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Particle Size and Digestion Stability in Dry Anaerobic Digestion of Municipal Solid Waste: A Review

* Dias K.K.W.D.S.W., Ariyarathna S.M.W.T.P.

Department of Chemical and Process Engineering, Faculty of Engineering, University of Peradeniya, Sri Lanka.
* Corresponding Author Email: e15074@eng.pdn.ac.lk

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Abstract: The uncontrolled decomposition of waste could lead to health and environmental issues like pandemic diseases, the spread of foul odors, and climate change. One of the most effective and environmentally friendly ways to manage municipal waste is anaerobic digestion. The efficiency and stability of anaerobic digestion may all be affected by particle size. Process stability depends on maintaining the biochemical equilibrium between acid and methane formers. The success or failure of the process can thus be determined by matching the particle size reduction selection. This study shows the importance of understanding the particle size reduction of Organic Fraction of Municipal Solid Waste (OFMSW) to understand how dry anaerobic digestion may produce optimum methane production based on data from different authors analyzing OFMSW from different countries. The main conclusion is that for optimal gas production, it is also essential to consider the feeding material size for these processes.

Index Terms: digestion stability, dry anaerobic digestion, municipal solid waste, particle size

1 Introduction

After the industrial revolution, developing countries' economies significantly affected their health and environment. They are the depletion of natural resources, pandemic diseases, pollution, and waste generation due to human activities. Therefore, solid waste disposal, treatment, and management are significant global challenges. The most critical challenge is that the amount of waste generated is increasing rapidly because of urbanization, rapid population growth, and modern lifestyles. Therefore, the generation of waste is an unavoidable product of human activity.

Many developing countries have identified that some of the existing waste management methods are no longer appropriate due to issues associated with disposal pathways, such as environmental and human health impacts. Continued open dumping and primitive solid waste landfilling in developing countries will have significant environmental and health effects since the uncontrolled decomposition of waste could lead to pandemic diseases, the spread of foul odors, and climate change [1]. Many current global waste management activities also allow for significant methane emissions. However, some waste management systems are designed to improve the benefits and reduce the negative impacts of Municipal Solid Waste (MSW) by using different modern technologies and methods. Among most waste management systems, such as pyrolysis, gasification, and solid waste incineration, anaerobic digestion (AD) is one of the alternative renewable energy technologies shown to be an acceptable option [2]. It is a biological process involving the decomposition of organic material by microorganisms without free oxygen. A wide range of organic matter can be used as a substrate for AD. This study focuses on the substrate, which is the organic material or organic fraction of MSW (OFMSW), such as household waste and sewage sludge.

Waste is difficult to define since it includes a wide range of substances that are becoming more complicated and varied. Waste created from residential sources, such as households, as well as institutional and commercial sources, such as offices, schools, hotels, and other sources, is referred to as MSW. Food, garden waste, paper, board, plastic, textiles, metal, and glass are the main components of MSW. The composition of MSW varies from one country to another according to their culture and development status. Fig. 1. shows composition variation of municipal solid waste in various countries such as China, India, and Indonesia… etc. [3].

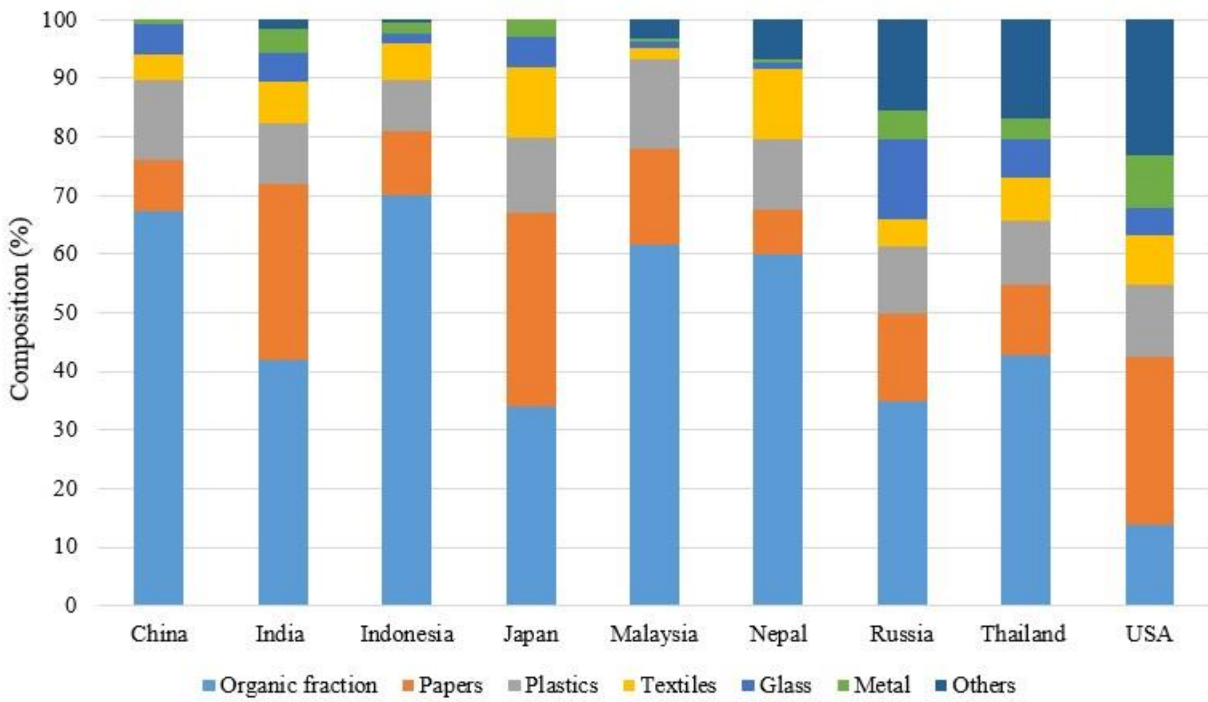

Fig. 1. Composition (%) variation of municipal solid waste in some selected countries

According to Fig. 1, a high proportion of organic fraction consists of MSW resulting from food residues, garden waste, and paper in various countries. Fig. 2. shows the composition of waste collection in Sri Lanka. Also, MSW from Sri Lanka consists of a very high moisture content of 70–80% (by wet weight) and a high fraction of organic matter at 65.5% (by weight) [4].

