Anaerobic Co-Digestion of Tomato Waste to Enhance the Production of Methane gas

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Abstract: **Tomatoes are the most commonly used vegetable for cooking purposes and the fastest damaging vegetable in its lifetime. Tomato waste is a low-cost source of organic compounds, such as antioxidants, soluble dietary fibers, and vitamins. The high initial moisture content of fresh tomato pomace makes this waste susceptible to the Digestion process. Tomato waste or any organic waste using an anaerobic digestion process will produce the biogas and also generates greenhouse gases like CO_2, CH_4, and other trace elements. But, to increase productivity adding sewage sludge (as a second substrate) also called a Co-substrate. The addition of two substrates in a digestion process is called as Co-Digestion process. This process will increase the C/N ratio, Alkalinity, Total solids, etc., which will balance the key parameters to speed up the digestion process and eventually biogas production. The biggest role in biogas production is played by different types of microorganisms that consume the organic matter, and it will reduce the strength of the waste microorganisms like saprophytic bacteria and methanogenic bacteria will play into action in the digestion process.**

Index Terms: **Tomato waste, Anaerobic Digestion, Biogas, Greenhouse gas, Microorganisms.**

I. INTRODUCTION

Organic waste output has increased significantly in recent years. Included are food leftovers, discarded fruit and vegetables, garden refuse, and other organic waste [1]. For this organic waste, treatment is urgently required. Aerobic and Anaerobic treatment processes are available for treating organic waste [2]. Aerobically processing organic waste consumes a lot of space, has an unpleasant odor, and creates greenhouse gases like CH_4 and CO_2 [2]. Anaerobic digestion is processing organic matter in an enclosed (airtight) space with the help of bacteria to degrade the organic matter and convert the waste into a useful product like Biogas [3].
Anaerobic Digestion can be done in two ways; those are

1. Mono-Digestion.
2. Co-Digestion.

Mono-digestion (i.e., anaerobic digestion using one feedstock) suffers from challenges associated with feedstock characteristics [4].

Co-digestion using multiple feedstocks provides the potential to overcome these limitations [4].

Two bacterial groups are used in the anaerobic digestion process to break down organic matter and create biogas, which has productivity of 0.45 $Nm^3/Kg/V$ and helps to lower the density and strength of waste [5]. Saprophytic bacteria are collectively referred to as acid formers.

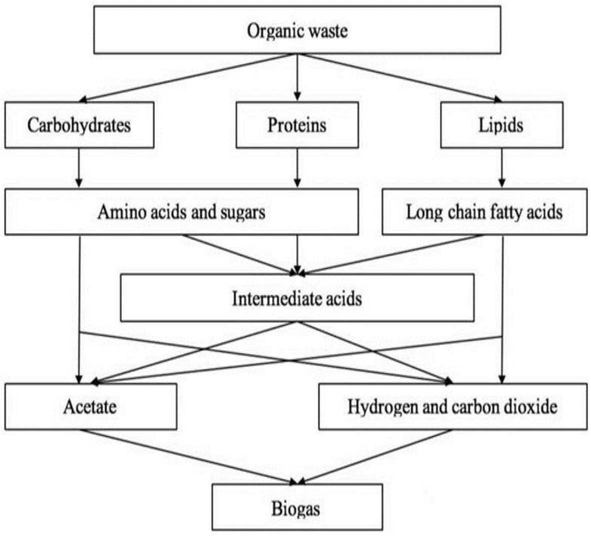

Figure 1. Simplification of Anaerobic Digestion

Methanogenic bacteria exploit the volatile fatty acids produced by saprophytic bacteria to create methane gas as a consequence of their metabolism [5]. This methane gas may be utilized as a source of energy for household and commercial purposes as well as fuel for automobiles. The digestion process is carried out in four stages by different types of microorganisms. The four stages are followed Hydrolysis, Acidogenesis, Acetogenesis, and methanogenesis [6]. In the hydrolysis process, organic matter breaks down into small pieces by microorganisms in the digestion, Acidogenesis will break down the remaining organic matter into the smallest pieces by releasing acids and forming volatile fatty acids. Using these VFA produces some gas in the Acetogenesis process [7]. Methanogenesis bacteria convert the biogas into methane gas. Temperature (37^o C) is the key parameter for these microbes to survive in the digester [7].

