both treatments, the time required for the temperature to increase and then decrease was less than 12 days. During the rapid temperature elevation stage (20 to 50 °C), the top layer of the mixture pile was similar to the bottom layer. However, the bottom temperature was higher than the top within the high-temperature stage ( $> 50$  °C). As shown in Fig. 3, the top and bottom layers of treatment 1 were all initiated within the second day of the rapid elevation stage and reached the high-temperature stage within 12 h. The maximum temperature of the top and bottom layers was 65 and 71 °C, respectively.

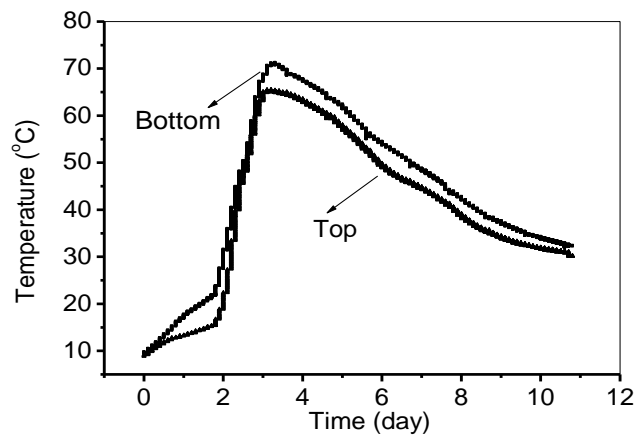


Fig. 3. Temperature profile during composting for treatment 1

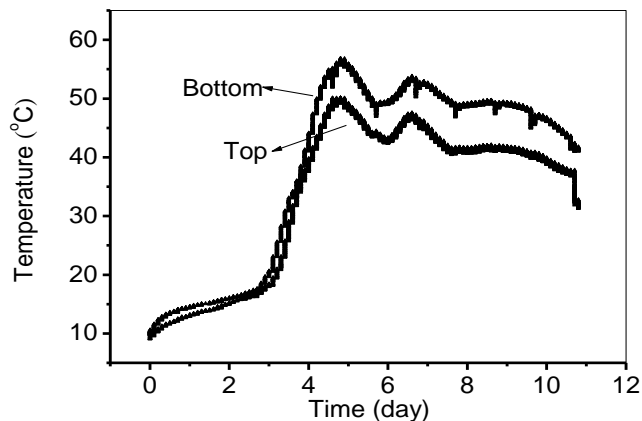


Fig. 4. Temperature profile during composting for treatment 2

As shown in Fig. 3, the temperature was above 55 °C in the top and bottom layers of treatment 1 for 3.0 and 3.5 days, respectively, which conforms to the aerobic compost requirement that the temperature be above 55 °C for the last three days of composting (EPA 1993). For treatment 2, the high temperature only lasted for 0.7 days, which was not sufficient to complete composting (Fig. 4). Overall, these findings indicate that the use of biogas residue alone does not lead to a sufficient temperature increase for composting; conversely, the sewage sludge addition improves composting conditions. Temperature is an excellent indicator of microbial activity in a composting pile (Bernal *et al.* 2009), and sewage sludge obviously plays an important role in promoting biogas residue organic matter degradation to generate and accumulate more heat.

### Change in Oxygen Concentration during Composting

As shown in Figs. 5 and 6, the oxygen concentration of treatments 1 and 2 during composting initially decreased, then gradually increased. As a result of stopping aeration in the initial stage of composting (1 to 2 days), oxygen levels decreased rapidly, which might be due to high consumption by microorganisms. When aeration began, oxygen concentrations changed periodically. Overall, the oxygen concentrations of both treatments were greater than 10% during the composting process, indicating aerobic conditions.

