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Effect of Pretreating Cattle Dung with Granulated Plantain Peel on Biogas Production

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Abstract

Biogas technology is a way of tackling the increase in the production of organic wastes and rural energy problems in many developing countries like Nigeria. This study investigated the effect of granulated plantain peels on the biogas yield from cattle dung. The volume of gas produced was measured on a 5-day basis, and the pretreated substrate produced 46,151.6 cm³ against 17,224.7 cm³ from the untreated sample. Results showed a 168% increase in biogas produced when cattle dung was pretreated. The flammability test showed that production started on the first day after retention for the substrate pretreated and that an appreciable amount of methane content was produced only on the third to fourth day. In contrast, in the control, production started on the third day, and appreciable methane was observed on the fourth to fifth day. The compression test showed that biogas could be compressed with minimal changes in temperature as the temperature observed amounted to only a 0.19 °C rise per bar increase in pressure. The biogas compression experiment gave an accumulated mass of 214 g at 6.34 bar compared to 1000 g at 6 bar for standard LPG refilling. It is recommended that the produced biogas be purified before commencing compression in future works.

Keywords: Digester, pretreated, cattle dung, substrate, methane

INTRODUCTION

One of the major environmental issues facing the world is the massive generation of organic waste (Wächter *et al.*, 2016), which has made most countries make sustainable waste management and prevention and reduction a political priority. This represents an important share of the common efforts to reduce pollution and greenhouse gas emissions and to mitigate global climate changes (Green and Sibisi, 2002). Age-long practices such as uncontrolled waste dumping, controlled landfill disposal and incineration of organic wastes are not considered optimal practices by the environmental standards because of their ecological risk (Yusof *et al.*, 2009; Fazzo *et al.*, 2020).

However, energy recovery and recycling have been the new trend in energy conversion of nutrients and organic matter in the production of biogas through anaerobic digestion (AD) of animal manure and slurries as well as of a wide range of digestible organic wastes, converting the substrates into renewable energy and offer a Natural Fertilizer for Agriculture (NAS) (Hamer, 2003). Anaerobic digestion(AD) is a microbiological process of decomposition of organic matter without oxygen to produce biogas in air-proof reactor tanks called digesters (Lisk, 1988). The microbial process converts organic carbon to its subsequent oxidation and

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reduction to its oxidized state (CO_2) and reduced form (CH_4) (Ravindranath, 2000; Green and Sibisi, 2005).

Furthermore, AD of organic waste in digesters occurs in four stages: hydrolysis, acidogenesis, cetogenesis, and methanogenesis in a biogas digester system (N´athia-Neves *et al*., 2018). These four stages result in the production of biogas comprising methane (55–70%) and carbon dioxide (30–45%) with traces of other gases such as hydrogen sulphide, hydrogen, and nitrogen (Awe *et al*., 2017). Interestingly, biogas is considered a low-carbon fuel source, which is of interest to rural communities in meeting their energy need for cooking (Dumitru, 2012). Darwin *et al*. (2016) reported that co-digestion of animal waste with plant waste was likely to produce more methane yield than digestion of livestock waste alone. This was supported by researchers such as Adeniran *et al.* (2018) in the co-digestion of poultry waste with banana peels, Ofoefule *et al*. (2010) in co-digestion of paper waste and cattle dung, Akinnuli and Olugbade (2014) in co-digestion of piggery waste and water hyacinth and Oparaku *et al*. (2013) in co-digestion of cassava peels blended with pig dung. Furthermore, it has been reported that the pretreatment of the slurry of animal waste with alkali bases, such as ashes from plants' waste, increases biogas production (Layode, 2017). Adeyanju (2008) reported that biogas yield was significantly increased in the co-digestion of pig wastes and cassava peels treated with wood ash. Aderinlewo and Layode (2018) reported that adding plantain peel ash to cattle dung increased biogas production by 70%. Aderinlewo *et al*. (2021) also reported that adding cocoa pod ash and cassava peel ash increased biogas production by 39.63% and 52.43%, respectively.