Anaerobic decomposition may be built and developed to operate in a wide range of configurations, including batch vs continuous processes, mesophilic vs thermophilic temperature conditions, high vs low particulate particles, and single vs. multistage processes [8].

Because batch process digesters need more initial construction money and a bigger volume of digesters (spread across numerous batches) to manage the same quantity of waste as continuous process digesters, they are more difficult to design but may be more cost-effective [9].

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TABLE I.
DESIRABLE CONDITIONS FOR ANAEROBIC DIGESTION

Operational Parameters	Optimum Range
Temperature	Psychrophilic (<20°C)
	Mesophilic (20.-40°C)
	Thermophilic (45-60°C)
	Hyper-thermophilic (>60°C)
pH	6.8-8.8
Alkalinity	2000-5000 mg/l as $CaCO_3$
Carbon to nitrogen ratio (C: N)	20-30
The substrate to inoculum (I/S)	0.5-2 and 2-3
Retention time	10-50 days
Volatile fatty acids	VFA<8000mg/l
Ammonia (NH_3)	NH_3<700mg/l
Hydrogen sulfide (H_2S)	H_2S<200mg/l

II. MATERIAL AND ITS COLLECTION

A. Tomato Waste (Substrate)

Tomato waste is collected from the local Erragadda vegetable market located in Hyderabad, India. It generates 100 kg of tomato waste daily. Which is a low-cost source of organic compounds, such as antioxidants, soluble dietary fibers, and vitamins. Fresh tomato pomace has a high initial moisture level, making it vulnerable to anaerobic digestion, which produces biogas from tomato waste and other organic waste [10]. The seeds are included as a source of edible oil, while tomato seed flakes are listed as a source of protein. The peel component of the trash contains significant amounts of phenolic and carotenoids [10]. The seeds are a source of protein (35%) and fat (60%) and account for around 10% of the fruit and 60% of the total waste, respectively (25%). They have a complex composition, with 17.6% protein, 2.2 percent fat, and 52.4 percent fiber. Essential amino acids accounted for 34.2 percent of total protein, with leucine being the most abundant, followed by lysine and isoleucine [11]. Unsaturated fatty acids made up 77.04 percent of total fatty acids, with linoleic acid being the most common [11].

B. Sewage sludge (Co-substrate)

Sewage sludge is collected from the Sewage Treatment Plant (STP) located at CVR College of Engineering, Hyderabad, India. Which is the Institutional drainage waste like Toilet waste, Flush waste, Hostel kitchen cleaning waste, etc. Sewage sludge, commonly referred to as bio solids, is the leftover, semi-solid material, which has high organic matter and moisture content.

The specific gravity, solids concentration as the relative proportion of solids, and sludge volume index (SVI) are some of the significant Physic-chemical parameters of sewage sludge [12]. In general, sewage sludge has a 20 percent fat content, a 50 percent carbohydrate content (sugar, starch, and fiber), a 30 to 40 percent organic matter content, a 3 percent total nitrogen content, a 1.5 percent total phosphorus content, a 0.7 percent total potassium content, a 10 to 20 percent C/N ratio, and a high concentration of heavy metal ions [13].

C. Inoculum

A little amount of material called an inoculum is used to start a culture containing bacteria, viruses, or other microbes [14]. In biology, the source substance utilized for inoculation is referred to as an inoculum. Inoculum is a material used as the inoculation source for a vaccine in medicine. In microbiology, pathogens are cells, tissues, or viruses used to inoculate a fresh culture [14].

Primary and secondary inoculum, which result in primary and secondary infection, are the two different forms of inoculum. The term "primary inoculum" refers to pathogens, such as spores, mycelium, etc., that overwinter or over summer and start an infection. During the same growing season, infections result in the production of secondary inoculum. Applying inoculum to a host is the procedure of vaccination [14]. Which is collected from the Biogas digestion reactor located at CVR College of Engineering, Hyderabad, India.

D. Cow Dung

Cow dung, often known as cow pats, cow pies, or cow manure, is the feces of bovine animals. Domestic cattle ("cows"), bison ("buffalo"), yak, and water buffalo are among these animals. Cow dung has antibacterial and prophylactic (disease-preventive) qualities, according to research [3]. Several investigations have found that cow dung extract has potent antibacterial properties against a variety of harmful microorganisms [3].

