# Biogas Productivity and Quality as influenced by Fermentation Temperature and Agitation Process

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**Abstract**

The main aim of this work is to study the influence of fermentation temperature and agitation speed on the biogas quality and productivity. To achieve that, the effect of fermentation temperatures (control, 35 and 45 °C) and three agitation speeds (50, 100 and 150 rpm) on the pH, total solids, volatile solids of slurry, biogas yield, methane yield, $CO_2$ and $H_2S$ was studied. The results show that the pH of slurry was ranged from 5.83 to 7.47 for all treatment. The TSS and VSS of slurry decreases with increasing fermentation temperature, agitation speed and retention time. The best fermentation temperature for biogas production was 35°C, the highest value of accumulated biogas yield was 87.82 $m^3$ per ton TS was found at a fermentation temperature of 35°C. The biogas yield increases with increasing agitation speed. The methane yield increased gradually until it reached the peak after 30 day for control and 20 day for 35 and 45 ºC fermentation temperature and then decreased until it reached day 60. The highest value of $CO_2$ yield was 5.2 $m^3$ per ton TS was obtained at 45°C fermentation temperature, while the lowest value of $CO_2$ yield was 4.8 $m^3$ per ton TS was obtained at a fermentation temperature of 35°C. The highest value of $H_2S$ yield was 1.8 $m^3$ per ton TS was obtained at 45°C fermentation temperature.

**Keywords:** biogas yield, cattle dung, Agitation Speed, Temperature, batch digester.

## Introduction

Biogas is an important renewable source of energy, which is generated by the action of *methanogenesis* bacteria on organic matter. It is produced by the decomposition of organic matter in anaerobic, damped and oxygen depressed environments. It contains methane, as the main component and other gases such as carbon-dioxide, $H_2S$, water vapor, NO, SO etc. It is a clean renewable energy which can replace fossil fuels, besides reducing the environment problems affected by the non-renewable sources **(Gupta *et al.*, 2012)**.

The important factors affecting the anaerobic digestion process are feedstock composition, inoculum to feed ratio, temperature, substrate mixing and substances concentration. If these variables are not being in the proper range, the methane production will be reduced **(Wang *et al.*, 2012)**.

Anaerobic digestion can be developed for different temperature ranges including, mesophilic temperatures of approximately 35°C and thermophilic temperatures ranging from 55 to 60°C **(Sanchez *et al.*, 2001)**. Conventional anaerobic digestion is carried out at mesophilic temperatures, that is, 35–37°C. However, the thermophilic temperature range is worth considering because it will lead to give faster reaction rates, higher gas production, and higher rates of the destruction of pathogens and weed seeds than the mesophilic temperature range. However, the thermophilic process is more sensitive to environmental changes than the mesophilic process **(Ahn and Forster, 2002 and El-Mashad *et al.*, 2003)**.

Temperature changes have different effects on different stages of the digestion process because of the communities of micro-organisms that are involved. The first stages of the digestion process (hydrolysis and acidogenesis) suffer very few ill effects from changes in temperature due to the mixed population involved in the process. This helps to ensure that at any temperature, there are some micro-organisms that are operating within their preferred temperature range. The later stages of the digestion process (acetogenesis and methanogenesis) require more specialized microorganisms and thus are more likely to be adversely affected by temperature changes **(Ward *et al.*, 2008)**. Methane production is strongly temperature dependent. Moreover, fluctuations in temperature have a greater effect on the activity of methanogens than operating temperature itself. As the micro-organisms involved in anaerobic digestion all have different optimum operating temperatures, fluctuations in temperature can adversely affect some groups whilst being advantageous to others. Hence, fluctuations can cause changes in the activity of different microorganism groups, which in turn can lead to changes in the concentration of intermediary digestion products, such as organic alcohols and acids. This in turn will affect the overall performance of the digester **(Gerardi, 2003)**. It is important to maintain a stable operating temperature and process failure can occur if temperature changes are in excess of 1 °C/day. It is recommended that changes in temperature should be kept at less than 0.6 °C/day in order to avoid this situation arising **(Appels *et al.*, 2008)**.

As with temperature, different micro-organisms have different optimum operating pH. Whilst most fermentative bacteria can function in a range between pH 4.0 and 8.5, the change in pH does have an effect on the products of fermentation. At low pH, the main products are acetic and butyric acid and at a pH of 8.0, the main products are acetic and propionic acid. Meanwhile, the microorganisms involved in methanogenesis are more sensitive to pH, with an optimum range of pH 6.8-7.2 **(Appels *et al.*, 2008)**.

Agitation or mixing of digester contents significantly helps to ensure intimate contact between micro-organisms, which leads to improved fermentation efficiency. **Coppinger (1979)** suggested that effect of varying degrees of mixing of digester contents improves biogas production. The major problem associated with the different designs of biogas plant is that a thick layer of scum formation appears at the top of the digester which blocks the gas from coming out of the upper free portion of the digester. Thus, no gas is available at the utility point.

Biogas production is deeply affected by many factors such as temperature, agitation, type of raw materials, feeding rate, C/N ratio, pH value and retention time. Temperature and agitation are the most important factors affecting biogas production. Un-optimum conditions of biogas fermentation result in poor gas productivity. So that, optimizing these factors have a great effect on the biogas yield. Therefore, the main aim of this work is to investigate the effect of fermentation temperature and agitation speed on the biogas quality and productivity.

## Materials and methods

The experiment was carried out at Agricultural and Bio-Systems Engineering Department, Faculty of Agriculture Moshtohor, Benha University, Egypt, during the period of January to September ,2019 season.

### 1. Materials:

#### 1.1. System description

Figure (1) illustrates the system description. It shows the system which consists of digester tanks, heating tank, heat exchanger, mold and gas bags.