This study, therefore, investigated the effects of pretreating cattle dung with granulated plantain peels on the biogas yield and presented a novel approach to enhancing biogas production from cattle dung by incorporating granulated plantain peel as a pretreatment step. Our findings demonstrate a significant increase in biogas yield, underlining this method's potential to improve biogas production systems' efficiency. The research contributes to the broader effort of developing sustainable and efficient waste management and energy production techniques, particularly in settings where plantain peel waste and cattle dung are readily available.

MATERIALS AND METHODS

The materials used for biogas production were a floating drum bio-digester, granulated plantain peels, cattle dung, an electronic (digital) scale with a 5000 g maximum capacity and 1g sensitivity, a mercury-in-glass thermometer, a pH meter, an infrared thermometer, compression machine with 1.5 hp gasoline engine and electronic pressure gauge.

Material Gathering and Processing for Biogas Production.

Fresh cattle dung was gathered from cattle sheds in the Directorate of University Farms (DUFARMS), Federal University of Agriculture, Abeokuta (FUNAAB), which is located approximately on latitude 7.23 ^{o}N and longitude 3.44 ^{o}E, Ogun State, Nigeria. The collection was done a day before retention for the most negligible manure decomposition.

Peels of plantains were collected in FUNAAB. The collected plantain peels were dried in the sun, and it took approximately twenty-one days for them to become exceedingly brittle. It was then reduced into granulated form using a hammer mill and stored in a polythene bag until needed. The fresh cattle dung was divided into two for the two digesters. Digester A includes granulated plantain peels and cattle dung. Digester B is the "Control experiment" digester that only contained cattle dung.

The substrates were mixed to the right consistency, cleaned of extraneous elements, and measured and loaded in the predetermined volume. The mass of the cattle dung in the loaded substrate was calculated. The amount of granulated plantain peels added to Digester A was 4% by mass of the cattle dung, which was measured using a Digital weighing balance (Camry (TCS-150-ZE11) electronic balance with accuracy 50 g).

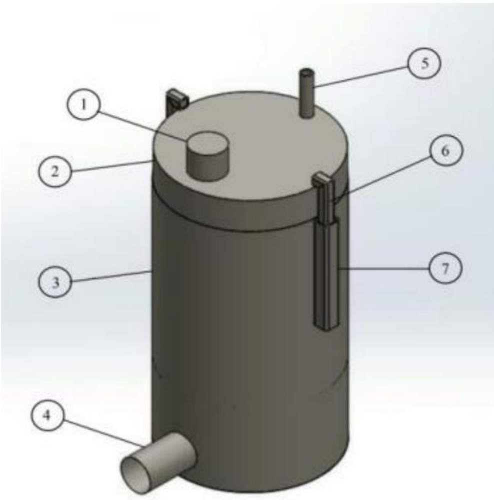
Experimental Set-Up Location

The experimental setup was at the College of Engineering Experimental Site, Federal University of Agriculture, Abeokuta. The biogas generation was carried out at a pre-selected location at the Experimental site. The coupling of the compression system and biogas compression was done at the Agricultural and Bio-Resources Engineering Department workshop.

Bio-Digester Description

In a floating drum bio-digester, a smaller steel drum was inverted inside a larger one. The bigger drum was the digester tank, while the smaller was the gas tank. The bio-digester works such that the produced biogas accumulated in the gas tank over the slurry in the digester tank. When biogas was produced, the gas tank rose while it sank as the gas was used or collected. Two guide frames at the sides of the drums kept the gas tank from tipping over as it rose. The amount of biogas produced or used can easily be computed from the changes in the height of the gas tank.

The bio-digester isometric view of floating drums is shown in Figure 1. It features apertures for substrate entry, gas collection, and a digestate outflow. The substrate inlet at the top of the floating drum enables feedstock to feed into the digester. Gas from the gas tank can be collected using the gas outlet. The experimental set-up of the digesters is shown on Plate 1.



S/N	Parts Description	Material
1	Substrate inlet	Stainless steel
2	Gas storage tank	Mild steel
3	Digester tank	Mild steel
4	Slurry outlet	Stainless steel
5	Gas outlet	Mild steel
6	Guard bars	Iron
7	Guard frame	Mild steel

Figure 1: Isometric view of floating drum bio-digester (Aderinlewo *et al.*, 2018)

Plate 1. The floating drum digesters

Volume of the Digester Tank Design

1. Volume of the Digester Tank

The digester tank is a cylindrical chamber; its volume is determined by equation (1).

