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Model combination of biodigester and composter

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ABSTRACT

The biodigester is a tool used to process organic matter into biogas and is a solution to manage the accumulation of organic waste. Piles of garbage, if left un-cleared, will have a negative impact on the environment in the form of water and soil pollution, and damage the aesthetics of the environment. This study aimed to create combination model of biodigester and composter in managing organic waste into biogas and compose. We focus to discuss about the parameters of observed in biodigester. This study method is a laboratory experiment. The reactor was deployed continuously, using a heater with a temperature of approximately 55-60 ºC and stirring between 100 rpm. The reactor temperature could be adjusted according to the living conditions of the thermophilic bacteria used at a temperature of 45-65 ºC and installed in an integrated manner with the fermenter. The study method on pH parameters is APHA 4500-H, chemical oxygen demand (COD) with spectrophotometry, total solid (TS) with APHA 2540B, volatile solid (VS) with APHA 2540E method, total suspended solid (TSS) with APHA 2540B method and volatile suspended solid (VSS) using the APHA 2540E method. The study results on HRT 10 with pH 7 showed an average yield of TS, VS, TSS, VSS, COD, and Alkalinity amounting to 31.613, 22.125, 12.629, 10.713, 17.625 and 4.481 mg L^{-1}, respectively. This study proposes a new combination model of biodigester and fermenter which is effective in manufacturing biogas and compost from organic waste.

Keywords: Boigas, CSTR, Biodigetser, Organic waste.
Article type: Research Article.

INTRODUCTION

Increased waste production is one of the problems faced by the Biodigester, which is a tool for degrading organic matter through an anaerobic process to produce biogas (Gao *et al.* 2019). Biodigester technology is useful for reducing greenhouse gas emissions such as methane (CH_4; Hoang & Kato 2021). Biogas is produced by decomposing organic materials such as organic waste from urban, household, and agricultural sources and other organic wastes (Norouzi & Dutta 2022). The biodigester is the process of decomposition of organic matter into biogas with the help of microorganisms (Kalsum *et al.* 2020). A biodigester is a reactor that operates under anaerobic conditions or without air, which produces methane gas (Veroneze *et al.* 2018). Methane gas released during the decomposition process from piles of organic waste or open dumping will cause a greenhouse effect (Uçkun Kiran *et al.* 2016). It is one of the causes of global warming, its impact 21 times greater than carbon dioxide (Skytt *et al.* 2020). Utilisation of methane for biogas plays a very positive role in overcoming the problem of the greenhouse effect, which has a negative impact on the environment and is the cause of global climate change. Other studies also reported that organic waste has the potential to contribute to increasing greenhouse gas emission (Zhang *et al.* 2019). Cudjoe *et al.* (2020) pointed out that gas produced from landfills has a high global