The MSW consists of a biodegradable organic fraction and a non-biodegradable fraction. The biodegradable fraction of MSW is OFMSW, also called bio-waste. The OFMSW is known for its high moisture and biodegradability due to a high amount of food waste, kitchen garbage, and scraps from households, restaurants, dining facilities, factory lunchrooms, and marketplaces [5]. The classification of OFMSW varies from country to country depending on many factors. While it is considered a mixture of food, garden waste, and paper in the USA, OFMSW is considered a mixture of wastes from parks, gardens, and kitchens in European countries [6].

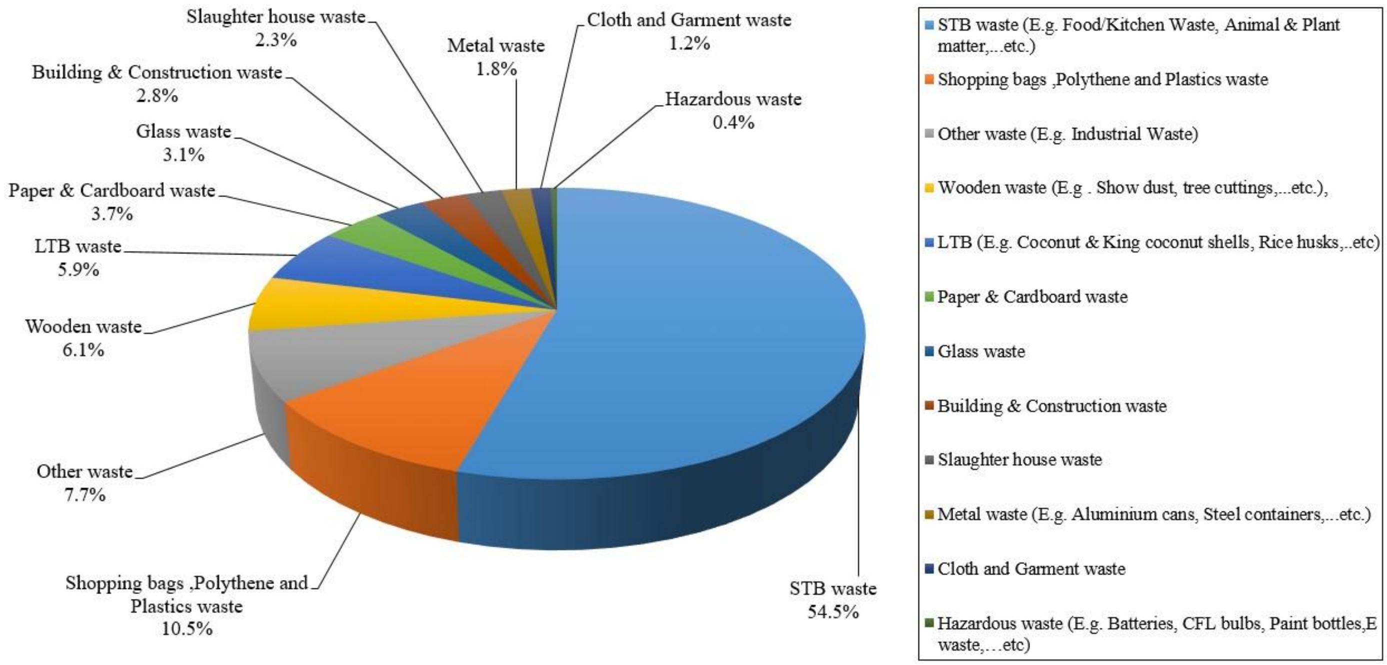

Fig. 2. Composition of MSW in Sri Lanka [7]

The anaerobic biodegradation inside landfills or open dumps will produce large quantities of landfill gas and leachate. The gas emissions of landfills are mostly Methane (CH_4) and Carbon dioxide (CO_2) produced by the anaerobic biodegradation of OFMSW, which are greenhouse gases that cause air pollution; hence, OFMSW will lead to global warming if it decomposes uncontrollably. Therefore, AD of OFMSW in a controlled way, may be an environmentally friendly technology for reducing the negative impacts of MSW, as well as its volume and toxicity and in addition to many other benefits, such as the potential for energy recovery, producing an end product suitable for soil conditioning, and reducing dependence on landfills.

There are three main types of anaerobic digestion of OFMSW based on the total solids (TS) content of the solid waste. They are: wet process (<10% Total Solids), semi-dry process (10–20% Total Solids), and dry process (>20% Total Solids). Dry anaerobic digestion, also known as "high-solid" anaerobic processes, is interesting because the amount of water applied to the raw waste is significantly low, resulting in a smaller digester, a higher organic loading rate potential, and reduced abrasion in the reactor from sand and grit due to the lack of moving parts. However, due to the high TS content, dry ADs also have certain drawbacks, including long degradation periods and the possible concentration of toxic and inhibitory compounds (e.g., volatile fatty acids, ammonia, and heavy metals) [8]. This will also result in lower methane output per kilogram of volatile solids (VS) and larger inoculation ratios per kilogram of VS [9].

The particle size of the substrate is an essential parameter of any biological process, and it releases internal organic molecules and increases the particle contact area, improving kinetics. Even though particle size is not as essential as the temperature or pH of the digester contents, it still impacts gas production. However, this is an important consideration, and the optimum particle size distribution is likely to balance optimizing biological processes while maintaining physical and biochemical stability.

However, compared with wet AD, limited and inconsistent studies are available for dry AD. Some of them are contradictory at times, although there is no clear conclusion as to the optimum particle size of the substrate on the stability of dry AD of MSW. Also, a limited number of studies are available for dry AD in the organic fractions of Sri Lankan MSW. In addition, almost all of the studies have been conducted on the

OFMSW of European, American, and other countries' waste. So, this work aims to analyze the relation between the particle size of the substrate and the stability of dry AD of MSW. The objectives of this review are; (a) To study the dry anaerobic digestion process, (b) To identify the stability of the dry AD process, (c) To identify factors like temperature, pH, Carbon to Nitrogen ratio, inoculation, particle size of the substrate and TS content that affect the stability of the dry AD process.