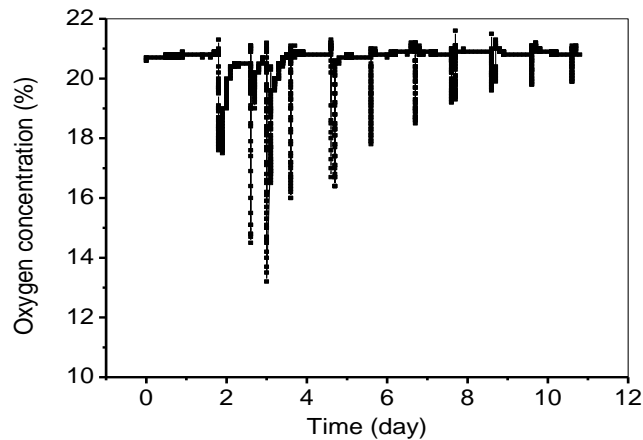


Fig. 5. Change in the oxygen concentration during composting for treatment 1

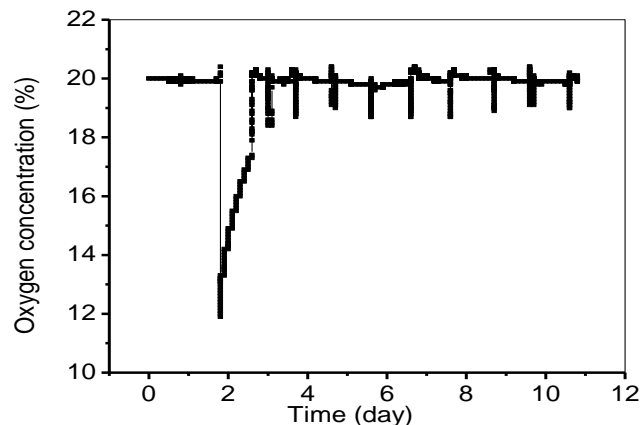


Fig. 6. Change in the oxygen concentration during composting for treatment 2

As shown in Figs. 5 and 6, the oxygen consumption rates of the two treatments differed. Specifically, the maximum oxygen consumption rate occurred on day three and then gradually decreased for treatment 1. The results are similar to the finding of Lasaridi and Stentiford (1998) and Chen (2011) who stated that oxygen consumption peak usually appear at stage of rapid temperature elevation. Conversely, the rate of oxygen consumption was essentially unchanged throughout the process for treatment 2. This difference indicates that the mixing of sewage sludge into biogas residue leads to stronger microbial activity and greater organic matter degradation.

### Change in Ammonia Release during Composting

During composting, the ammonia concentrations of treatment 1 and 2 increased at first, then gradually declined (Figs. 7 and 8).