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warming potential. Conversion of organic waste into biogas using a biodigester has a very high potential, however previous study needs to be optimised again to produce biogas that is optimal and does not damage the environment. The potential for biogas development is very large due to the large availability of raw materials in the form of organic waste, such as food waste produced by the food processing industry (Sarker *et al.* 2018). Biogas energy can also be obtained from manure or livestock waste (Nasiruddin *et al.* 2020), organic waste from the market, etc. Utilisation of biogas energy from a biodigester has many benefits, namely reducing the effect of greenhouse gases, preventing the spread of disease, reducing unpleasant odours, generating heat and mechanical/electrical power, as well as by-products of the biogas formation process in the form of solid and liquid fertilizers. Such management and utilisation of waste will be economically very competitive, as the prices of fuel oil and inorganic fertilisers increase. Utilisation of organic waste as an energy source will be economically competitive, compared to the constant increases in the prices of petroleum and inorganic fertilisers. In addition, this method is considered environmentally friendly and a sustainable organic material processing practice. Biodigester technology as a tool for converting organic matter into biogas is very simple and easy to practice, and the equipment for making biodigester is easy to obtain. Previous authors like Irvan *et al.* (2018) have delved deep into the field of processing organic matter into biogas, examining zero-waste technology in processing palm oil mill waste after the milling process. Irvan's study carried out fermentation of palm oil mill effluent (POME) into biogas using a continuous stirred tank reactor (CSTR) and utilising thermophilic microbes to degrade organic waste, producing active liquid organic fertiliser or activated liquid organic fertilizer (ALOF). The study of (Irvan *et al.* 2020) used a single-stage biodigester for POME processing with various stirrings in the reactor. Research with a two-stage reactor was carried out by Barua & Kalamdhad (2019) using a two-stage CSTR reactor, utilising water hyacinth as raw material, while Butar Butar *et al.* (2020) examined the utilisation of Caringin Main Market waste and solid residues used as compost in the biodigester. Further study to be carried out will aim at optimising the management and utilisation of biogas reactor effluent, which is a liquid by-product of the biogas production process or the processing of organic matter into biogas. One of them can be a source of pollution of the soil (Paolini *et al.* 2018). The reactor effluent contains organic matter and microorganisms (Wang *et al.* 2017), which can be used as an activator in the composting process. Hence, in this study, the processing of organic waste will be updated by making a combination model of biodigester and composter in converting organic waste into biogas and compost. In the process, this study will also make a simulation using Aspen plus a combination of biodigester and composter. The novelty of this study is a model of a combination of biodigester and composter in converting organic waste into biogas and compost, as also a projection of biogas yields of the reactor used. Aspen plus makes it easier for investigators in terms of time, manpower and limitations of analytical tools in the laboratory to get the desired results and research objectives (Dasgupta & Chandel 2019). In the early stages, this study was carried out on a laboratory scale, with the primary raw material being an organic waste. The weaknesses of the study in laboratory are the long-time constraints, the high cost and the limited availability of tools, and the limited results as this study could only analyse organic matter content in general, such as TS, VS, TSS, VSS and COD (Budiyono *et al.* 2014). In order to achieve more perfect results, it is continued with the second stage using aspen plus software to get results with more complex analyses (Orhan *et al.* 2012), such as starch, cellulose, hemicellulose, xylose, cellulose, ethanol, soluble protein, triolein and palmitic-olein compounds. Aspen plus in this study aimed to minimize and provide efficiency in the study process (Damartzis *et al.* 2012). The aspen plus software is expected to provide optimal conditions for combining biodigester and composter in managing organic waste into biogas and compost from biodigester and fermenter units (Glivin *et al.* 2021). Aspen plus can also control operating conditions in thermodynamic study, conducted by Dasgupta & Chandel (2019) on biogas production from municipal waste organic waste by varying temperatures. This study will create a simulation using aspen plus a combination of biodigester and composter in managing organic waste into biogas and compost. So, the novelty of this study is a combination model of biodigester and composter in managing organic waste into biogas and compost; the second novelty is a projection of biogas yield from the reactor used

MATERIALS AND METHOD

The system in this study consists of a combination of biodigester and composter equipment in converting organic waste into biogas and compost (Fig. 1). The system includes a CSTR reactor, fermenter, storage tank, gas meter, gas tank, and temperature control panel. This study also uses equipment to analyse parameters such as furnace, oven, desiccator, petri dish, measuring cup, beaker, soil test, and pH meter. The series of equipment in this study can be seen in Fig. 1.

Fig. 1. Combination model of biodigester and composter in converting organic waste into biogas and compost.

Materials for the first reactor or the biodigester are organic waste from restaurants and cafes, and rice husk for the second reactor/fermenter. The experiment was carried out in the laboratory using a starter in the form of methanogenic bacteria derived from the manufacture of biogas on a pilot scale at the Institute for Community Service (LPPM) of the University of North Sumatra, Indonesia. Raw materials or feeds were derived from organic waste from restaurants and rice husks. The working temperature of the fermenter was at a thermophilic condition of 55 ºC, (the pH of the fermenter was around 7 and stirring was carried out at 100 rpm). The varied variable is Hydraulic Retention Time (HRT). Parameter analysis to be carried out in this study includes the analysis of the raw materials used, namely organic restaurant waste with initial analysis time (t_0) of waste and analysis time of each collection (t_i). The liquid analyses consist of pH, M-alkalinity, total solid (TS), content analysis, volátile solid (VS), COD (Chemical Oxygen Demand) and gas analysis. The study methods on pH parameters were APHA 4500-H, chemical oxygen demand (COD) with spectrophotometry, total solid (TS) with APHA 2540B, volatile solid (VS) with APHA 2540E method, total suspended solid (TSS) with APHA 2540B method and volatile suspended solid (VSS) using the APHA 2540E method.