2 BASIC OF THE AD PROCESS

AD is a biochemical process in which several kinds of anaerobic microorganisms degrade organic materials in the absence of oxygen. The main product is energy-rich biogas, and a co-product is nutritious digestate. There are four main steps in the anaerobic decomposition of OFMSW. They are hydrolysis, acidogenesis, acetogenesis, and methanogenesis steps. The progress and types of products are shown in Fig. 3. for each step.

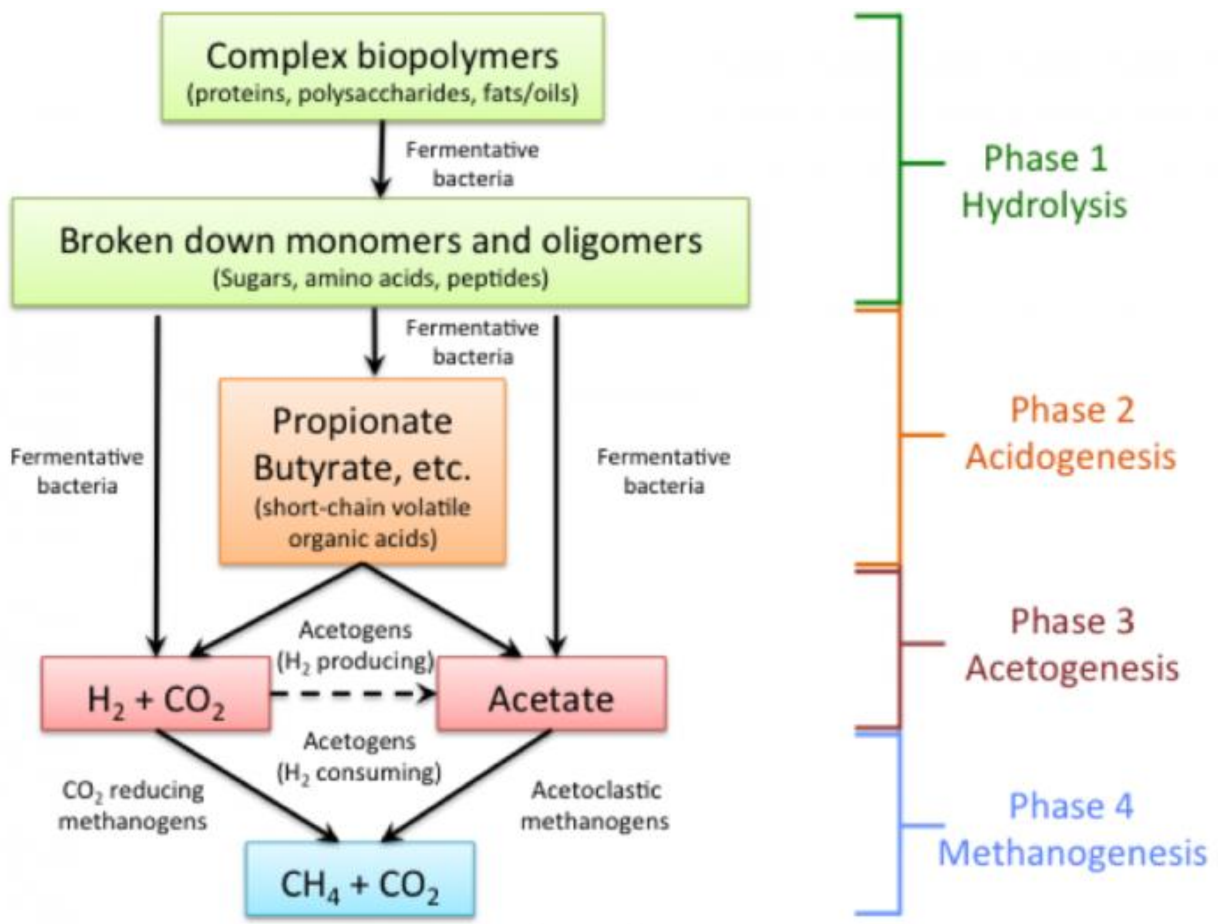

Fig. 3. Schematic of biodegradation steps of OFMSW [10]

Hydrolysis is the first step of anaerobic decomposition. It converts complex organic material such as proteins, polysaccharide, fats/oils into liquefied monomers and Oligomers (sugars, amino acids, peptides) by hydrolysis bacteria, as shown by Equation (1) [10].

$$Bio\ Mass\ +\ H_2O \rightarrow Monomers + Oligomers + H_2 \quad (1)$$

Equations (2) and (3) show how acidogenic bacteria can produce intermediate volatile fatty acids and other products in the acidogenesis stage by absorbing the hydrolysis products through their cell membranes. These fatty acids belong to a class of short-chain volatile organic acids such as acetates, propionate, and butyrate [11].

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2 \quad (2)$$

$$C_6H_{12}O_6 +\ 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O \quad (3)$$

Acetogenesis is the third step of the AD process, also referred to as the dehydrogenation stage. In this stage, both long-chain fatty acids and volatile fatty acids and alcohols are converted into hydrogen, carbon dioxide, and acetic acid by acetogenic bacteria, shown in Equations (4)–(6) [11].

$$CH_3CH_2COO^- +\ 3H_2O \rightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2 \quad (4)$$

$$C_6H_{12}O_6 +\ 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad (5)$$

$$CH_3CH_2OH +\ 2H_2O \rightarrow CH_3COO^- + H^+ + 3H_2 \quad (6)$$

Methanogenesis is the stage where methanogenic microorganisms consume accessible intermediates to produce Methane. Equations (7)–(9) show reactions during methanogenesis [12]. The substrate quantity introduced into the reactor volume in a given time, Organic loading rate (ORL), the composition of feed and the temperature affect the methanogenesis stage.

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (7)$$

$$2CH_3CH_2OH +\ CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (8)$$

$$4H_2 +\ CO_2 \rightarrow CH_4 + 2H_2O \quad (9)$$

CH_4 and CO_2 are the main components of the gaseous product of AD. Typically, the composition of Methane is 53–70 vol%, and carbon dioxide is 30–50 vol% [13].

2.1 Affecting parameters on dry AD

Several factors influence the production of biogas and the performance of the AD process. For the AD process, the rate at which the microorganisms develop is of great importance. Therefore, the digester's operating parameters are controlled in order to optimize microbial activity and thus increase AD performance. Some of them are temperature, pH, carbon-nitrogen ratio, inoculation, particle size of the substrate, and TS content.