$V_d = \pi {R_d}^2 H_d$ (1)

Where: V_d is the volume of the digester tank; R_d is the radius of the digester tank, 15.6 cm; H_d is the height of the digester tank, 50 cm.

$$V_d = \pi \times 15.6^2 \times 50 = 38{,}227 \text{ cm}^3$$

The average digester volume is 38,227 cm^3.

2. Volume of Gas Tank

The volume of the gas tank was calculated using equation (2)

$$V_{gt} = \pi {r_{gt}}^2 h_{gt} \quad (2)$$

Where: V_{gt} is the volume of the gas tank; r_{gt} is the radius of the gas tank, 40 cm; h_{gt} is the height of the gas tank, 14 cm.

$V_{gt} = \pi \times 14^2 \times 40 = 24{,}630 \text{ cm}^3$

3. Volume of Substrate

The substrate was loaded to fill an average of two-thirds of the digester tank, and the corresponding mass of cattle dung and that of the granulated plantain peel were calculated. The substrate was a mixture of cattle dung and water at a ratio of 1:1 by volume.

$$V_c = V_w = \frac{V_d}{3} \quad (3)$$

Where: V_c is the volume of cattle dung; V_w is the volume of water; V_d is the volume of the digester, 38,227 cm^3.

$V_c = V_w = \frac{38{,}227 \text{ cm}^3}{3} = 12{,}740 \text{ cm}^3$

4. Mass of cattle dung

The mass of cattle dung used in the consistent substrate with the calculated volume of cattle dung is given by:

$Mc = \rho \times Vc$ (4)

Where ρ (density of animal waste, such as poultry waste) = 1.7 g/cm^3 (Akivie, 2018).

M_c = 1.7 × 12,740 = 21,658 g

≈ 21,500 g

5. Amount of Granulated Plantain Peel Calculation

The amount of the granulated plantain peel (GPP) applied was 4% of the mass of the cattle dung.

Mass of GPP = 4% of M_c

= 0.04 × 21,658 = 866 g

The loaded substrates were retained in the digesters for 53 days.

Performance Evaluation of the Bio-digester

1. Data collection for biogas production

Data were collected on the pH of substrates before and after loading, the daily temperature at the retention site, and the height of the rising gas tank. Before loading and after retention, the pH of the substrate was assessed using a pH meter. A mercury-in-glass thermometer was used to measure the daily temperature at the retention site. A meter tape measured the change in gas tank height over the retention period of 5 days.

2. Volume of gas produced

Using equation (5), the volume generated at any 5-day interval was calculated from the change in the height of the gas tank.

$$V_g = \pi r_{gt}^2 \Delta h_{gt} \quad (5)$$

Where V is the volume of gas produced at intervals of five days, r is the gas tank's radius, and Δh is the height change for the gas tank.

3. Flammability test

A flammability test was carried out on the biogas generated in the bio-digesters to test for the presence of methane in combustible proportions. The biogas from the bio-digester was collected in tyre tubes for the test, and a modified camping burner joined with a filling head was used. A hose and galvanized valve were used to link the burner to the tube. All openings were sealed to keep outside air from further diluting the biogas and affecting the result. As the biogas flowed out, a naked flame from a lighter was brought toward the burner.

It was observed whether the biogas ignited on the burner as it was released toward the naked flame or whether it put out the naked flame. The colour with which it burns was also noted whenever the biogas burns, as this indicates the relative proportion of methane in the biogas.

4. Gas Compression

The compression machine's engine was started, and the cylinder was filled once all parts were assembled correctly and fitted. Before, during, and after filling, the mass, temperature, and pressures were measured and recorded. The cylinder was left on the scale as it was filled, and mass readings were taken every 30 seconds.

At the same interval of 30 seconds, an infrared thermometer was used to gauge the cylinder's temperature as it was being filled, and the readings from the pressure gauge were also recorded.

5. Data Analysis

Data obtained for the volume of gas obtained from bio-digester A (mixture of cattle dungs and granulated plantain peels) and bio-digester B (cattle dungs only) were analyzed using the t-test of 2021 Minitab Statistical Software at a 5% significant level.