It also contains 24 more minerals, such as nitrogen and potassium, as well as minute quantities of sulfur, iron, magnesium, copper, cobalt, and manganese. It has been discovered that the antibacterial qualities of cow manure from a variety of cows are efficient against Klebsiella pneumonia [4].

Indian cow dung has demonstrated antimicrobial activity against all tested microbes and had stronger antibacterial activity than other cow dung extracts [4].

The milk, dung, and urine of the cow can be used to cure illnesses including psoriasis, skin conditions, eczema, arthritis, inflammation, leprosy, and more. Cow urine is also utilized as a medicine in India, Nigeria, Nepal, and Myanmar [3].

However, this behavior has dramatically increased since the COVID19 epidemic hit India. Under the name of "cow dung therapy," many people are consuming cow dung and urine for COVID treatment. Hundreds of Hindu activists celebrated by drinking cow urine last year in India. Cow Dung is collected from the dairy form at a local place [3].

TABLE II.
PROXIMATE ANALYSIS OF SUBSTRATE MATERIALS

Name	pH	Alkalinity (mg/l)	Total Solids (%)	Volatile Solids (%)
Tomato waste	4.65	370	6.65	92.48 of TS
Sewage sludge	8.21	750	16.41	98.17 of TS
Inoculum	6.85	580	5.3	75.47 of TS
Cow Dung	5.74	395	6.65	91.72 of TS

III. METHODOLOGY AND PROCEDURE

The entire experimental setup was carried out in a 120 ml capacity sample digester bottle with a working volume of 50, 70, and 90 ml, and the remaining space is left for biogas production. Total two levels were performed in this work, those are Mono-Digestion and Co-Digestion.
Mono-Digestion (only Tomato waste)
Co-Digestion (Both tomato waste and sewage sludge)

In both conditions, the Inoculum to substrate ratio (I/S) plays a major role in the digestion process and increases the productivity of biogas. But higher I/S ratio will damage the entire digestion process. I/S ratio is taken in different proportions like 1, 2, and 3. In these 3 instances, mono and co-digestion were tested for better results.

All the substrate materials which are collected for anaerobic co-digestion are blended into semi-solid form to reduce the particle size by using organic free distilled water with the ratio of 1:1 (substrate: distilled water).

These samples are collected in the required composition and tested for proximate analysis in the laboratory. The results are as follows.

TABLE III.
COMPOSITION OF MONO-DIGESTION

Parameter	Mix-I (ml)	Mix-II (ml)	Mix-III (ml)
Tomato waste	20	20	20
Inoculum	20	40	60
Cow dung	10	10	10
Effective volume	50	70	90
Bottle capacity	120	120	120

TABLE IV.
COMPOSITION OF CO-DIGESTION

Parameter	Mix-IV (ml)	Mix-V (ml)	Mix-VI (ml)
Tomato waste	10	10	10
Sewage sludge	10	10	10
Inoculum	20	40	60
Cow dung	10	10	10
Effective volume	50	70	90
Bottle capacity	120	120	120

Figure 2. 120 ml capacity Sample Digester Bottle.

Figure 3. Sample Preparation.

Here the temperature is the key factor for the anaerobic condition. Proper conditions like p^H, Alkalinity, and temperatures will affect the production of biogas and methane. P^H and alkalinity are adjusted in the sample, by adding buffer solutions, and proper temperature will be maintained by placing in a BOD incubator.

The sample digester bottles are kept in BOD (Biochemical Oxygen Demand) Incubator at 35^0 C for about the entire degradation is completed. Biogas and methane gas are collected regularly.

TABLE V.
PROXIMATE ANALYSIS OF MONO-DIGESTION

Mix Design	pH	Alkalinity (mg/l)	Total Solids (%)	Volatile Solids (%)
Mix-I	8.3	650	5.3	75 of TS
Mix-II	8.8	645	6.8	70 of TS
Mix-III	8.2	662.5	8.1	65 of TS

TABLE VI.
PROXIMATE ANALYSIS OF CO-DIGESTION

Mix Design	pH	Alkalinity (mg/l)	Total Solids (%)	Volatile Solids (%)
Mix-IV	8.1	605	5.4	70 of TS
Mix-V	8.1	632.5	5.5	75 of TS
Mix-VI	8.2	645	5.6	71 of TS