Temperature is one of the variables that influences the AD process the most. Many researchers generally report three temperature ranges and optimum points; for example, some authors reported that the psychrophilic range is less than 20°C, the mesophilic range is 20–45°C, and the thermophilic range is between 45–65°C with optimal temperatures being 15, 35, and 55°C respectively [14], [15]. Although, AD technology is feasible under almost all climatic conditions, the digestion process does not perform satisfactorily at a mean temperature below 15 °C (low temperature) [16]. In addition, the operation between 33 and 37 °C (in Mesophilic conditions) is more stable and requires a negligible energy expense [17].

pH, known as the negative logarithm of the concentration of hydrogen ions, is one of the essential parameters. In some experiments, it was found that low pH values (below 7.5) inhibited anaerobic digestion by increasing levels of volatile fatty acid accumulation [18]. Nevertheless, the higher pH values (about 8.5) did not show any residue of acetic acid and butyric acid, which are responsible for the acidity of the mixture. The ratio of carbon-nitrogen (C/N) ratio expresses the relationship in organic materials between the amount of carbon and nitrogen. In the AD process, the standard way to analyze the presence of sufficient nutrient levels is through the ratio of C/N, for which no fixed value is defined. However, optimal C/N ratios in anaerobic digesters are between 20 and 30, and they have also reported that a lower C/N ratio implies that there is more nitrogen in the system, which leads to ammonia accumulation and a pH value above 8.5, which is toxic to methanogenic bacteria [9]. A higher C/N ratio implies less nitrogen in the system, caused by methanogens rapidly consuming nitrogen and producing less gas. This will eventually result in the failure of the process.

TS is referred to as the total dry matter content of the feedstock. By comparing wet AD to dry AD operates at a high TS content. The usage of higher waste per volume of digester in dry AD may cause accumulation inhibitors and lower methane production per kilogram of VS compared to wet AD, but a higher methane yield per unit volume of digester could be gained from dry anaerobic digestion [9].

2.2 Stability of dry AD

Process stability depends on maintaining the biochemical equilibrium between acid and methane formers, while instability is typically demonstrated by a sudden rise in the volatile acid concentration with a corresponding decrease in methane gas output. The anaerobic process can be toxic to some compounds at high concentrations. Generally, inhibition depends on the inhibitor concentration, the substrate composition, and the bacteria's adaptation to the inhibitor. Common inhibitory materials in anaerobic digestion include volatile fatty acids (VFA), free ammonia, H_2S, heavy metals, and hazardous substances [16].

Methanogenesis bacteria are the most susceptible to ammonia inhibition. Reviewing some studies reveals two potential ammonia inhibition mechanisms and promising explanations for how ammonia toxicity occurs [19]. The first mechanism is the methane synthesizing enzyme by ammonium ions, and the second mechanism is disrupting the proton and potassium balance inside the cell functioning is inhibited when the un-dissociated ammonia form diffuses through the cell membranes. The share of ammonia increases with increasing temperature and pH values. This inhibition can allow intermediate digestion products such as VFA to become imbalanced and accumulate, possibly contributing to digester acidification. To overcome the ammonia inhibition, increasing the C/N ratio (by using carbon-rich waste like paper and cardboard) and co-digestion with other materials could be used [9].

VFA is produced in the rate-limiting step of the hydrolysis step in the dry AD process. The main components of VFA are acetic acid, propionic acid, and butyric acid. AD process inhibition happens when VFA is produced at a higher rate in the hydrolysis stage than is absorbed by acetogenesis or methanogenesis steps, and for a high concentration of propionic acid is produced [18]. Because propionic acid is difficult to degrade, this contributes to decreased pH and methanogenic archaea inhibition. Percolate recirculation and decreasing the substrate-to-inoculum ratio are the most common solutions to overcome

VFA accumulation in a batch reactor [9].

3 INFLUENCE OF PARTICLE SIZE ON METHANE PRODUCTION

In any biological process, pretreatment of the substrate by reduction of particle size is a standard method. The reduction of the size of particles on the substrate (by crushing or shredding) in order to maximize the area of the surface subjected to degradation encourages and accelerates the kinetics. In addition, natural barriers to bacterial attack are disrupted, such as films, waxy coatings, and other surface protectants that prevent the microbe from accessing the components to be decomposed.

3.1 Comparison of effects on methane yield with particle size change in different substrates

There are many studies on the effect of particles on wet AD. However, there have been a few limited studies on the effect of particles on dry AD. Because of this, when compared to dry AD, wet AD had better energy equilibrium and economic performance [20]. Among those studies, some of the studies supporting the above argument have provided inconsistent results. Table 1. shows the effect of methane yields with particle size change in different studies.

According to Table 1, the effects on methane yield with particle size change in different substrates can be summarized into the following three points.

1. Methane yield decreases with particle size reduction.
2. There is no static difference in methane yield with particle size reduction.
3. Methane yield increases with particle size reduction.

As mentioned above, when particle size is reduced, the surface area-to-mass ratio is increased. The faster the bioconversion, the larger the surface area available for bacterial attack or biochemical activity. This fact is proven by some researchers' experiments. For example, an increase of 0.108 to 0.217 m^3/kg_{vs} methane yield when Corn Stover particle size was gradually reduced from 12.7 to 1 mm [21]. Corn Stover samples are stored under-covered and uncovered conditions. Corn Stover was used as a substrate, and effluent from a mesophilic liquid anaerobic digester fed with sewage sludge was used as the inoculum for this AD process. The average C/N ratio of Corn Stover samples is 58, and particle sizes of 1 and 12.7mm were tested. The 1L volume of each reactor feedstock-to-inoculum ratio of 1:3 mixtures was loaded. Nitrogen gas is pumped into the headspace of the reactor to avoid traces of oxygen. The process is a batch mesophilic dry digester maintained at 37 ± 1°C for 40 days at 160 rpm shaking. Then biogas was collected, biogas composition was determined, and the results obtained from the modeling process are shown in Fig. 4.

The main reason for methane yield increases with particle size reduction is the larger total surface area; generally, lignocellulosic biomass containing smaller particle sizes has more outstanding methane production. Smaller particle sizes of lignocellulosic biomass increase the availability of cellulose and hemicellulose to microorganisms and enzymes [28]. Also, grinding can improve digestibility by reducing the degree of cellulose crystallinity and decreasing the degree of cellulose polymerization [29].