RESULTS AND DISCUSSION

Gas Production Measurement

The change in height and the biogas yield in Bio-digester A are shown in Table 1. During the first interval of 5 days, 17,818.0 cm^3 total volume of biogas was produced, and biogas production started from the first day after retention. During the second interval of 5 days, the gas volume produced was 6718.3 cm^3 (62.3% less than the previous). The third interval of 5 days produced 8105.7 cm^3 (20.7% more than the previous interval). About the third interval of 5 days, production started reducing from day 18, with 4016.4 cm^3 being produced on the fourth interval of 5 days, corresponding to a 50.5% decrease from the previous. The fifth, sixth, seventh, eighth and ninth intervals of 5 days produced 3104.1, 2848.0, 1825.6, 1022.3 and 657.2 cm^3, respectively, which gave the reduction against the previous interval as follows: 21.8, 9.3, 35.9, 44.0, and 35.7% respectively. Significant gas production ended between Day 48 and Day 53, and the total volume of gas produced in Bio-digester A through the period of retention was 46,151.6 cm^3 (Table 1)

Table 1: Biogas measurement (Bio-digester A- Cattle dung with granulated plantain peel)

Days	Gas tank height (cm)	Change in tank height (cm)	Volume of gas produced (cm^3)
1 - 5	24.4	24.4	17818.0
6 - 11	33.6	9.2	6718.3
12 - 17	44.7	11.1	8105.7
18 - 23	50.2	5.5	4016.4
24 - 29	54.5	4.3	3104.1
30 - 35	58.4	3.9	2848.0
36 - 41	60.9	2.5	1825.6
42 - 47	62.3	1.4	1022.3
48 - 53	63.2	0.9	657.2
		Total =	46151.6

The change in height and the biogas yield in Bio-digester B (control bio-digester) are shown in Table 2. Biogas production started on the third day after retention with a volume of 2117.8 cm^3 within the first interval of 5 days. Within the second 5-day interval, the volume of gas produced increased by 67.7% to 3552.4cm^3. A percentage increase of 19.2% against the previous interval was also recorded within the third interval of 5 days, corresponding to 4235.5 cm^3. The decline in production started from day 18 to day 23, as a 30.6% reduction in production volume was recorded for the fourth interval of 5 days, corresponding to 2937.5 cm^3. The declination continued over the next ten days, with 1912.8 and 888.1 cm^3 produced within the fifth and sixth intervals of 5 days, respectively, corresponding to a 34.9 and 53.6% reduction against each previous production. The seventh interval of 5 days produced a surprising increase in yield with a 15.4% increment at 1024.7 cm^3. The eighth and ninth intervals of 5 days produced 409.9 and 146.0 cm^3, which resulted in a 60.0 and 64.4% reduction in produced volume compared to the previous intervals. Significant gas production ended between Day 46 and Day 49, and the total volume of gas produced in Bio-digester B through the retention period was 17,224.7 cm^3 (Table 2).

The trends illustrated in Table 1 and Table 2 are shown comprehensively in Figure 3.

Table 2: Biogas measurement (Bio-digester B - Cattle dung alone)

Days	Gas tank height (cm)	Change in tank height (cm)	Volume of gas produced (cm³)
1 – 5	3.1	3.1	2117.8
6 – 11	8.3	5.2	3552.4
12 - 17	14.5	6.2	4235.5
18 - 23	18.8	4.3	2937.5
24 - 29	21.6	2.8	1912.8
30 - 35	22.9	1.3	888.1
36 - 41	24.4	1.5	1024.7
42 - 47	25.0	0.6	409.9
48 - 53	25.22	0.2	146.0
		Total =	17224.7