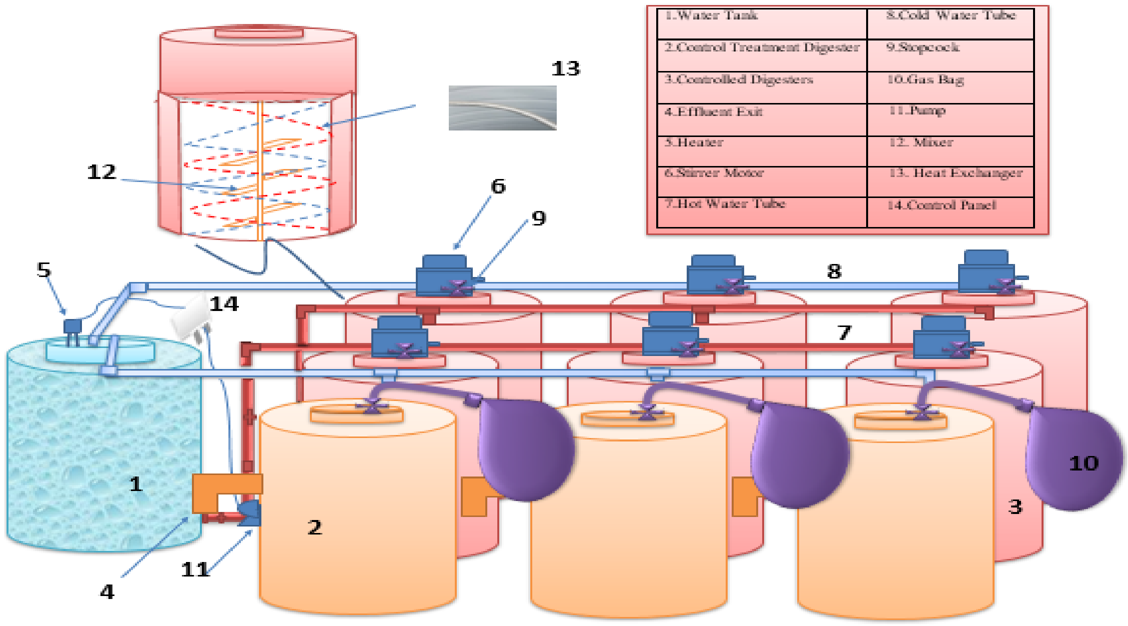


Figure (1): The experimental setup.

The system consists of nine digester tanks 1.0 $m^3$ capacity that used for biogas production. Dimensions of each tank are 1.0 m diameter and 1.3 m height. It is made of polyethylene and covered by glass rock sheet. A four-inch (10.16 cm) PVC pipe diameter was used for feeding the raw materials, the length of feeding pipe was 0.88 m. Also, the digester tank was provided with drainage opening at 1.0 m height above the digester bottom. The diameter of drainage hole was three inches (7.62 cm). The mixing system consisted of (a) a stainless steel mixing shaft (1 inch (2.54 cm) diameter and 1.0 m length) installed through the center of the tank, (b) Three, six-vanes flow disc impellers used to ensure adequate mixing in the vertical direction and (c) a heavy duty electric motor (0.5 hp) with a gear head reducer mounted on the tank and connected to a mixing speed controller. The digester was provided with heat exchanger for heating to maintain required temperature of materials. The gas was collected in the bag made of Tedlar materials (2 Millimeter thickness).

The heating system consists of heating tank, 1.0 $m^3$ capacity that used for heating water. Dimensions of heating tank are 1.0 m diameter and 1.3 m height. It is made of polyethylene and covered by glass rock sheet. Electric heater (2 kW) was used for heating water. The hot water was circulated by a pump (Model First QB60 – Flow Rate 30 L $min^{-1}$ – Head 25 m – Power 0.5 hp, Italy) from the heating tank to the heat exchanger. The hot water was pumped to the heat exchanger by pump through iron pipes of 1.0 inch (254 mm) in diameter. Figure (2) shows the heating system.

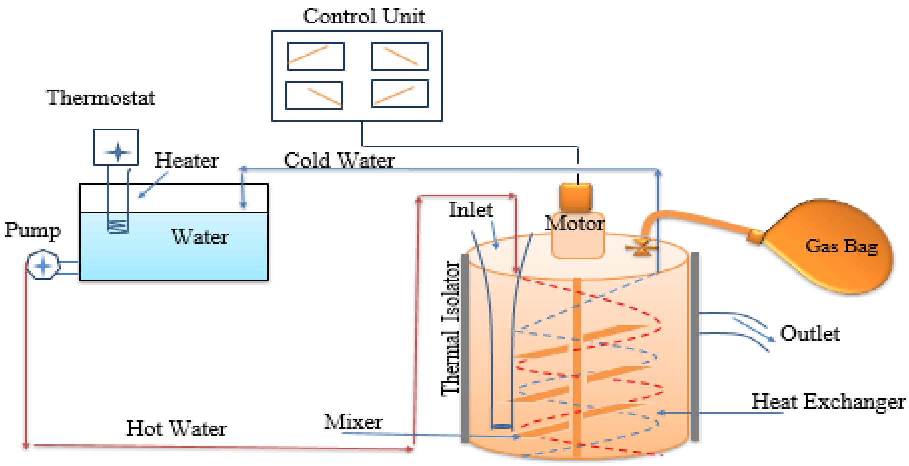


Figure (2): The heating system.

### 1.2. Cattle dung:

The manure used was produced from Cattle dung at Experimental Research Station at the Faculty of agriculture, Moshtohor, Benha University. There were no variations in the dung composition, as all experiments were performed from the same batch of dung. The Cattle dung properties that used in the manufacturing the biogas are listed in table (1).

**Table 1**. Properties of the Cattle dung used in biogas making.

| Properties | Result |
|---|---|
| Moisture content (%) | 72.07 |
| pH | 6 |
| Total solid (%) | 27.93 |
| Total Nitrogen (T.N) (%) | 0.75 |
| Organic Matter (O.M) (%) | 34.2 |
| Organic carbon (O.C) (%) | 17.7 |
| Total Potassium (ppm) | 861.92 |
| Total Phosphorus (%) | 0.02 |
| C/N ratio | 23.6 |

## 2. Methods:

### 2.1. Treatments:

The treatments include: three fermentation temperatures (control, 35 and 45 °C) and three agitation speeds were 50, 100 and 150 rpm. The experimental design was a split plot.

### 2.2. Measurements:

Temperature was recorded using a thermo-couple thermometer (Model Digi-Sense 69202-30; Range: -250 to 1800 °C, USA) daily. Moisture content (wet basis) throughout this study was measured by drying at 105 ºC for approximately 24 h or at constant weight **(ASAE, 1998)**.

pH was analyzed in a 1:5 (v/v) water extract using a glass electrode according to **Rayment and Higginson (1992)**. Total organic carbon (TOC) by the dry combustion method at 540 ºC for 4 h according to **Abad *et al.* (2002).** Total organic matter was measured by combustion at 550 ºC for 8 h according to **TMECC (2001)** and total nitrogen (TN) by Kjeldahl digestion (Model Vapodest – Range 0.1 mg to 200 g N, Germany) **(Bremmer and Mulvaney, 1982)**. Potassium (K) was determined by atomic absorption (Model EMI9783B – Range 190-930 nm, USA) and phosphorus (P) was determined colorimetrically following the **Murphy and Riley (1962)** method.

Total solids are the solid substance presented in the sample which contains both organic and inorganic matter. Freshly collected samples of each of 5 gm of slurry was weighed using electrical balance and placed inside an electric hot air-oven maintained at 105°C using a crucible and stayed in the oven for 24 hours and then taken out, cooled in a desiccator and weighed. The total solid was calculated according to the following equation:

$$\mathrm{TS} = \frac{MDS}{\mathrm{MFS}} \times 100 \qquad (1)$$

Where:

%TS: Percentage of total solid, MDS: Mass of dry sample and MFS: Mass of fresh sample.