Table 1. Comparison of methane yields with particle size change in different studies

No.	Feedstock	Particle size (mm)	Methane Yield (m^3/kg_{VS})	Effect	Reference
1	Wheat straw	0.11 0.67 1.45	0.052 0.075 0.096	Yield decreases with size reduction	Motte, Escudié, Bernet, Delgenes, Steyer, and Dumas [18]
2	Mechanically-sorted OFMSW	15 24	0.114 0.148		Basinas, Rusín, and Chamrádová [22]
3	Rice straw	10 25	0.240 0.232	No difference in yield	R. Zhang, and Zhang [23]
4	Banana peel	1 5 10	0.281 0.294 0.266		Tumutegyereize, Muranga, Kawongolo, and Nabugoomu [24]
5	Hand-sorted OFMSW	2 4	0.35 0.34		Y. Zhang, and Banks [25]
6	Corn Stover	5 10 15	0.12 0.15 0.15		Li, Zhu, Wan, and Park [26]
7	Thermally pre-treated waste activated sludge	0.002 0.008 0.016 0.037 0.053 0.062 0.074 0.105	0.21 0.18 0.17 0.15 0.14 0.13 0.11 0.09	Yield increases with size reduction	Vigueras-Carmona, Martínez Trujillo, García Rivero, Membrillo Venegas, and Zafra Jiménez [27]
8	Corn Stover	1 12.7	0.217 0.108		Wang, Xu, Liu, Cui, and Li [21]

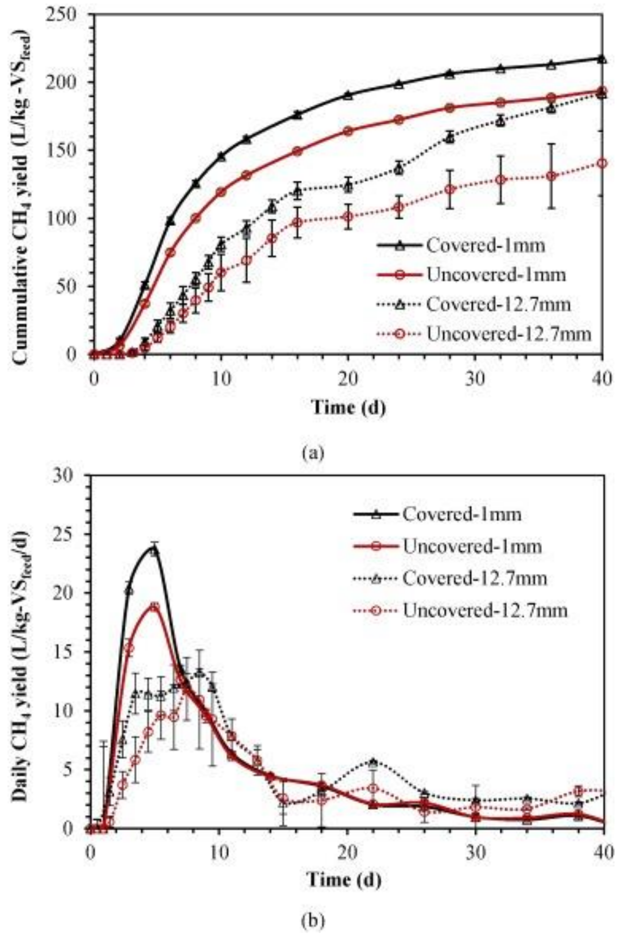

Fig. 4. Effects of Corn Stover particle size on dry AD: (a) cumulative methane yields, and (b) daily methane yields [21]

A 25% increase in gas production when the particle size diameter of office paper was reduced from 215mm to about 41mm [19]. Three different sizes of office paper as MSW were examined for this pilot-scale high-solids AD process. A complete mixed reactor with a total reactor volume of 2250 L is used with mechanical mixing. The typical operating temperature is 55°C for 30 days. The effect of office paper particle size, from 41 to 215mm, on methane gas production was evaluated, and the result is shown in Fig. 5.

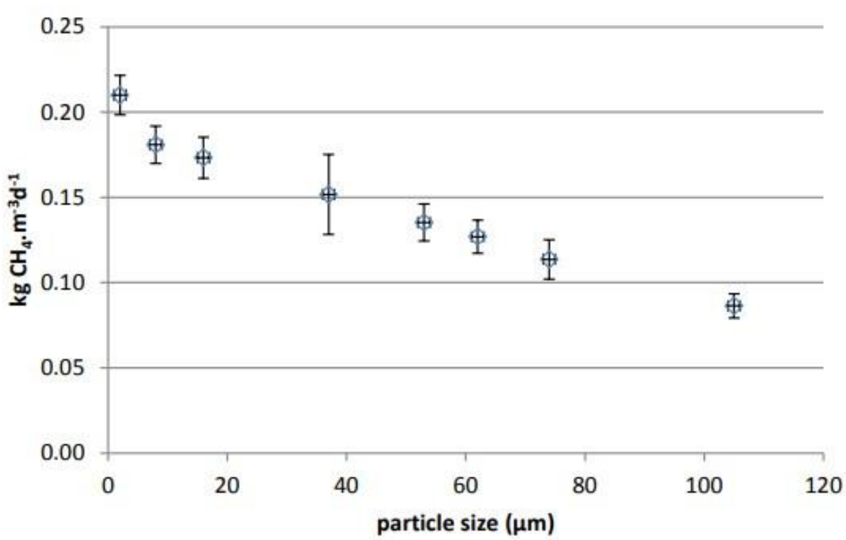

Fig. 5. Effect of particle size on methane yield [19]

It is noted that some studies examined the effect of particle size on the anaerobic digestion of solid waste residues in landfills and tomato residues [19]. At the same time, increasing the particle size of thermally pretreated sewage-activated sludge decreased the methane production rate [27].Waste-activated sludge from the wastewater treatment plant is the substrate for this process. Samples of 50 ml with particle sizes of 105, 74, 62, 53, 37, 16, 8, and 2.2 μm are tested. The process is carried out at 35 °C with dry anaerobic digestion. The results were statistically analyzed to evaluate the effect of particle size on methane production rate, as shown in Fig. 6.