Work Procedures

This study involved an anaerobic digestion process by designing a combination of biodigester and composter made in an integrated manner. The type of reactor designed was a stirred tank flow reactor to produce biogas. In the initial stage, restaurant waste mixed with methanogenic starter with a composition of 1:10 solids, water was poured into the feed tank, and stirred until homogeneous. The mixture was fed into a reactor with a working volume of 10 L at a temperature of 55 ºC. The process began with treatment without giving an organic load (batch) until the pH and alkalinity were stable (2000-4000 ppm). After a stable condition was achieved, a continuous stage was carried out, adding an organic load gradually at a temperature of 55 ºC, pH 7 and the alkalinity was stable (2000-4000 ppm). It was kept stable so that the conditions of microbial life in the reactor could develop properly. To prevent a decrease in pH and alkalinity, $NaHCO_3$ could be added to the reactor from the beginning of the process until the end of the operation. Analyses of pH, alkalinity, COD, TS, VS, TSS, and VSS during the process were carried out every day, while the analysis of COD and gas was carried out every 3 days until the end of the process. Analysis of pH, M-alkalinity and COD used samples that came out of the overflow in the reactor, while the analysis of TS, VS, TSS, and VSS used samples located at sampling points along the reactor. The biogas formed was measured through a gas meter connected to the reactor and the analysis carried out was the gas composition of CH_4, CO_2 and H_2S using a gas detector.

RESULTS AND DISCUSSION

Research results of reactor loading up process

The fermentation process to degrade organic matter into biogas requires adaptation for microbial growth (Jurgutis *et al.* 2020). The microbial adaptation stage in the biogas reactor is referred to in this study as Loading Up. In the Loading Up process in the biogas reactor, this study used a starter microbes sourced from the pilot plant of the University of North Sumatra (USU), Indonesia. The temperature in this study was 55 ºC, with a stirrer speed of 100 rpm. The pH in the reactor was +7. During the fermentation process, the degradation of organic matter into biogas was controlled to control the pH, so that the pH in the reactor during the process remained constant through the addition of sodium bicarbonate ($NaHCO_3$). In this study, the target HRT was 10, and to attain it the HRT was gradually decreased from 250 to 200, 100, 67, 50, 33, 25, 20, and 10.

pH and alkalinity profile during reactor loading process

pH is one of the parameters controlled during the loading up process and is regulated and controlled according to the conditions favoured by methanogenic bacteria, so that the biogas formation process runs optimally (Lee *et al.*

2019). The optimal pH for methanogenic bacteria was 6.5-8, while a pH above 8 or below 6 would inhibit the process in the methanogenic phase (Khan *et al* 2019). As the loading-up process was highly dependent on pH conditions, the pH was adjusted according to the conditions appropriate for methanogenic bacteria, so that the anaerobic digestion process could run optimally. The optimum pH conditions for producing the best biogas were in the range of 6.6-7.6. If the operating conditions were in the pH range of 5-6.2, it would result in toxic substances in the methane bacterial population, reducing the efficiency of biogas production. Therefore, the loading up process was controlled by pH 7. The graph of the alkalinity and pH profile can be seen in Fig. 2.

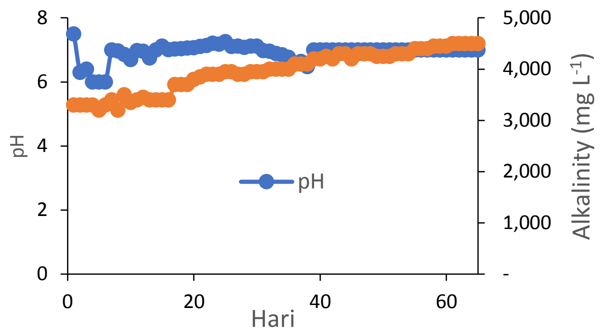


Fig. 2. pH and alkalinity profile.