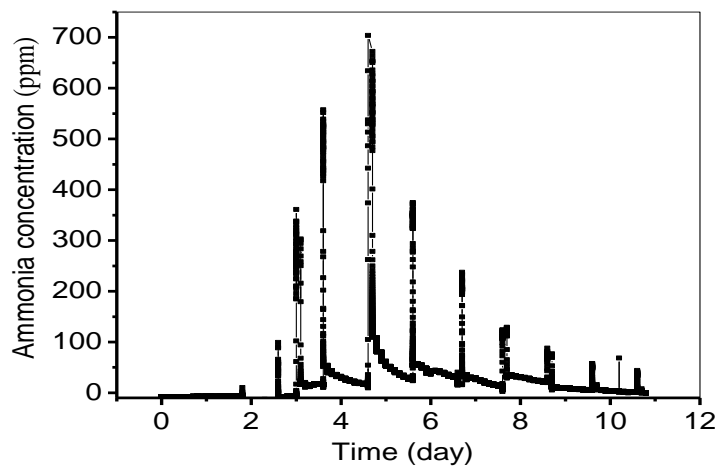


Fig. 7. Change in the ammonia content during composting for treatment 1

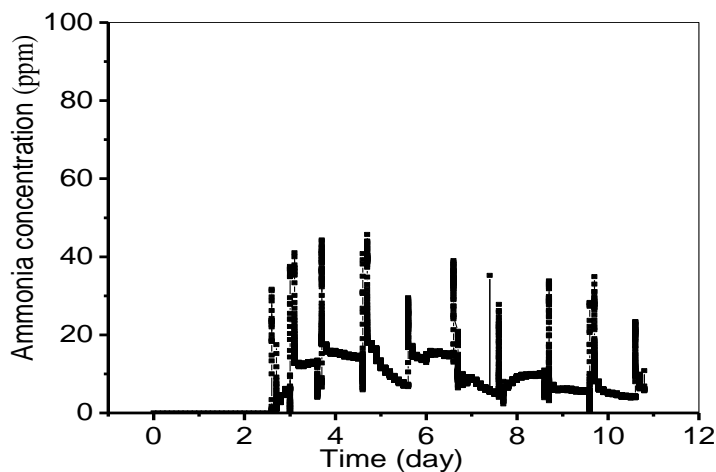


Fig. 8. Change in the ammonia content during composting for treatment 2

However, the ammonia concentration increased rapidly in conjunction with the temperature increase. A maximum was reached on day 5, and the temperature decreased

gradually past day 8. The variation seen indicates that ammonia is mostly released during the high-temperature stage, which has been suggested as a critical stage for ammonia release (Chen 2011). This finding is in agreement with the results of Lu (2009), who found that the increase in the proportion of sewage sludge to municipal solid waste in composting was due to increased nitrogen loss in the form of ammonia. The ammonia concentration of treatment 2 remained below 40 ppm throughout the composting period, which was much lower than that of treatment 1. These results could be due to two factors. First, the low C/N ratio in sludge and biogas residue led to a higher nitrogen content of the mixture; thus, the excess nitrogen was transformed into volatile ammonia (Eklind and Kirchmann 2000; Pagans *et al.* 2006; Suffet *et al.* 2009). Second, the biological activity of biogas residue was limited by thermal-hydrolysis before composting was started; thus, the low synthetic enzyme activity resulted in low volatile ammonia production.

### Change in Carbon Dioxide Release during Composting

During the aerobic composting process, the carbon dioxide concentration in treatment 1 reached a maximum after 2 days, then declined rapidly (Fig. 9). During the initial temperature elevation stage, the amount of carbon dioxide increased because of the stop in intermittent aeration. However, strong microbial activity promoted organic matter degradation immediately upon resumption of aeration, resulting in the carbon dioxide concentration peaking (8%), after which it declined gradually as the microbial activity decreased. The change in carbon dioxide was similar to that in temperature, but opposed to that in oxygen. This variation has previously been demonstrated by Frederick *et al.* (1998), and is in accordance with typical change pattern of carbon dioxide released from aerobic composting. The abrupt carbon dioxide production peak meant that carbon in the mixture of sludge and biogas residue was oxidized, accompanied by synchronous oxygen consumption under the action of adequate aerobic microorganisms. However, the carbon dioxide concentration in treatment 2 was only 2%, indicating that no additional carbon was oxidized and converted to carbon dioxide because of the absence of aerobic microorganism in mixture of biogas residue and wood chips only, leading to lower oxygen consumption (Kulikowska and Klimiuk 2010).