Determinations of volatile solids do not distinguish precisely between inorganic and organic matter because the loss on ignite is not confined to organic matter. It includes losses due to decomposition or volatilization of some mineral salts. The TS obtained was ignited at 550 °C in a muffle furnace for five hours to determine the volatile and fixed solid content of the sample and to calculate the volatile solid content using the following equation:

$$VS = MSD - \frac{\mathrm{MASH}}{\mathrm{MSD}} \times 100 \qquad (2)$$

Where

%VS: percentage of volatile solid, MDS: Mass of dry Sample, M (ASH): the remaining mass after ignition which is called fixed solid (the total solid that composed volatile and fixed slides).

The biogas yield was measured daily by using the following equation:

$$\mathrm{V} = (\mathrm{W}_1 - \mathrm{W}_2) \times \rho \qquad (3)$$

Where:

V is the biogas, $m^3$

$W_1$ is the bag weight with gas, g

$W_2$ is the bag weight empty, g

ρ is the biogas density, 0.717 kg $m^{-3}$

The composition of biogas was measured by gas chromatography analysis.

The daily energy production as mentioned by **El-Bakhshwan, *et al*., (2015)** was determine using the following equation:

$$\mathrm{Ep} = \mathrm{Bp} \times \mathrm{CV} / \mathrm{Dv} \qquad (4)$$

Where:

$E_p$ = Energy production, (MJ /day);

Bp = Biogas production ($m^3$ gas / $m^3$digester /day);

CV = Calorific value of biogas, (MJ/$m^3$ gas) which measured by Gas Chromatograph, and Dv = Digester volume ($m^3$digester).

The power consumption (kW) of different electric motors was determined by recording the voltage and current strength by using the clamp meter (Model DT266 - Measuring range 200/1000A and 750/1000V with an accuracy of ± 0.01, China) to measure the line current strength (I) and the potential difference value (V).

The total electric power requirement (PR) was calculated by the following equation:

$$\mathrm{PR} = \frac{I \times V \times \eta \times \cos\theta}{1000} \qquad (6)$$

**Where:**

| | | |
|---|---|---|
| PR | is the power required, kW | |
| I | is the current, amperes | |
| V | is the voltage, volts | |
| η | is the Mechanical efficiency assumed to be 0.95 | **(Metwally, 2010).** |
| Cos θ | is the power factor, dimensionless | |

The daily gas production was measured by collecting the produced gas in bag used to collect the gas. This was connected to the fitting to regulate the flow of gas in / out of the bag and weight it.

## Results and Discussion

### 1. pH of slurry:

Figure (3) shows the effect of fermentation temperature (control, 35 and 45 ºC) on slurry pH during the retention period. The results indicate that the slurry pH ranged from 6.17 to 7.47, 6.23 to 7.27 and 6.53 to 7.23 for control, 35 and 45 ºC temperature, respectively. These results agree with those obtained by **Appels *et al.* (2008)** whose found that the optimum range of pH ranged from 6.8 to 7.2. The results also indicate that the highest pH (7.47) was obtained from control (32.5°C) temperature, while the lowest pH (6.17) was obtained at a fermentation temperature of control (32.5°C).

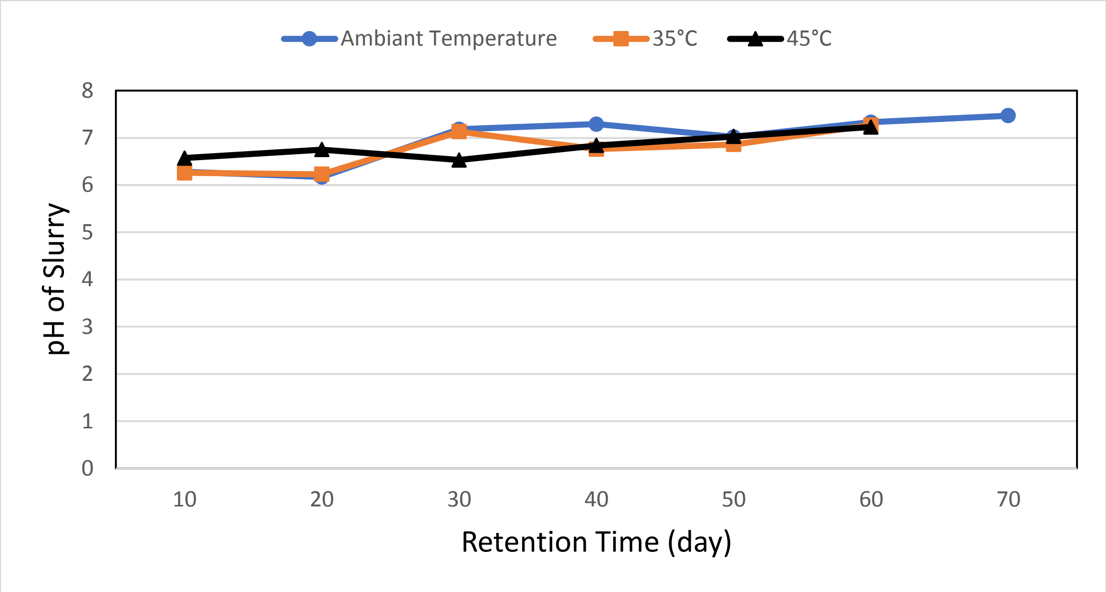


**Figure (3):** The effect of fermentation temperature on slurry pH during the retention period.

**Table (2)** shows the effect of agitation speeds (50, 100 and 150 rpm) on slurry pH during the retention period (60 days). The results indicate that the slurry pH ranged from 6.57 to 7.37, 6.27 to 7.17 and 6.87 to 7.37 for 50, 100 and 150 rpm agitation speed, respectively at 35°C fermentation temperature. At 45 °C fermentation temperature, the slurry pH ranged from 5.53 to 7.03, 5.43 to 7.13 and 6.63 to 7.43 for 50, 100 and 150 rpm agitation speed, respectively. The results also indicate that the highest pH (7.43) was obtained with 150 agitation speed at 45 °C fermentation temperature, while the lowest pH (5.43) was obtained with 100 rpm at 45 °C fermentation temperature.