In all studies, the efficiency of the digester was directly affected by the particle size of the feed material. A smaller particle size improves the substrate utilization rate, and hence the gas production rate is increased. The rate of methane gas production can be shown to be inversely proportional to the average substrate particle diameter. At the same time, smaller particle sizes may reduce material handling and help increase gas production rates. However, reducing feedstock particles below a specific size is expensive and uneconomical.

Although methane yield has increased through the reduction of particle size, research on the advantages of particle size reduction in dry AD is limited and often contradictory. When wheat straw particle size was gradually reduced from 1.4 to 0.7 and 0.1mm, a 22% and 46% drop in methane production was found in one experiment, respectively [18]. Biodegradable organics, increasing methane production. As a result of particle reduction, the lack of water in the dry AD system limits mass transfer and affects the distribution of methane production intermediate metabolites.

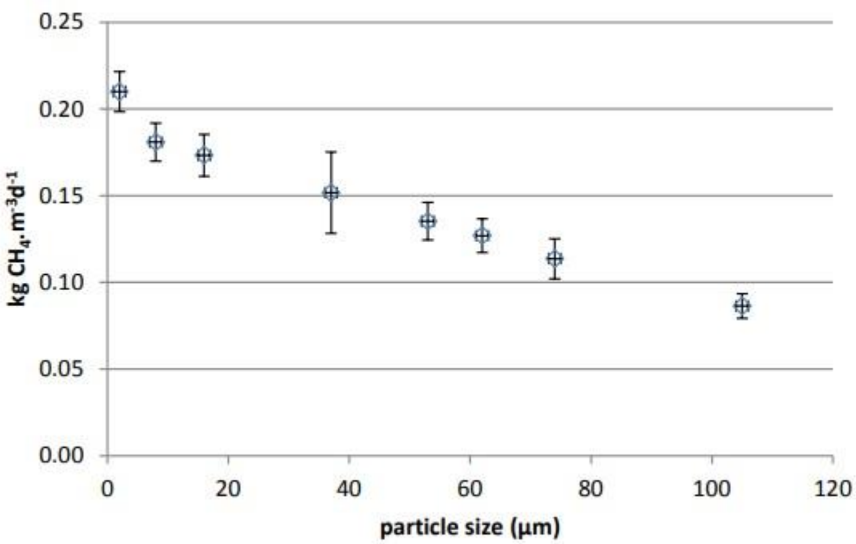

Fig. 6. Effect of particle size on the rate of methane production [27]

The study was carried out with wheat straw with particle sizes of 1.45, 0.67, and 0.11mm [18]. The inoculum of the research is OFMSW from a solid-state AD pilot treatment plant. Depending on the S/X ratio, NH_4Cl was added to samples to maintain a C/N ratio of about 40 in a 500-ml sealed flask. The process is a batch mesophilic dry digester maintained at 35 ± 1°C for 273 days. This study evaluated the dynamic effect of three factors: S/X ratio, TS content, and particle size. Biogas composition and production were measured using a micro-gas chromatograph and pressure measurements. The results were obtained from the three-level Box-Behnken plan by adjusting the TS content from 15% to 25%, the S/X ratio (in volatile solids) between 28 and 47, and particle size [18].

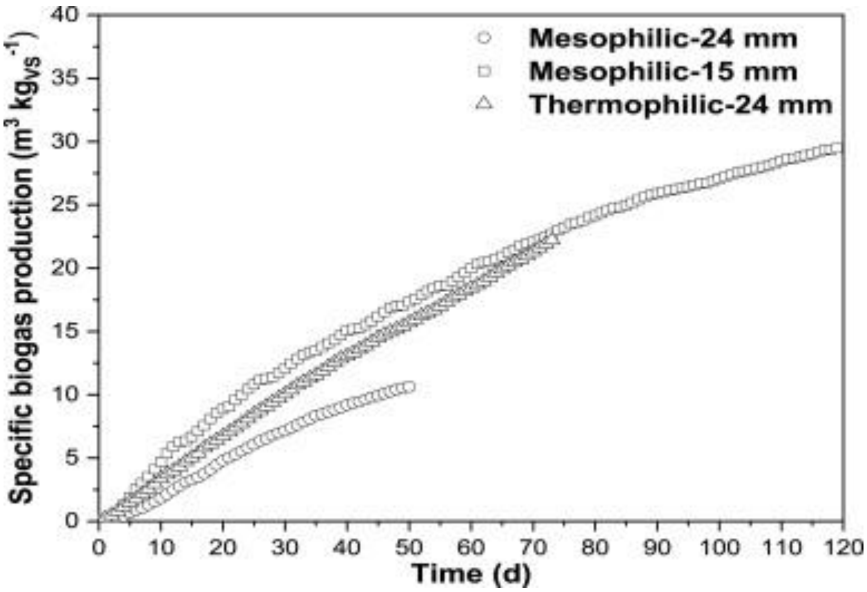

Fig.7. Specific biogas production during dry mesophilic AD of OFMSW particle sizes 15 and 24mm and dry thermophilic AD of OFMSW particle size of 24mm [22]

Furthermore, this study revealed that using a fine fraction raised the rate of VFA accumulation and caused a system failure, even though this fraction had the maximum methane potential under the conditions tested. When dry-AD failed, the distribution of VFA indicated that the acetogenesis and methanogenesis pathways had been disrupted. The failure of AD mechanisms resulted in an accumulation of acetic and butyric acids from fermentation pathways and propionic acid, which is difficult to degrade.

Also, in another study, it was revealed that 24mm particles produced 10.6 m^3/kg_{VS} of methane yield during 50 days, which is much less than the 17.3 m^3/kg_{VS} of methane yield obtained by 15 mm particles during the same period [22]. Two particle fractions of OFMSW were referred to as 15 and 24mm. The inoculum-to-substrate ratio was 1.75 g_{VS}/g_{VS}. Bottle reactors were maintained at 40 ± 0.5°C by placing them in a water bath for 40 days. Using kinetic modeling of biochemical methane potential, the effect of particle size is evaluated, as shown in Fig. 7.