IV. RESULTS

TABLE VII.
CUMULATIVE RESULTS OF MIX-I

Sample	Biogas (ml)	Average Biogas (ml)	Methane gas (ml)	Average methane gas (ml)
Sample-I	1256	1273.59	730.12	750.48
Sample-II	1292		771.78	
Sample-III	1273		755.55	

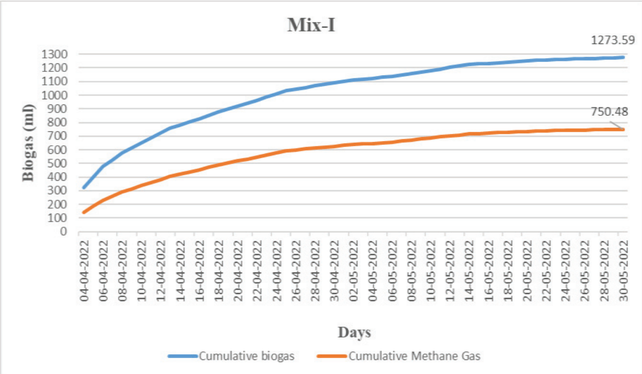

Figure 4. Graphical representation of Mix-I

TABLE VIII.
CUMULATIVE RESULTS OF MIX-II

Sample	Biogas (ml)	Average Biogas (ml)	Methane gas (ml)	Average methane gas (ml)
Sample-I	1144	1258.38	681.98	717.85
Sample-II	1461		829.31	
Sample-III	1152		642.6	

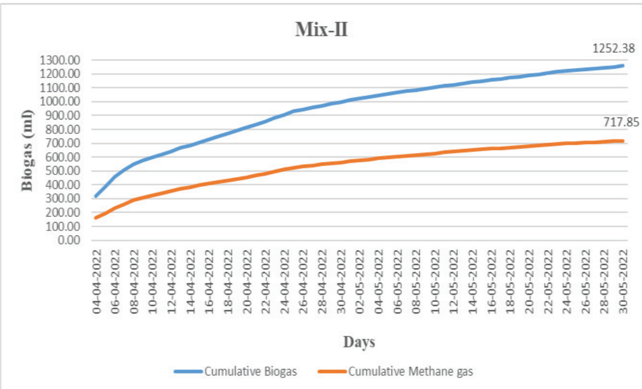

Figure 5. Graphical representation of Mix-II

TABLE IX.
CUMULATIVE RESULTS OF MIX-III

Sample	Biogas (ml)	Average Biogas (ml)	Methane gas (ml)	Average methane gas (ml)
Sample-I	684	762.78	356.53	391.85
Sample-II	788		413.7	
Sample-III	816		405.02	

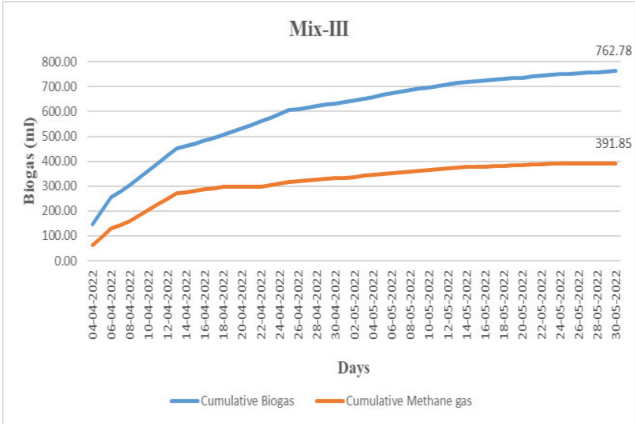

Figure 6. Graphical representation of Mix-III

TABLE X.
CUMULATIVE RESULTS OF MIX-IV

Sample	Biogas (ml)	Average Biogas (ml)	Methane gas (ml)	Average methane gas (ml)
Sample-I	888	887.27	572.3	595.76
Sample-II	924		566	
Sample-III	850		649	