**Table 2**. The effect of agitation speeds on slurry pH during the retention period.

| **Retention time, day** | **Fermentation Temperature, °C** | | | | | |
|---|---|---|---|---|---|---|
| | **35** | | | **45** | | |
| | **50 rpm** | **100 rpm** | **150 rpm** | **50 rpm** | **100 rpm** | **150 rpm** |
| | **pH slurry** | | | | | |
| 10 | 6.57 | 6.3 | 6.9 | 6.73 | 6.43 | 6.53 |
| 20 | 6.77 | 6.23 | 6.7 | 5.63 | 5.83 | 6.78 |
| 30 | 7.06 | 7.07 | 7.27 | 5.53 | 5.43 | 6.63 |
| 40 | 6.83 | 6.57 | 6.87 | 6.83 | 6.63 | 7.05 |
| 50 | 6.93 | 6.27 | 7.37 | 6.93 | 7.13 | 7.03 |
| 60 | 7.37 | 7.17 | 7.27 | 7.03 | 7.23 | 7.43 |

Multiple regression analysis was carried out to obtain a relationship between the pH of slurry as dependent variable and different both of fermentation temperature and agitation speed as independent variables. The best fit for this relationship is presented in the following equation: -

$$pH = 6.92 - 0.03T + 0.003S + 0.016t \qquad R^2 = 0.86 \qquad (7)$$

**Where:**

T is the fermentation temperature, °C
S is the agitation speed, rpm
t is the retention time, day

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

**3.2. Total Solids of slurry (TSS):**

Figure (4) shows the effect of fermentation temperature (control, 35 and 45 ºC) on TSS of slurry during the retention period. The results indicate that the TSS of slurry decreases with increasing fermentation temperature and retention time. It could be seen the TSS of slurry decreased from 9.10 to 1.26, 10.13 to 1.03 and 10.12 to 0.63% for control, 35 and 45 ºC temperature, respectively, when the retention time increased from 10 to 60 day. The results also indicate that the TSS slurry was decreased from 1.26 to 0.63% when the fermentation temperature increased from control (32.5 ºC) to 45 ºC, respectively, at the end of experimental (60 days).

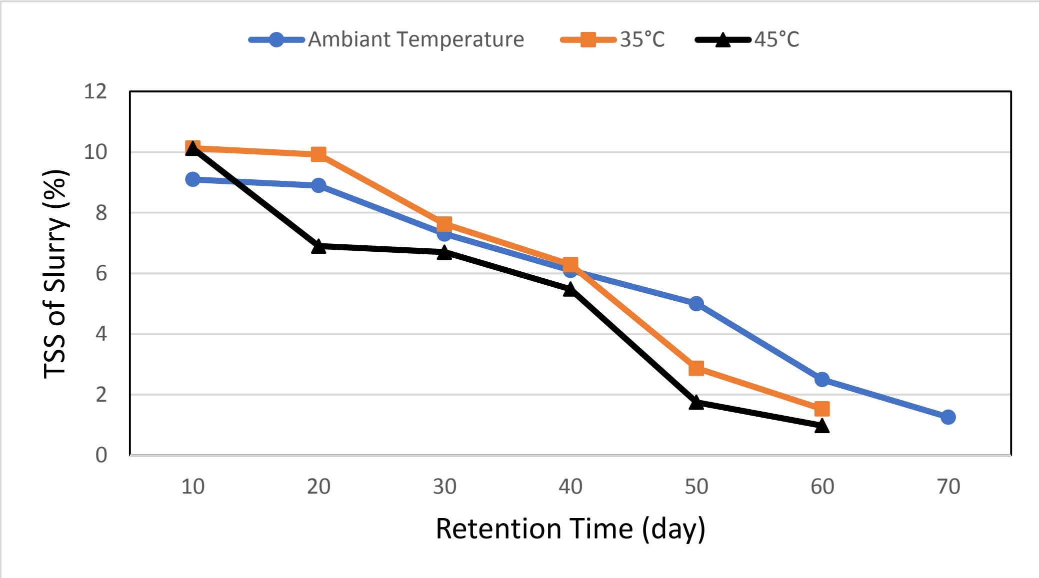


**Figure (4):** The effect of fermentation temperature on TSS of slurry during the retention period.

Table (3) shows the effect of agitation speed (50, 100 and 150 rpm) on TSS of slurry during the retention period (60 days). The results indicate that the TSS of slurry decreases with increasing agitation speed and retention time. It could be seen the TSS of slurry decreased from 10.24 to 3.26, 10.16 to 1.20 and 9.98 to 0.01% for 50, 100 and 150 rpm agitation speed, respectively, when the retention time increased from 10 to 60 day, at 35°C fermentation temperature. At 45°C fermentation temperature, the TSS of slurry decreased from 10.10 to 2.08, 10.30 to 0.73 and 9.95 to 0.13% for 50, 100 and 150 rpm agitation speed, respectively, when the retention time increased from 10 to 60 day. The results also indicate that, the TSS of slurry decreased from 3.36 to 2.08, 1. 20 to 0.73 and 0.10 to 0.03% for 50, 100 and 150 rpm agitation speed, respectively, when the fermentation temperature increased from 35 to 45°C at the end of experimentation period (60 days). The TSS of slurry decreased from 3.36 to 0.1 and 2.08 to 0.03% for 35 and 45°C, respectively, when the agitation speed increased from 50 to 150 rpm at the end of experimentation period (60 days).

**Table 3.** The effect of agitation speeds and fermentation temperature on TSS of slurry during the retention period.

| **Retention time, day** | **Fermentation Temperature, °C** | | | | | |
|---|---|---|---|---|---|---|
| | **35** | | | **45** | | |
| | **50 rpm** | **100 rpm** | **150 rpm** | **50 rpm** | **100 rpm** | **150 rpm** |
| | **TSS of slurry, %** | | | | | |
| 10 | 10.24 | 10.16 | 9.98 | 10.1 | 10.3 | 9.95 |
| 20 | 9.8 | 10 | 7.5 | 7 | 6.2 | 7.5 |
| 30 | 8.1 | 7.3 | 6.25 | 6.2 | 7 | 6.9 |
| 40 | 6.42 | 6.2 | 4.61 | 5.25 | 5.4 | 5.8 |
| 50 | 4.61 | 2.36 | 1.63 | 4.08 | 1.09 | 0.09 |
| 60 | 3.36 | 1.2 | 0.1 | 2.08 | 0.73 | 0.03 |

Multiple regression analysis was carried out to obtain a relationship between the total solids of slurry as dependent variable and both of fermentation temperature and agitation speed as independent variables with retention time. The best fit for this relationship is presented in the following equation:

$$TSS = 16.53 - 0.08T - 0.01S - 0.18t \qquad R^2 = 0.91 \qquad (8)$$

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

**3. Volatile solid of slurry (VSS):**

Figure (5) shows the effect of fermentation temperature (control, 35 and 45 ºC) on VSS of slurry during the retention period. The results indicate that the VSS of slurry decreases with increasing fermentation temperature and retention time. It could be seen the VSS of slurry decreased from 7.28 to 1.25, 8.10 to 0.72 and 8.82 to 0.10 % for control, 35 and 45 ºC temperature, respectively, when the retention time increased from 10 to 60 day. The results also indicate that the VSS slurry was decreased from 1.25 to 0.10 % when the fermentation temperature increased from control (32.5 ºC) to 45 ºC, respectively, at the end of experimental (60 days).