Coarse particles contain organic matter that is chemically enclosed and not easily digested. The limited access of microorganisms to this biodegradable substance means that carbohydrate, protein, and lipid transformations are limited, thus limiting the rate of AD. As mentioned earlier, the difference in chemical composition, particularly in micronutrients, between fine and coarse particle samples was low enough that these substances are unlikely to produce significant differences in methane generation. As a result, the higher methane production is most likely due to the increased surface area of fine particles. The high surface area allows acidogenic bacteria and methanogenic archaea to access higher amounts of biodegradable organics, resulting in increased methane production.

However, R. Zhang and Zhang [23], Tumutegyereize, Muranga, Kawongolo and Nabugoomu [24], Zhang and Banks [25], Li, Zhu, Wan and Park [26], and Agyeman and Tao [30] showed no significant effect on the methane yield for different particle sizes. Among them, one study found that the 1mm banana peel particle size had a lower average methane content than the 5 and 10mm peel particle sizes [24]. Dried banana peels were reduced to 1, 5, and 10mm in particle size. An inoculum is taken from the digester. Statistical data were analyzed to evaluate the effect of banana peel particle size on methane yield, and the obtained results of methane content with different particle sizes are shown in Fig. 8.

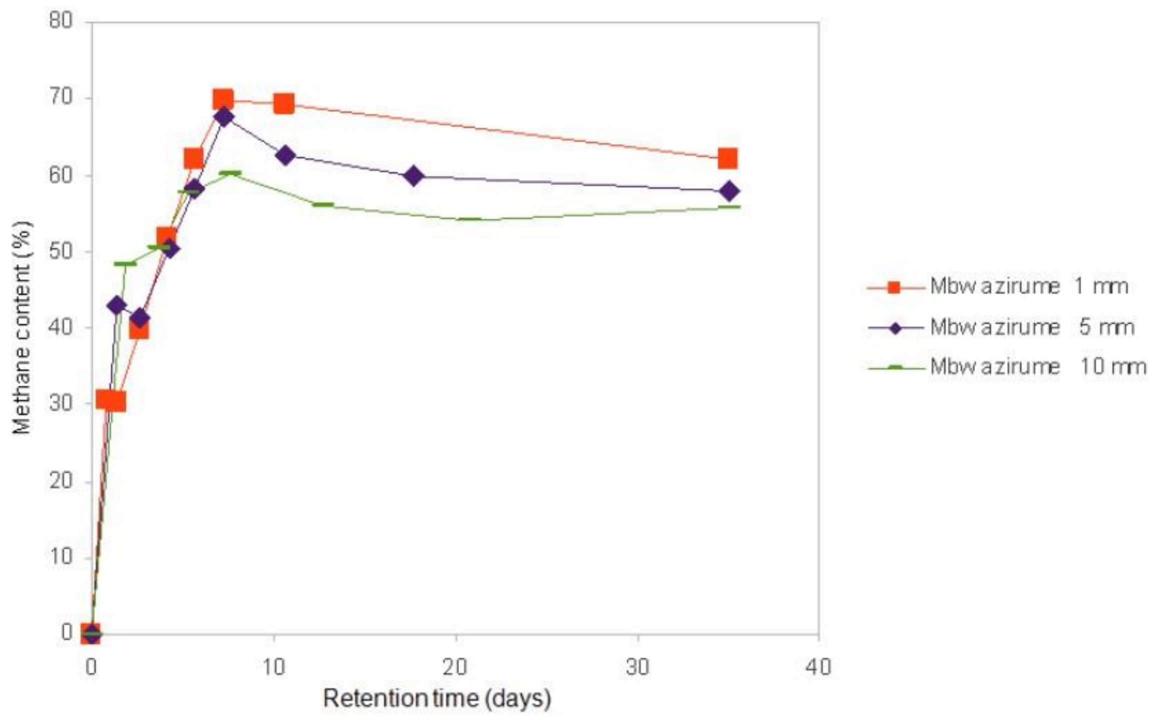

Fig. 8. Effect of particle size on methane content [24]

While the 1mm peel particle size provided a higher rate of biogas, the quality was low due to the low methane content. This is likely due to the large surface area exposed to the hydrolyzing enzymes when small particles are used, resulting in an overload of intermediate acids that cannot all be utilized by the slow methanogens for methane generation, resulting in an acidic condition that affects biogas quality. R. Zhang and Zhang [23] found that grinding rice straws from 25 to 10 mm did not affect methane production. The average C/N ratio of rice straw was 75.7. Another study, showed that reducing Corn Stover particles from 15 to 5mm had no significant effect on methane yield [26]. There is a congruence between the observations of R. Zhang and Zhang [23] and these findings. The results obtained for biogas yields of Corn Stover with different particle sizes are shown in Fig. 9.

However, R. Zhang and Zhang [23] reported that smaller straw particles digested better, resulting in higher solid reduction and biogas production; however, the size reduction was found to be more beneficial when combined with thermal pretreatment. As mentioned above, grinding produced the best digesting results because it ruptured cell walls to a higher degree than chopping alone, providing chemicals and microbes with easy access to the straw. During the initial periods, smaller particles allowed more soluble sugars to be available in the reactors. It results in a higher rate of biogas production.

Also, Y. Zhang and Banks [25] showed no significant effect on the methane yield by reducing hand-sorted OFMSW particle size from 4 to 2mm. Agyeman and Tao [30] have reported an improved methane production rate of 10–29% and a specific methane yield of 9–34% by using co-digestion of dairy manure and food waste and decreasing the particle size of food waste from 8 to 2.5mm. Also, dewatering of digester effluent has increased significantly due to reduction in particle size of food waste [30].