Fig. 2 illustrates that the pH profile during the degradation process at loading up was stable, where the pH value was found to be in the range of 6-8 (Yogafanny 2015) in the degradation process of organic matter into biogas utilising methanogenic microbes. According to (Chow 2020), in the biogas production process, microbes utilise volatile fatty acids (VFA) to be consumed as food ingredients, so that alkalinity and pH will increase until conditions were stabilised. As in the reactor, the pH fluctuates every day, with the lowest value at 6. There was a change in the alkalinity value in the biogas reactor. The pH value in HRT 250 was in the range of 6-7.5, while the alkalinity in HRT 250 was 3,200 - 3,400 mg L^{-1}. At HRT 200, the pH value was 6.7-7 and the alkalinity in the range of 3,200-3,400 mg L^{-1}. At HRT 100, pH values were in the range of 7.01-7.11, while the alkalinity in the range of 3,400 – 3,850 mg L^{-1}. At HRT 67, the pH values were 7.08 -7.26 with alkalinity in the range of 3.900-3.950 mg L^{-1}. At HRT 50, the pH value was 6.64 - 7.12 with alkalinity values ranging from 3950 to 4000 mg L^{-1}. At HRT 20, 25, and 10 the pH started to be stabilised at pH 7, while the alkalinity was in the range of 4,300-4,500 mg L^{-1}. The alkalinity and pH values of HRT 250 – HRT 10 were changed, however, were still in the category, according to Khan *et al.* (2019). The optimal pH value in biogas reactors was 6-8. The pH parameter was important and should be controlled in the biogas formation process, as it affected the performance of an anaerobic reactor, and the bacteria in the reactor being very sensitive to changes in pH.

Degradation of organic materials during the loading-up process

The amount of organic matter in the reactor or Organic Loading Rate (OLR) is closely related to HRT and substrate concentration. Hence, to achieve a good digester process, there should be a measurement of OLR. The amount of OLR is a parameter that describes the amount of volatile solid (VS) that is fed into the reactor every day. VS is part of the organic matter in the reactor or organic solids that are decomposed into biogas (Kamyab & Zilouei 2020). The purpose of looking at the OLR is to see the performance of the biogas reactor, with the number of VS in the reactor as an indicator (Sarker *et al.* 2018). The chemical oxygen demand (COD) parameter describes the organic compounds present in the volatile fatty acid (VFA) in the raw material that is fed into the reactor or influent and the reactor output liquid or effluent. In the process of forming biogas, VFA is expected to reduce the COD value in the reactor, so that the biogas yield can be greater. To see the effect of HRT 250, 200, 100, 67, 50, 33, 25, 20, 10, see Fig. 3. This Fig. shows the decomposition of organic materials observed in this study from the results of VS and COD analyses. In this study, daily VS and COD analyses can be seen from changes in HRT starting from 250, 200, 100, 67, 50, 33, 25, 20 and 10. COD and VS values both fluctuated with values on HRT 250. So that, VS was in the range of 25% - 34%, while the COD on HRT 250 was 17-19%. In addition, on HRT 200, VS was 23-26% and the COD was 25 -28; at HRT 100, VS was 21-24%, while COD was 31-32%; at HRT 67, VS was 20-23%, while COD was 31-35%; at HRT 50, VS was 18-21, while COD was 39-44%; at HRT 33, VS was 17-18%, while COD was 44-50%; at HRT 25, VS was 14-16% and COD was 39-44%; at HRT 20, VS was 13-18% and COD was 44-50 %; Finally, at HRT 10, VS was 23-30 %, while COD was 50 -53%.

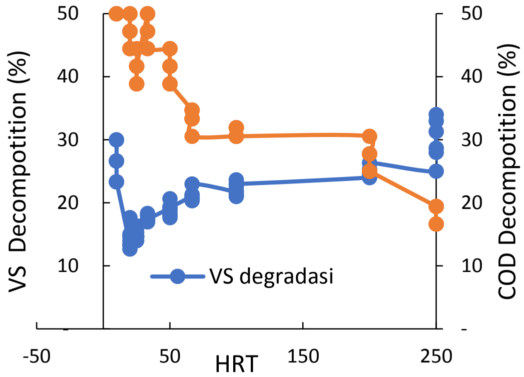


Fig. 3. Degradation of organic materials during loading.