Multiple regression analysis was carried out to obtain a relationship between the volatile solids of slurry as dependent variable and both of fermentation temperature and agitation speed as independent variables with retention time. The best fit for this relationship is presented in the following equation:

$$VSS = 15.00 - 0.09T - 0.01S - 0.14t \qquad R^2 = 0.89 \qquad (9)$$

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

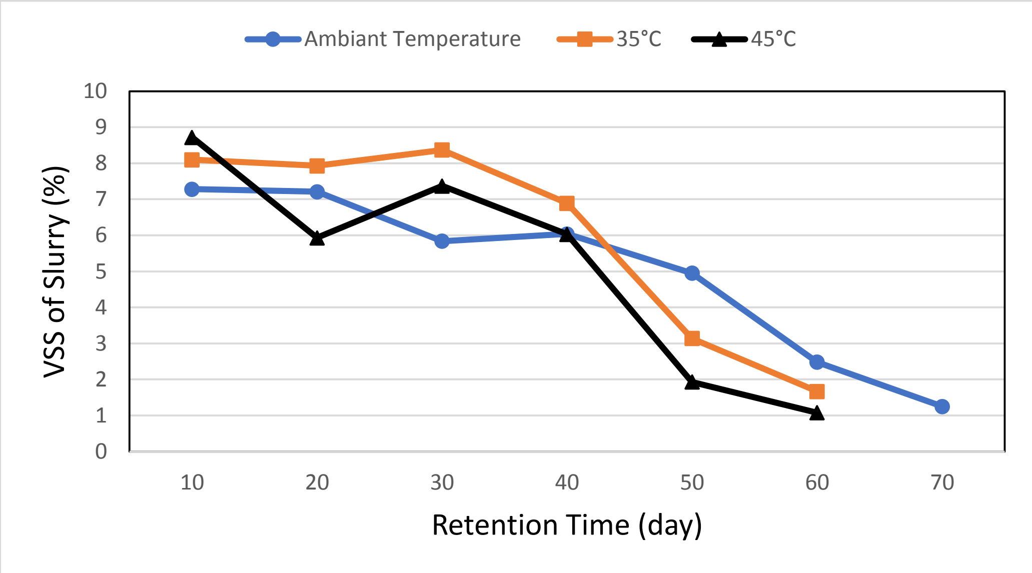


**Figure (5):** The effect of fermentation temperature on VSS of slurry during the retention period.

Table (4) shows the effect of agitation speed (50, 100 and 150 rpm) on VSS of slurry during the retention period (60 days). The results indicate that the VSS of slurry decreases with increasing agitation speed and retention time. It could be seen the VSS of slurry decreased from 8.19 to 3.68, 8.13 to 1.32 and 7.98 to 0.10% for 50, 100 and 150 rpm agitation speed, respectively, when the retention time increased from 10 to 60 day, at 35°C fermentation temperature. At 45°C fermentation temperature, the VSS of slurry decreased from 7.74 to 2.29, 8.86 to 0.80 and 8.56 to 0.05% for 50, 100 and 150 rpm agitation speed, respectively, when the retention time increased from 10 to 60 day. The results also indicate that, the VSS of slurry decreased from 3.68 to 2.29, 1. 32 to 0.80 and 0.10 to 0.05% for 50, 100 and 150 rpm agitation speed, respectively, when the fermentation temperature increased from 35 to 45°C at the end of experimentation period (60 days). The VSS of slurry decreased from 3.36 to 0.10 and 2.08 to 0.05% for 35 and 45°C, respectively, when the agitation speed increased from 50 to 150 rpm at the end of experimentation period (60 days).

**Table 4**. The effect of agitation speeds on VSS of slurry during the retention period.

| Retention time, day | Fermentation Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 35 | | | 45 | | |
| | 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| | VSS of slurry, % | | | | | |
| 10 | 8.19 | 8.13 | 7.98 | 8.74 | 8.86 | 8.56 |
| 20 | 7.96 | 7.84 | 8 | 6.02 | 5.33 | 6.45 |
| 30 | 8.22 | 8.88 | 8 | 6.82 | 7.7 | 7.59 |
| 40 | 6.85 | 7.04 | 6.79 | 5.78 | 5.94 | 6.38 |
| 50 | 5.05 | 2.59 | 1.78 | 4.49 | 1.2 | 0.1 |
| 60 | 3.68 | 1.32 | 0.10 | 2.29 | 0.8 | 0.05 |

### 3.4. Some properties of slurry:

Table (5) shows the effect of fermentation temperature (control, 35 and 45 ºC) on some properties of slurry (moisture content, total nitrogen, total potassium and total Phosphorus) before and after fermentation. The results indicate that the moisture content of slurry increased after fermentation. It could be seen the moisture content of slurry increased from 72.07 to 93.5, 93.6 and 94.7 % for control, 35 and 45 ºC temperature, respectively. Additionally, the moisture content increases with increasing fermentation temperature, it could be seen that, the moisture content increased from 93.5 to 94.7 %, when the fermentation temperature increased from control to 45 ºC, respectively. Total nitrogen and total potassium of slurry increases after fermentation. They were increased from 0.75 to 1.88, 0.75 to 1.19 and 0.75 to 1.24% and 861.92 to 1196.86, 861.92 to 1294.73 and 861.92 to 1150.35 ppm for control, 35 and 45 ºC temperature, respectively.

**Table 5.** The effect of fermentation temperature on some properties of slurry.

| Properties | Before fermentation | After fermentation | | |
|---|---|---|---|---|
| | | Control | 35 | 45 |
| Moisture Content, % | 72.07 | 93.5 | 93.6 | 94.7 |
| T. Nitrogen, % | 0.75 | 1.88 | 1.19 | 1.24 |
| T. Potassium, ppm | 861.92 | 1196.89 | 1294.73 | 1150.35 |
| T. Phosphorus, % | 0.02 | 0.06 | 0.006 | 0.06 |

**5. Biogas yield:**

Figure (6) shows the effect of fermentation temperature (control, 35 and 45 ºC) on biogas yield during the retention period. The results indicate that the biogas yield ranged from 0.14 to 9.62, 0.36 to 26.54 and 0.11 to 20.82 $m^3$ per ton TS for control, 35 and 45 ºC temperature, respectively. it could be seen that the biogas yield increased gradually until it reached the peak after 30 day for control and 20 day for 35 and 45 ºC fermentation temperature and then decreased until it reached day 60. The biogas yield reached a maximum value was 26.54, 20.82 and 9.62 $m^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively. After the biogas yield peak, a progressive decrease in biogas yield is observed, to reach a final value of 0.14, 0.36 and 0.11 $m^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively at day 60. The results also indicate that the highest value of biogas yield (26.54 $m^3$ per ton TS) was obtained from 35°C fermentation temperature, while the lowest value of biogas yield (9.62 $m^3$ per ton TS) was obtained at a fermentation temperature of 32.5°C. The best fermentation temperature for biogas production was 35°C, while, the highest value of accumulated biogas yield was 87.28 $m^3$ per ton TS was found at a fermentation temperature of 35°C. These results agreed with those obtained by **El-Mashad *et al.*, (2004)**.