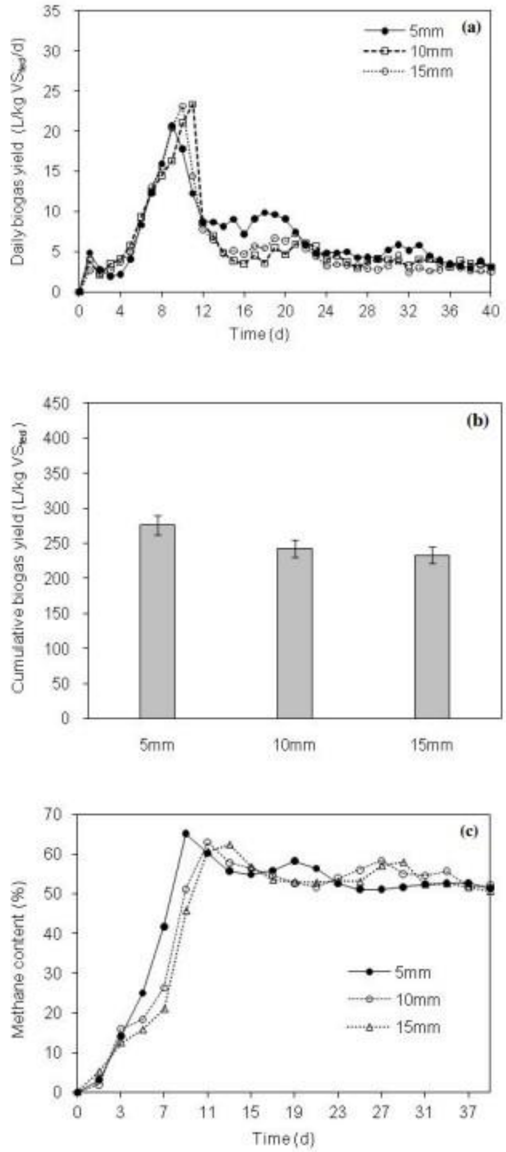

Fig. 9. Biogas yields of Corn Stover with different particle sizes at 37°C (a) daily biogas yields, (b) cumulative biogas yields, and (c) methane content of biogas. [26]

3.2 Special case

Krause, Chickering, Townsend, and Pullammanappallil [31] evaluated the effects of substrate size and temperature on the biochemical methane potential (BMP) by using MSW samples. The MSW component sample consists of office paper, newspaper, corrugated cardboard, paperboard, and coated paper. Samples were used as substrate particle sizes of <2mm and 20–100 mm. The effects of substrate size and temperature on the biochemical methane potential (BMP) assay were tested for each MSW component sample. Fig. 10. shows methane generation by waste components.

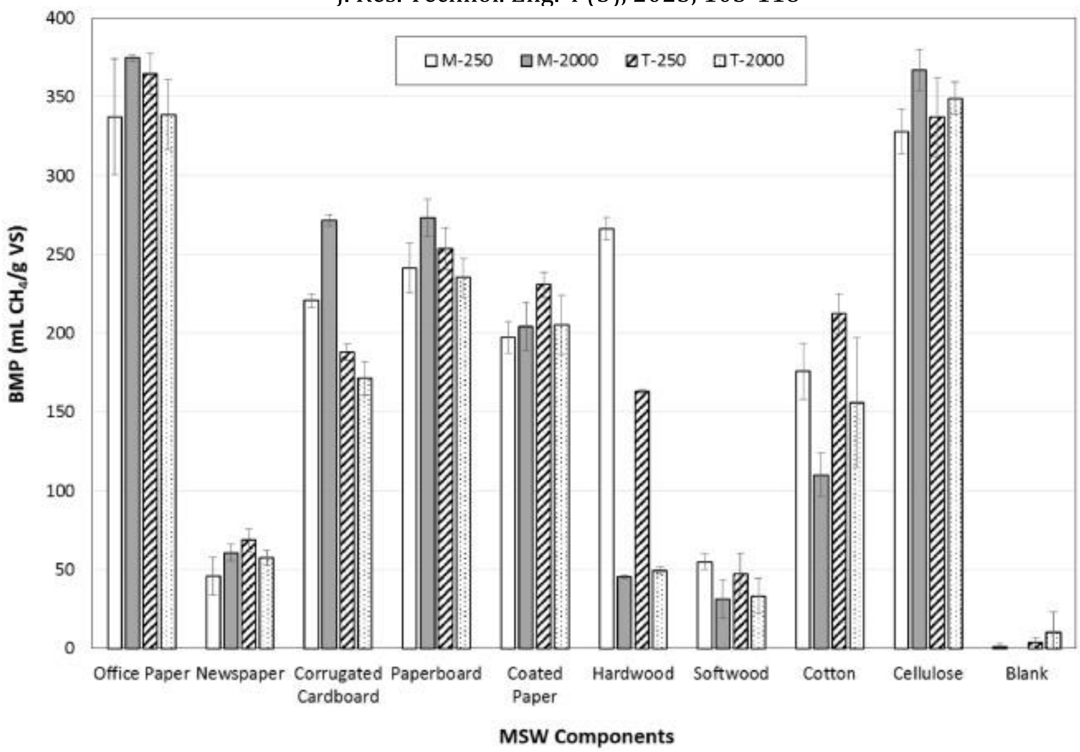

Fig. 10. Biochemical methane potentials of MSW components at two particle sizes and two temperatures [31]

Here, the M-250 samples are mesophilic size-reduced samples, the M-2000 samples are mesophilic as-disposed samples, the T-250 samples are size-reduced thermophilic samples, and the T-2000 samples are thermophilic as-disposed samples. The particle size did not affect the BMPs of office paper, newspaper, or coated paper [31]. Because the material thickness is relatively low, the process does not result in a significantly larger surface area. BMPs from size-reduced mesophilic cardboard and paperboard were significantly lower than those from as-disposed cardboard and paperboard. Also, this study revealed that the particle size of paper products has a lower effect on methane yield.

4 Conclusion

The particle size of the feedstock material impacts the reactor's performance, as smaller particles produce more biogas. Because methane-producing bacteria have better contact with the substrate's degradable organic matter, the difficulty of material handling during mixing and pumping may be minimized if the particle size is reduced. To produce a more homogenous mixture, particle size reduction is required before feeding the reactor. However, excessive particle size reduction could accelerate the substrate rate of hydrolysis, resulting in a buildup of VFA and ammonia that could destabilize the reactor. The success or failure of the process can thus be determined by matching the particle size reduction selection. The findings of this study apply to small-scale operations, and more research is needed to relate these findings to the operation of full-scale continuous digestion processes. Also, a limited number of studies are available for dry AD in the organic fraction of Sri Lankan MSW. Therefore, more research should be done to develop optimum biogas production with stable performance for MSW in Sri Lanka.

Because of limited and inconsistent existing studies, the need for further research on particle size reduction in dry anaerobic digestion of OFMSW is highlighted. More comprehensive research is required to determine the optimal particle size for enhancing stability and efficiency. It is crucial to consider the particle size of the feeding material to optimize gas production and improve stability. Future studies should focus on identifying the ideal particle size distribution that balances biological processes with physical and biochemical stability.

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