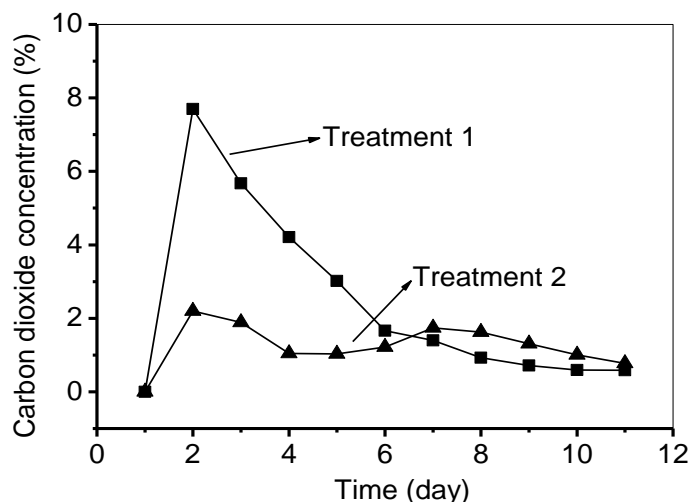


Fig. 9. Change in the carbon dioxide concentration during composting

### Change in Condensed Water Amount during Composting

During the initial temperature elevation (0 to 2 days for treatment 1, and 0 to 3 days for treatment 2), no condensed water was produced because aeration was stopped. At the start of intermittent aeration, a large portion of water vapor condensed (Fig. 10). The change in condensed water was parallel to that in temperature, with the maximum occurring on day 6, followed by a decrease to the end of the period. The amount of condensed water in treatment 2 was much lower (approximately 50%) than that of treatment 1. This difference implies that dehydration is very poor if the biogas residue is composted alone without added sewage sludge. These findings agree with those of Navaee-Ardeh *et al.* (2006), who suggested that composting dehydration is realized by binding water and precipitation triggered by aerobic microbial activation, as well as evaporation from the surface of the waste (Velis *et al.* 2009).

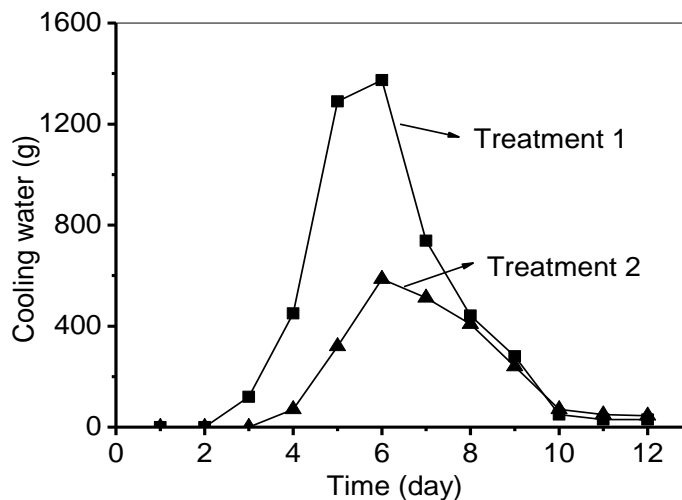


Fig. 10. Change in the amount of condensed water during composting

### Comparison of Dewatering, Stabilization, and Reuse Indices after Composting

As shown in Table 2, the changes in dewatering, stabilization, and reuse indicated that the addition of sewage sludge promoted biogas residue composting. The moisture content of the compost amended with the sewage sludge was 44%, which was far less than that of residue alone (61%), indicating that the former had a greater decrease in volume. The organic matter content of the amended compost was less than 24% of the biogas residue alone. This indicates that the compost amended with sewage sludge that had additional active microorganisms accelerated the organic matter degradation until stabilization.

A little unexpectedly, the maturity of amended compost was less than that of residue alone after composting, but insignificantly. Enrichment of sewage sludge-amended waste with volatile organic acids, which are closely associated with phytotoxicity, may result in the decrease in maturity indicator (Brinton 1998; Garcia *et al.* 1992). Nevertheless, the absolute maturity value (87%) met the maturity index standard (80%) for reuse as soil amendment (Tiquia and Tam 1998).



**Table 2.** Moisture, Organic Matter, and Maturity after Composting

Comparison of Indexes	Biogas Residue Alone	Addition of Sewage Sludge to Biogas Residue
Moisture	61 ± 2% a	44 ± 1% b
Organic matter	50 ± 3% a	38 ± 2% b
Maturity (germination index)	92 ± 2% a	87 ± 3% a

Note: \*Mean values followed by a different letter are significantly different (P<0.05).

## CONCLUSIONS

1. Biogas residue amended with sewage sludge resulted in a temperature elevation and prolonged high temperature sufficient to meet the requirements for aerobic composting as compared to composting of thermal-hydrolyzed biogas residue alone.
2. The levels change of oxygen, ammonia, and carbon dioxide seen during the addition of sewage sludge to biogas residue were typical of those of aerobic composting.
3. Increased dewatering, better stabilization, and acceptable maturity were attained in response to the addition of sewage sludge to biogas residue.

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