The fluctuations in COD and VS values in the reactor were caused by microbes that needed adjustments to reduce organic matter into biogas (Isa *et al.* 2020). In this study, there was an increase in COD reduction at HRT 10, due to an increase in OLR in the reactor. Musa *et al.* (2018) found that by elevating the organic loading rate, COD reduction will also increase exhibiting that the influent substrate on HRT 10 is higher than on the other substrates. The COD reduction value is expected to be stable when the influent reactor is entered with the same volume for a long time or HRT 10 as the target. According to Widarti *et al.* (2013), the loading-up of the reactor occurs by elevating the OLR, until it reaches a stable level, aims to adapt the methanogenic bacteria in the reactor. VS (volatile solid) is one of the parameters that can show the degradation of organic matter over time in the reactor and can be an indicator of the potential for methane gas production (Bres *et al.* 2018). In the analysis of VS decomposition, fluctuations tend to increase; starting from HRT 250 though HRT 10, the value of VS reduction elevates along with the decrease in HRT in the biogas reactor (Veluchamy *et al.* 2018). The VS value increases from HRT 250 through 10, since methanogenic microbes work well to degrade organic matter into biogas (Freitas *et al.* 2020). In the study of biogas from restaurant waste, the highest VS reduction was obtained at HRT 10, which was 30%. Thus, the higher the organic matter in the biogas reactor influent, the higher the volume of biogas formed (Widarti *et al.* 2013).

Hydraulic Components and Reactions in the Aspen Plus simulation process

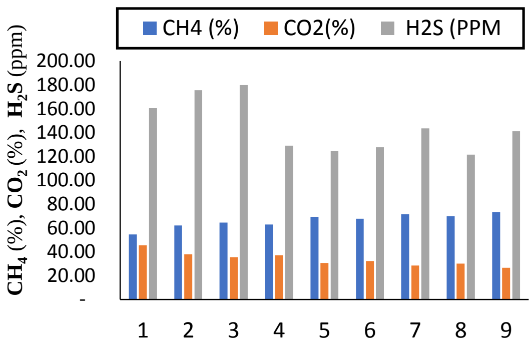
This study uses Aspen Plus simulation, and a reaction occurs in the RCSTR, where the list of hydrolysis reactions can be seen in Table 1 (Rajendran *et al.* 2014), exhibiting the reactions that occur in the hydrolysis process. The hydrolysis process of restaurant waste into biogas in this study consisted of 12 hydrolysis reactions whose components consisted of starch, cellulose, hemicellulose, xylose, protein, triolein, tripalmate, palmino-oliein, and palmito-linolein. A similar reaction was also carried out by Rajendran *et al.* (2014). In the initial phase of the process, very complex organic materials are simplified or broken down into very simple compounds. Compounds can be dissolved in water with the help of enzymes produced by microorganisms present in the solution; this is called the hydrolysis process (Westerholm *et al.* 2019). The result of this hydrolysis process is a soluble monomer wherein the protein is broken down into amino acids and triglycerides. Complex carbohydrates such as polysaccharides, cellulose, lignin, starch and fibre are converted into simple sugars, such as glucose and fat into glycerol acid (Rajagopal *et al.* 2019). In the simulation of gas formation from restaurants using Aspen Plus, a CSTR reactor is used. There are 12 hydraulic reactions.

Amino acid components and reactions, acidogenic, acetogenic, methanogenic reactions in the Aspen Plus simulation process