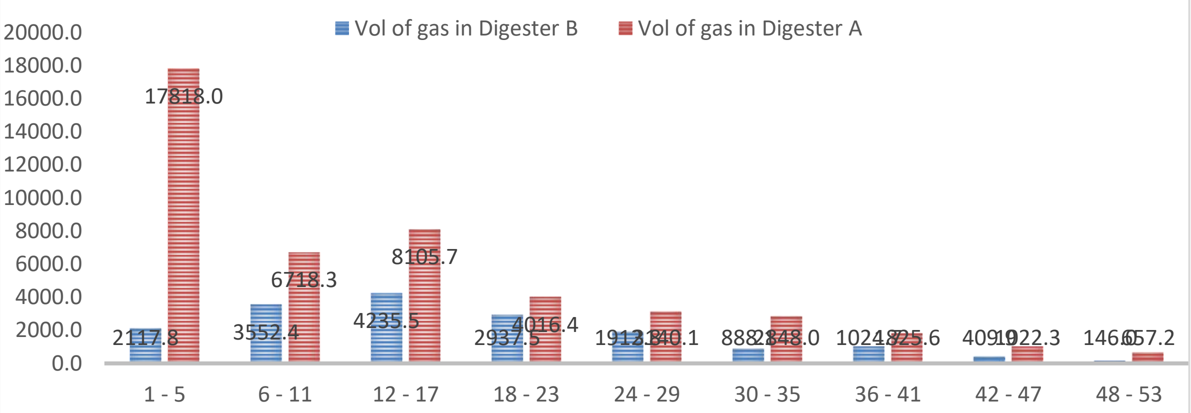


Figure 3: Histogram of volume of gas produced.

The biogas produced from bio-digester A (46151.6 cm³) was higher than the biogas produced from bio-digester B (17224.5 cm³) by 37.3%. This means that Digester A produced an estimated 870.8 cm³ of gas per day on average for 53 days, while Digester B produced an estimated 325.0 cm³ per day on average over that same time.

It was established by Aderinlewo *et al.* (2021), Adeniran and Layode (2018), and Cassini *et al.* (2006) that the pre-treatment of cattle dung by the addition of an alkaline material helped in the increased digestion of the waste and biogas production. Therefore, pre-treatment with granulated plantain peels has been shown to positively affect the anaerobic digestion of waste, which confirms the statement made by some researchers mentioned above.

The t-test conducted on the biogas production from two bio-digesters yielded a t-value of 1.99 and a p-value of 0.04 (one-tailed). The result indicates a statistically significant difference in biogas production between the two bio-digesters, with the pre-treatment effect considered significant at $p < 0.05$.

The increased biogas production from pretreated substrates not only enhances renewable energy output but also contributes to more sustainable waste management practices. This is corroborated by Saitawee et al. (2014), who found that co-digestion of cattle dung with organic wastes under optimized conditions significantly improves biogas yields (Saitawee *et al.*, 2014).

Ambient Temperature Measurement
A mercury-in-glass thermometer was used to measure the surrounding temperature. The average temperature was 35.2 °C, varying from 28 to 40 °C, as shown in Figure 4. This is well within the mesophilic temperature range of 20 to 45 °C, with an optimal range of 30 to 39 °C, as described by Schiraldi and Rosa (2014).

Gas Compression Measurement

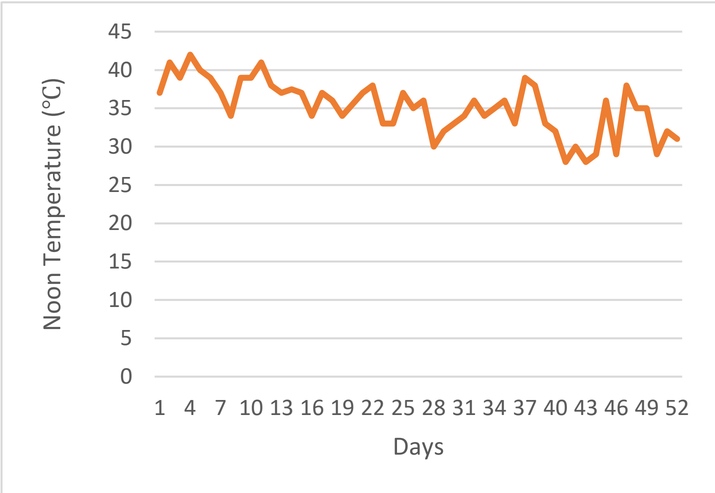


Figure 4: Graph of daily ambient temperature

At the beginning, before compression started, the cylinder and filling head weighed 3280 g, the surrounding air temperature was 33.4°C, and no pressure was present. Readings of the parameters were recorded at around 30-second intervals during the filling process, which lasted about 120 seconds, as shown on Plate 2.