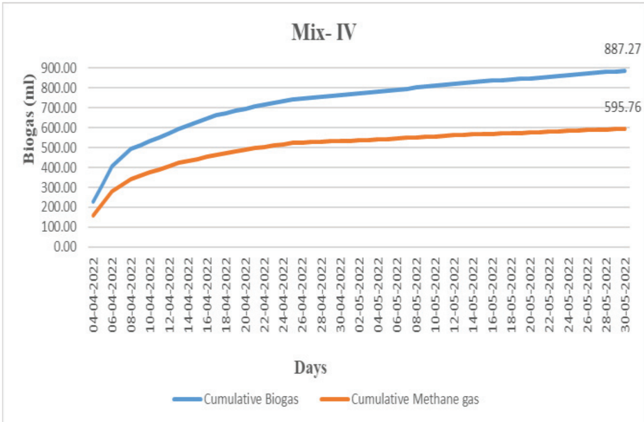

Figure 7. Graphical representation of Mix-IV

TABLE XI.
CUMULATIVE RESULTS OF MIX-V

Sample	Biogas (ml)	Average Biogas (ml)	Methane gas (ml)	Average methane gas (ml)
Sample-I	1680	1648.32	1089.76	1092.1
Sample-II	1630		1125.9	
Sample-III	1635		1063.45	

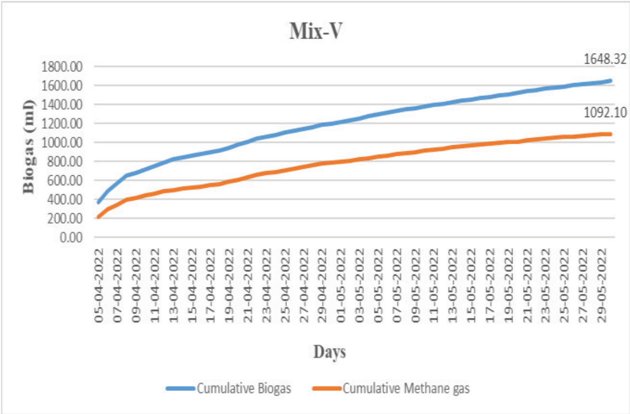

Figure 8. Graphical representation of Mix-V

TABLE XII.
CUMULATIVE RESULTS OF MIX-VI

Sample	Biogas (ml)	Average Biogas (ml)	Methane gas (ml)	Average methane gas (ml)
Sample-I	612	561.18	359.07	327.62
Sample-II	510		303.33	
Sample-III	562		329.02	

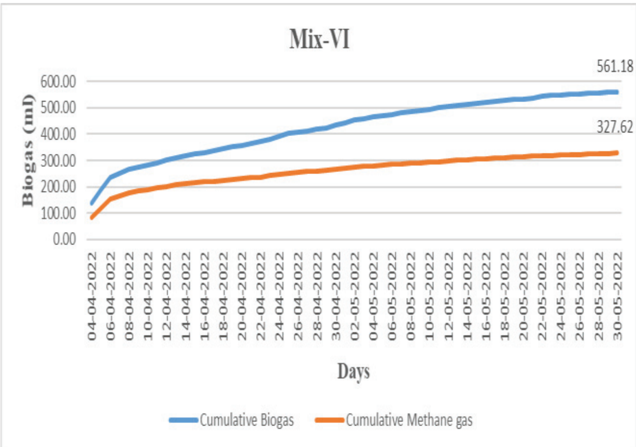

Figure 9. Graphical representation of Mix-VI

TABLE XIII.
PROXIMATE ANALYSIS OF MONO-DIGESTION

Mix Design	pH	Alkalinity (mg/l)	Total Solids (%)	Volatile Solids (%)
Mix-I	3.85	300	3.1	58 of TS
Mix-II	4.1	350	2.7	55 of TS
Mix-III	3.9	350	2.8	57 of TS

TABLE XIV.
PROXIMATE ANALYSIS OF CO-DIGESTION

Mix Design	pH	Alkalinity (mg/l)	Total Solids (%)	Volatile Solids (%)
Mix-IV	3.74	329	2.4	58 of TS
Mix-V	3.68	312	2.7	55 of TS
Mix-VI	3.67	296	2.9	57 of TS

V. COMPARISONS AND DISCUSSION

Day to Day Biogas was collected from all the mixes, into a Glass syringe (50 ml capacity) from Digester bottles for around 60 days. Generally, Biogas contains majorly Carbon dioxide (CO_2), Methane (CH_4), and other trace elements. Collected Biogas then passed through Potassium Hydroxide Solution (KOH) to separate the Carbon Dioxide from the biogas.