Rajendran *et al.* (2014) reported a list of amino acids, acidogenic reactions, acetogenic, methanogenic and kinetic constants. This process occurs in the CSTR reactor. In the Aspen simulation, all reactions are input to generate a simulation of the formation of biogas production. As many as 33 reactions occurred, from the amino acid process, like acidogenic reaction, acetogenic to methanogenic reactions, etc. Acidogenesis (fermentation) is the second phase process in the formation of biogas. The raw material during fermentation is the product of hydrolysis (amino acids, fatty acids, and sugars) which is referred to as a substrate (Chow *et al.* 2020). The raw materials or substrates are converted with the help of acidogenic bacteria into the main degradation products in the form of carbon dioxide, acetic acid and hydrogen which function as methane precursors which can be directly utilised in the methanogenic process by methanogenic bacteria. The intermediate product, volatile fatty acid alcohol (VFA), in this process, produces hydrogen sulfide (H_2S) and ammonia (NH_3) as by-products (Becker *et al.* 2015). The reactions in acidogenesis reveal two reactions, in which process the hydrolysis products are converted by acidogenic bacteria into methanogenic bacteria substrates. In this process, bacteria active in the polymer hydrolysis stage are also active during the acidogenesis process. So, acidogenic bacteria and bacteria on hydrolysis are also referred to as bacteria that can survive under aerobic and anaerobic conditions, or obligate anaerobes (Sarkar & Venkata Mohan 2020). They reported the stages in the acetogenesis process, where 6 reactions occur. The acetogenesis process is a product of intermediates formed during the process as follows: The first is alcohol, with more than one carbon atom, branched chains and aromatic fatty acids as well as volatile fatty acids (VFA) with more than two carbon atoms (C). The products of the acidogenesis process, which cannot be converted directly into methane compounds by methanogenic bacteria, are converted into these bacteria substrates during acetogenesis (Nandayani *et al.* 2021). In the process at the methanogenesis stage, two reactions occur. The raw material at the methanogenesis stage is a product of acetogenesis, which is the last phase of anaerobic digestion in the biogas formation process. Acetic acid and CO with H_2 are converted into methane by the archaea methanogens bacteria. In normal anaerobic digesters, acetate is the precursor to 70% of the total methane formation, the remaining 30% of CO_2/H_2. In a balanced anaerobic decomposition, all products from the previous metabolic phase are converted into subsequent products, resulting in a complete conversion of biodegradable organic components to biogas.

Biogas composition quality

Restaurant waste has the potential to produce methane, since according to Valença *et al.* (2021), restaurant or its food wastes are a waste of resources, both human resources and energy resources and also damages the environment. Therefore, it is converted into energy in the form of usable biogas. Since one of the objectives of this study is to see the composition of biogas, the detailed results can be seen in Fig. 4.



1 = HRT 250; 2 = HRT 200; 3 = HRT 67; 5 = HRT 50; 6 = HRT 33; 7 = HRT 25; 8 = HRT 20; 9 = HRT 10.

Fig. 4. Quality of biogas composition.

One of the parameters seen in this study is the composition of biogas, to ascertain the concentrations of CH_4 (%), CO_2 (%) and H_2S (ppm). Fig. 4 illustrates the quality of biogas from HRT 250, 200, 67, 50, 33, 25, 20, to 10. In this study, the concentration of CH_4 (%), CO_2 (%), H_2S (ppm) fluctuated every day. At HRT 250, CH_4 was 54.50%, CO_2 45.50% and H_2S 160.50 ppm; at HRT 200, CH_4 62.14%, CO_2 37.86% and H_2S 175.71 ppm; at HRT 100, CH_4 64.43%, CO_2 35.57% and H_2S 180 ppm; at HRT 67, CH_4 62.86%, CO_2 37.14% and H_2S 129 ppm; at HRT 50, CH_4 69.25%, CO_2 30.75% and H_2S 124.38 ppm; and at HRT 10, CH_4 was 73.50%, CO_2 26.50% and H_2S 141.25 ppm. The higher the CH_4 composition in biogas production, the better it will be for use as a renewable fuel (Valença *et al.* 2021). The best CH_4 composition in this study was at HRT 10, with the resulting CH_4 composition of 73.50%, while the optimum CH_4 composition was in the range of 55-75% and the CO_2 value was

25-45%. The concentration of CH_4 (%), CO_2 (%) and H_2S changed every day due to the adjustment of the performance of methanogenic bacteria to form methane gas in the biogas reactor (Tsapekos *et al.* 2021).

CONCLUSION

From this study, it can be concluded that the best conditions were HRT 10 with a pH of 7, TS 31,613 mg L^{-1}, VS with an average yield of 22,125 mg L^{-1}, TSS with an average yield of 12,629, VSS was 10,713 mg L^{-1} and COD with an average yield of 17,625, while the average alkalinity yield was 4.481 mg L^{-1}. This study proposes a new combination model of biodigester and fermenter which is effective in manufacturing biogas and compost from organic waste.

Conflicts of interest

This study and writing are the result of a research on student detachment from natural resource management and the environment. There is no conflict of interest between the authors or with others, as this paper is purely for the contribution of scientific knowledge in the field of waste management and bioenergy with the topic of Model Combination of Biodigester and Composter.

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