The cylinder weighed 3313 g at the second measurement, equivalent to 55 g of biogas at 33.8 degrees Celsius and 3.21 bar of pressure. The biogas mass, temperature, and pressure were 67 g, 34.3°C, and 4.59 bar, respectively, during the third measurement, as shown in Table 3.
The cylinder weighed 3382 g at the last measurements, equivalent to 102 g of biogas. 6.34 bar of pressure was reached, and the temperature increased to 34.6°C. The compression test showed that biogas could be compressed with minimal changes in temperature as the temperature observed amounted to only a 0.18°C rise per bar increase in pressure. The mass of accumulated biogas was small compared to the standard LPG mass and pressure. The biogas compression experiment gave an accumulated mass of 102 g at 6.34 bar compared to that of standard LPG, which will give 1056.67 g at that same pressure, estimated from the standard report of 3000 g at 18 bars for the same size 3 kg cylinder (lpg-cylinder, 2022).

Plate 2: Compression system

Table 3: Measurement of mass, temperature and pressure during compression

S/N	Mass (g)	Accumulated Biogas Mass (g)	Temperature (°C)	Pressure (bar)
1	3280	-	33.4	0.00
2	3313	33	33.8	3.21
3	3347	67	34.3	4.59
4	3382	102	34.6	6.34

Flammability Test

The observations and inferences made on the flammability tests carried out on the gas generated during the early days of retention and after retention are shown in Table 4. The gas produced in Digester A was collected, and a flammability test was carried out on Days 1, 2, 3, 4 and 53, while the gas generated in Digester B was collected for a flammability test on Days 3, 4, 5 and 53.

In Digester A, the gas produced on Day 1 and Day 2 quenched the flames they were exposed to. The gas of day 3 attracted the flame with a faint flickering blue flame. On day 4, the faint blue flame was steady. The gas at day five had a light-yellow outer layer. In Digester B, gas produced on Day 3 extinguished the flame it was exposed to, while that of days 4 and 5 burnt with a faint blue and yellow flame, respectively.

Pretreatment also speeds up output since gas production began on Day 1 after retention in the digester with the treated substrate as opposed to Day 3 in the digester using only poultry waste. From the flammability test, gas production in digester A started from Day 1 after retention with the gas of Days 1 and 2 extinguishing flames exposed to it. This can be said to be that the gas has very little or no methane and is made mainly of CO_2. In Digester B, production did not start until Day 3, and the flammability test showed that considerable methane was produced on Day 4.

At Day 53, the gas from digesters A and B burnt with an apparent yellow flame when exposed to a naked flame.

Table 4: Flammability test results

Days	Digester A (gas)	Flame colour	inference	Digester B (gas)	Flame Colour	Inference
1	Yes	-	No methane	No	-	-
2	Yes	-	No methane	No	-	-
3	Yes	Faint blue	Low methane	Yes	-	No methane
4	Yes	Faint blue	Low methane	Yes	Faint blue	Low methane
5	Yes	Light yellow	Appreciable methane	Yes	Light yellow	Appreciable methane
53	Yes	Deep yellow	High methane	Yes	Deep yellow	High methane

pH Measurements

Table 5 shows the measured pH of the digesters' contents before and after retention. The content of Digester A (cattle dung and GPP) had a pH of 6.4 and 7.7 before and after retention, respectively. In contrast, the content of Digester B (cattle dung alone) had a pH of 6.1 and 7.4 before and after retention, respectively.

The two digesters operated within the pH range for optimum biogas production, and an increment was observed after digestion, making the slurry more basic. Notably, the increment was more pronounced in Digester A than in Digester B due to the addition of the alkaline granulated plantain peels, similar to the result obtained by Aderinlewo *et al.* (2021) in using alkaline materials for pretreatment of animal waste.

Table 5: pH measurements of the two biodigesters

Digester	pH before retention	pH after retention
A	6.4	7.7
B	6.1	7.4

CONCLUSION

Cattle manure retained without pretreatment produced 17,224.7 cm^3 of biogas, while cattle dung processed with granulated plantain peel produced 46,151.6 cm^3. The experimental results demonstrate a 168% increase in biogas yield compared to non-pretreated samples. This notable improvement not only underscores the effectiveness of incorporating granulated plantain peels but also highlights the potential of this method in optimizing biogas production for energy applications.

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