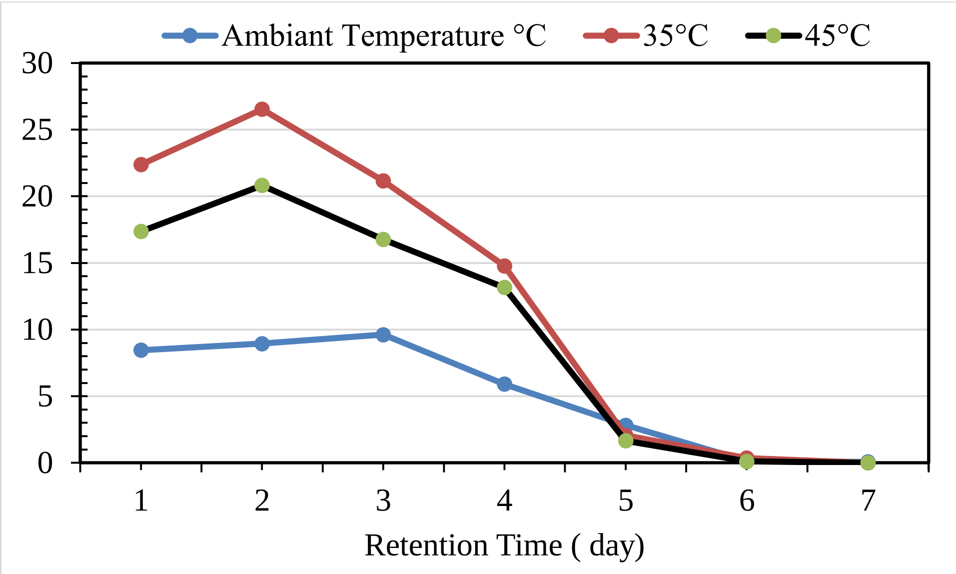


**Figure (6):** The effect of fermentation temperature on biogas yield during the retention period.

Table (6) shows the effect of agitation speed (50, 100 and 150 rpm) on biogas yield during the retention period (60 days). The results indicate that the biogas yield increases with increasing agitation speed. It could be seen**,** when the agitation speed increasing from 50 to 150 rpm, the biogas yield increased from 16.97 to 29.52 and 16.09 to 29.19 $m^3$ per ton TS, respectively, at 35 and 45°C after 10 day.

The results also indicate that the biogas yield increased gradually until it reached the peak after 20 day and then decreased until it reached day 60 and then it seemed to be constant. The biogas yield reached a maximum value was 19.34 and 24.43, 27.47 and 29.85 and 33.05 and 29.35 $m^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively. After the biogas yield peak, a progressive decrease in biogas yield is observed, to reach a final value of 0.89 and 0.16, 0.28 and 0.19 and 0.01 and 0.15 m$^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively at day 60.

Multiple regression analysis was carried out to obtain a relationship between the biogas yield as dependent variable and different both of fermentation temperature and agitation speed as independent variables. The best fit for this relationship is presented in the following equation:

$$BY = 39.616 - 0.287T + 0.046S - 0.56t$$
$$R^2 = 0.87 \qquad (10)$$

Where:

BY is the biogas yield, m$^3$ per ton TS

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

**Table 6.** The effect of agitation speeds on biogas yield during the retention period.

| Retention time, day | Fermentation Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 35 | | | 45 | | |
| | 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| | Biogas yield, m$^3$ per ton TS | | | | | |
| 10 | 16.97 | 20.65 | 29.52 | 16.09 | 20.17 | 29.19 |
| 20 | 19.34 | 27.47 | 33.05 | 20.43 | 29.85 | 29.35 |
| 30 | 19.10 | 19.91 | 24.22 | 19.07 | 19.61 | 17.62 |
| 40 | 11.96 | 13.45 | 18.95 | 2.25 | 2.16 | 2.07 |
| 50 | 3.49 | 1.70 | 0.98 | 0.72 | 0.64 | 0.63 |
| 60 | 0.89 | 0.19 | 0.01 | 0.11 | 0.13 | 0.10 |

**3.6. Methane yield:**

Figure (7) shows the effect of fermentation temperature (control, 35 and 45 ºC) on methane yield during the retention period. The results indicate that the methane yield ranged from 0.09 to 6.25, 0.25 to 18.31 and 0.07 to 13.95 m$^3$ per ton TS for control, 35 and 45 ºC temperature, respectively. it could be seen that the methane yield increased gradually until it reached the peak after 30 day for control and 20 day for 35 and 45 ºC fermentation temperature and then decreased until it reached day 60. The methane yield reached a maximum value was 6.25, 18.31 and 13.95 m$^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively. After the methane yield peak, a progressive decrease in methane yield is observed, to reach a final value of 0.09, 0.25 and 0.07 m$^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively at day 60. The results also indicate that the highest value of methane yield (18.31 m$^3$ per ton TS) was obtained from 35°C fermentation temperature, while the lowest value of methane yield (6.25 m$^3$ per ton TS) was obtained at a fermentation temperature of 32.5°C.

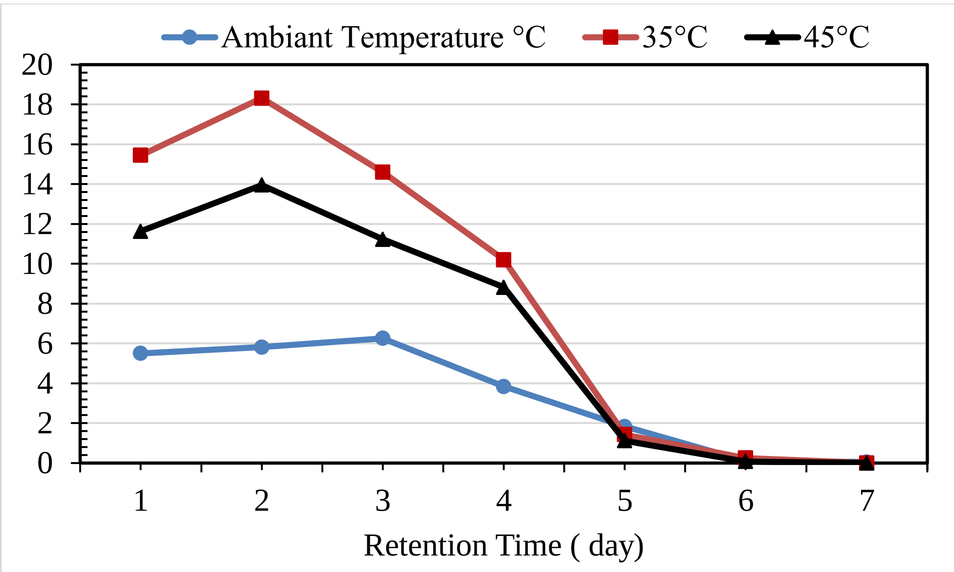


Figure (7): The effect of fermentation temperature on methane yield during the retention period.

Table (7) shows the effect of agitation speed (50, 100 and 150 rpm) on methane yield during the retention period (60 days). The results indicate that the methane yield increases with increasing agitation speed. It could be seen**,** when the agitation speed increasing from 50 to 150 rpm, the methane yield increased from 11.20 to 19.48 and 11.26 to 20.44 $m^3$ per ton TS, respectively, at 35 and 45°C after 10 day.