From Table VII. Biogas and methane gas were collected for around 60 days, Cumulative biogas was about 3821 ml and methane gas was 2257.45 ml. The percentage of methane is around 59%.

From Table VIII. Biogas and methane gas were collected for around 60 days, Cumulative biogas was about 2757 ml and methane gas was 2153.89 ml. The percentage of methane is around 78%.

From Table IX. Biogas and methane gas were collected for around 60 days, Cumulative biogas was about 2288 ml and methane gas was 1175.25 ml. The percentage of methane is around 58%.

From Table X. Biogas and methane gas were collected for around 60 days, Cumulative biogas was about 2662 ml and methane gas was 1787.3 ml. The percentage of methane is around 67%.

From Table XI. Biogas and methane gas were collected for around 60 days, Cumulative biogas was about 4945 ml and methane gas was 3279.11 ml. The percentage of methane is around 70%.

From Table XII. Biogas and methane gas were collected for around 60 days, Cumulative biogas was about 1684 ml and methane gas was 991.42 ml. The percentage of methane is around 58%.

TABLE XV.
AVERAGE RESULTS OF BIOGAS AND METHANE

Mix	Average Biogas (ml)	Average methane gas (ml)
Mix-I	1273.59	750.48
Mix-II	1252.38	717.85
Mix-III	762.78	391.85
Mix-IV	887.27	595.76
Mix-V	1648.32	1092.10
Mix-VI	561.18	327.62

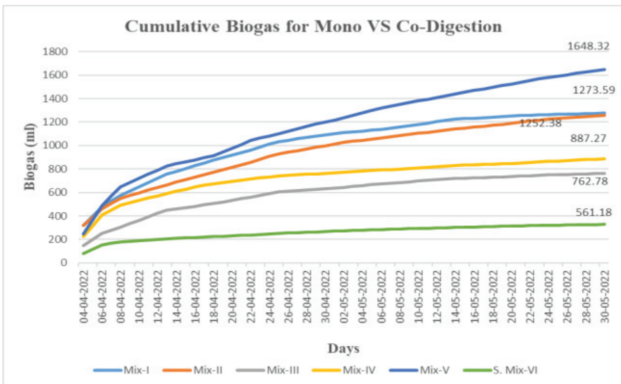

Figure 10. Graphical representation of Biogas for Mono VS Co-Digestion.

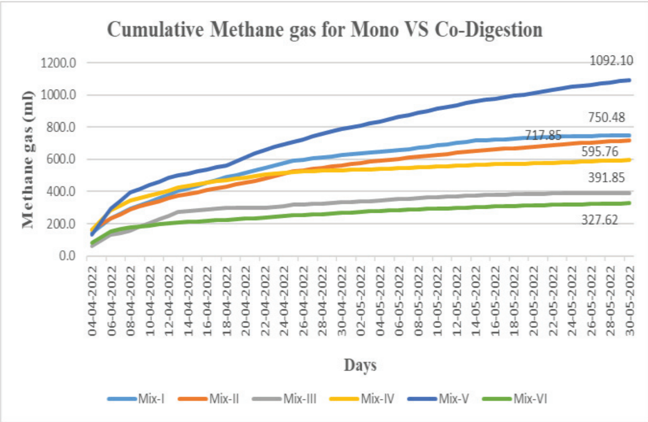

Figure 11. Graphical representation of Methane gas for Mono VS Co-Digestion.

From the overall results, Mix-V achieved the maximum amount of biogas and methane gas production, among all other mixes in the stipulated time (i.e., 60 days).

Mix-V design is the Co-digestion process, this mix contains Tomato waste (10 ml), Sewage sludge (10 ml), Inoculum ("2", I/S ratio), and Cow dung (10 ml).

Inoculum to substrate ratio plays a major in this anaerobic digestion process, Lower I/S ratio achieves good results in the mono-digestion process. Adding sewage sludge to the mono-digestion process (i.e., Co-digestion) produces better results compared to mono-digestion.

VI. Conclusions

Based on the achieved results from the Experimental as well as Graphical representations of Anaerobic Digestion: The production of Biogas & methane gas is achieved in all the mixes. Among those mixes, Co-Digestion, 1:1 Proportion of tomato waste with Sewage sludge (T: S), and the Inoculum to substrate (I/S) ratio, "2.0" achieved the highest production of methane gas. Compared to Mono-Digestion.

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