The results also indicate that the methane yield increased gradually until it reached the peak after 20 day and then decreased until it reached day 60 and then it seemed to be constant. The methane yield reached a maximum value was13.18 and 14.09, 18.95 and 20.59, 22.80 and 20.44 $m^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively. After the methane yield peak, a progressive decrease in methane yield is observed, to reach a final value of 0.60 and 0.07 , 0.13 and 0.09, 0.0 and 0.07 $m^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively at day 60. These results agreed with those obtained by **Vavilin and Angelidaki, (2005)**.

Multiple regression analysis was carried out to obtain a relationship between the methane yields as dependent variable and different both of fermentation temperature and agitation speed as independent variables. The best fit for this relationship is presented in the following equation:

$$MY = 25.96 - 0.169T + 0.03S - 0.38t$$
$$R^2 = 0.89 \qquad (11)$$

Where:

MY is the Methane yield, $m^3$ per ton TS

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

**Table 7.** The effect of agitation speeds on methane yield during the retention period.

| Retention time, day | Fermentation Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 35 | | | 45 | | |
| | 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| | Methane yield, $m^3$ per ton TS | | | | | |
| 10 | 11.20 | 13.63 | 19.48 | 11.26 | 14.12 | 20.25 |
| 20 | 13.18 | 18.95 | 22.80 | 14.09 | 20.59 | 20.44 |
| 30 | 12.76 | 13.14 | 15.99 | 12.97 | 13.33 | 11.98 |
| 40 | 8.01 | 9.01 | 12.70 | 1.55 | 1.49 | 1.43 |
| 50 | 2.20 | 1.07 | 0.62 | 0.45 | 0.40 | 0.39 |
| 60 | 0.60 | 0.13 | 0.00 | 0.07 | 0.09 | 0.07 |

### 3.7. $CO_2$ yield:

Figure (8) shows the effect of fermentation temperature (control, 35 and 45 ºC) on $CO_2$ yield during the retention period. The results indicate that the $CO_2$ yield ranged from 0.03 to 2.21, 0.06 to 4.78 and 0.03 to 5.21 $m^3$ per ton TS for control, 35 and 45 ºC temperature, respectively. it could be seen that the $CO_2$ yield increased gradually until it reached the peak after 30 day for control and 20 day for 35 and 45 ºC fermentation temperature and then decreased until it reached day 60. The $CO_2$ yield reached a maximum value was 2.21, 4.78 and 5.21 $m^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively. After the $CO_2$ yield peak, a progressive decrease in $CO_2$ yield is observed, to reach a final value of 0.03, 0.06 and 0.03 $m^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively at day 60. The results also indicate that the highest value of $CO_2$ yield (5.21 $m^3$ per ton TS) was obtained from 45°C fermentation temperature, while the lowest value of $CO_2$ yield (2.21 $m^3$ per ton TS) was obtained at a fermentation temperature of 32.5°C.

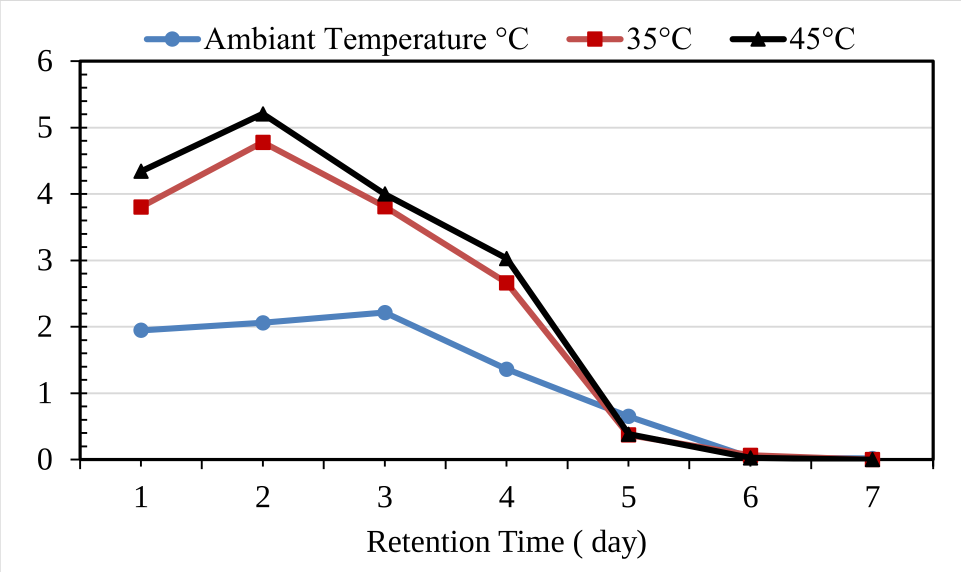


Figure (8): The effect of fermentation temperature on $CO_2$ yield during the retention period.

**Table (8)** shows the effect of agitation speed (50, 100 and 150 rpm) on $CO_2$ yield during the retention period (60 days). The results indicate that the $CO_2$ yield increases with increasing agitation speed. It could be seen**,** when the agitation speed increasing from 50 to 150 rpm, the $CO_2$ yield increased from 4.2 to 7.3 and 4.3 to 7.0 $m^3$ per ton TS, respectively, at 35 and 45°C after 10 day.

The results also indicate that the $CO_2$ yield increased gradually until it reached the peak after 20 day and then decreased until it reached day 60 and then it seemed to be constant. The $CO_2$ yield reached a maximum value was 4.4 and 4.9, 6.0 and 7.2 and 7.4 and 7.9$m^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively. After the $CO_2$ yield peak, a progressive decrease in $CO_2$ yield is observed, to reach a final value of 0.018 and 0.027 , 0.004 and 0.032 and 0.0 and 0.025 $m^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively at day 60.

**Table 8**. The effect of agitation speeds on $CO_2$ yield during the retention period.

| Retention time, day | Fermentation Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 35 | | | 45 | | |
| | 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| | $CO_2$ yield, $m^3$ per ton TS | | | | | |
| 10 | 4.2 | 5.2 | 7.3 | 4.3 | 5.4 | 7.0 |
| 20 | 4.4 | 6.0 | 7.4 | 4.9 | 7.2 | 7.9 |
| 30 | 4.2 | 4.6 | 5.6 | 4.4 | 4.5 | 4.1 |
| 40 | 2.4 | 2.7 | 3.8 | 0.6 | 0.6 | 0.5 |
| 50 | 0.7 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |
| 60 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Multiple regression analysis was carried out to obtain a relationship between the $CO_2$ yield as dependent variable and different both of fermentation temperature and agitation speed as independent variables. The best fit for this relationship is presented in the following equation:

$$CY = 8.42 + 0.0391T + 0.011S - 0.139t$$

$$R^2 = 0.87 \qquad (12)$$

Where:

CY is the $CO_2$ yield, $m^3$ per ton TS

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

**3.8. $H_2S$ yield:**

Figure (9) shows the effect of fermentation temperature (control, 35 and 45 ºC) on $H_2S$ yield during the retention period. The results indicate that the $H_2S$ yield ranged from 0.1 to 0.9, 0.02 to 1.59 and 0.01 to 1.8 $m^3$ per ton TS for control, 35 and 45 ºC temperature, respectively. it could be seen that the $H_2S$ yield increased gradually until it reached the peak after 30 day for control and 20 day for 35 and 45 ºC fermentation temperature and then decreased until it reached day 60. The $H_2S$ yield reached a maximum value 0.9, 1.59 and 1.8 $m^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively. After the $H_2S$ yield peak, a progressive decrease in $H_2S$ yield is observed, to reach a final value of 0.1, 0.02 and 0.01 m$^3$ per ton TS at different fermentation temperature control, 35 and 45°C, respectively at day 60. The results also indicate that the highest value of $H_2S$ yield (8.33 m$^3$ per ton TS) was obtained from 45°C fermentation temperature, while the lowest value of $H_2S$ yield (0.01 m$^3$ per ton TS) was obtained at a fermentation temperature of 45°C.

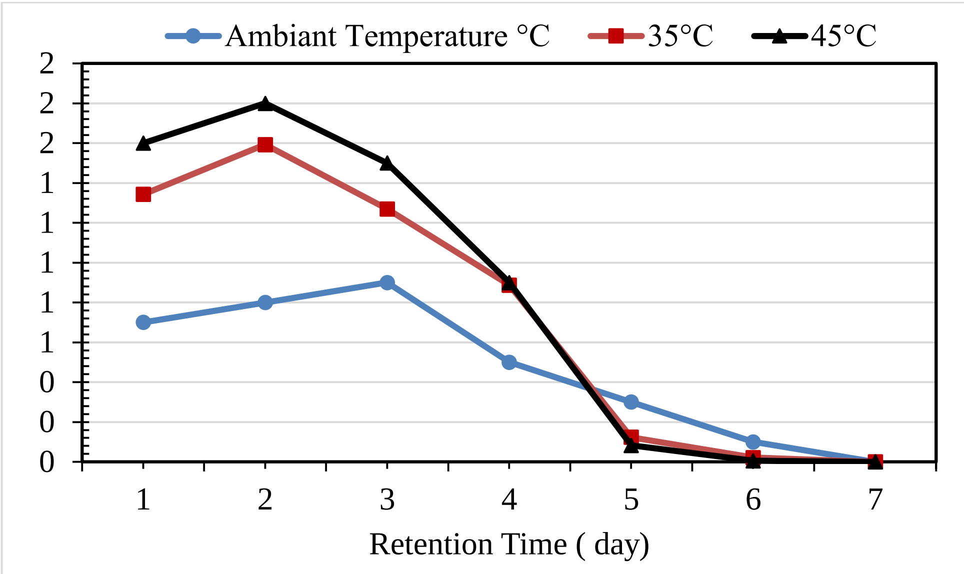


Figure (9): The effect of fermentation temperature on $H_2S$ yield during the retention period.

Table (9) shows the effect of agitation speed (50, 100 and 150 rpm) on $H_2S$ yield during the retention period (60 days). The results indicate that the $H_2S$ yield increases with increasing agitation speed. It could be seen**,** when the agitation speed increasing from 50 to 150 rpm, the $H_2S$ yield increased from 0.01 to 0.03 and 0.20 to 0.29 m$^3$ per ton TS, respectively, at 35 and 45°C after 10 day.

The results also indicate that the $H_2S$ yield increased gradually until it reached the peak after 20 day and then decreased until it reached day 60 and then it seemed to be constant. The $H_2S$ yield reached a maximum value was 0.43, 0.47 and 0.57 and 0.48, 0.85 and 0.87 m$^3$ per ton TS for 50, 100 and 150 rpm agitation speed at both fermentation temperature 35 and 45°C, respectively. After the $H_2S$ yield peak, a progressive decrease in $H_2S$ yield is observed, to reach a final value of 0.01, 0.02 and 0.00 and 0.02, 0.02 and 0.01 m$^3$ per ton TS for 50, 100 and 150 rpm agitation speed at different fermentation temperature 35 and 45°C, respectively at day 60.

**Table 9**. The effect of agitation speeds on $H_2S$ yield during the retention period.

| Retention time, day | Fermentation Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 35 | | | 45 | | |
| | 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| | $H_2S$ yield, m$^3$ per ton TS | | | | | |
| 10 | 0.01 | 0.02 | 0.03 | 0.20 | 0.30 | 0.29 |
| 20 | 1.87 | 2.27 | 3.25 | 1.77 | 2.22 | 3.21 |
| 30 | 1.16 | 1.19 | 1.45 | 1.14 | 1.18 | 1.06 |
| 40 | 0.04 | 0.04 | 0.06 | 0.01 | 0.01 | 0.01 |
| 50 | 0.35 | 0.17 | 0.10 | 0.11 | 0.10 | 0.10 |
| 60 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Multiple regression analysis was carried out to obtain a relationship between the $H_2S$ yield as dependent variable and different both of fermentation temperature and agitation speed as independent variables. The best fit for this relationship is presented in the following equation:

$$HY = 1.978 + 0.0058T + 0.001S - 0.037t$$

$$R^2 = 0.86 \qquad (11)$$

**Where:**

HY is the $H_2S$ yield, m$^3$ per ton TS

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

### 3.9. Energy production and power consumption:

Figure (10) shows comparison between power consumption and energy production of fermentation temperature (control, 35 and 45 ºC) and agitation speed .The results indicate that the highest value of Energy production was 2561.44 MJ and the lowest value of the power consumption was 150.08 kW, at fermentation temperature 35°C and 150 rpm as agitation speed . Multiple regression analysis was carried out to obtain a relationship between the power consumption (Pc) as dependent variable and different both of fermentation temperature and agitation speed as independent variables. The best fit for this relationship is presented in the following equation:

$$P_C = 164.75 - 1.759(FT) + 7.184(AS) \quad R^2 = 0.786 \qquad (14)$$

Where:

Pc is power consumption, kw per 60 day.

This equation could be applied in the range of 35 to 45°C fermentation temperature and from 50 to 150 rpm of agitation speed.

**Table 10**. The effect of temperature and agitation speeds on Energy production.

| Fermentation Temperature, °C | | | | | | |
|---|---|---|---|---|---|---|
| 32.5 | 35 | | | 45 | | |
| Without agitation | 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| Energy production, MJ | | | | | | |
| 768 | 1721.92 | 2000.64 | 2561.44 | 1407.84 | 1741.12 | 1895.36 |

**Table 11**. The effect of temperature and agitation speeds on Power consumption.

| Fermentation Temperature, °C | | | | | |
|---|---|---|---|---|---|
| 35 | | | 45 | | |
| 50 rpm | 100 rpm | 150 rpm | 50 rpm | 100 rpm | 150 rpm |
| Power consumption, kW | | | | | |
| 367.04 | 203.61 | 150.08 | 461.02 | 149.18 | 325.07 |

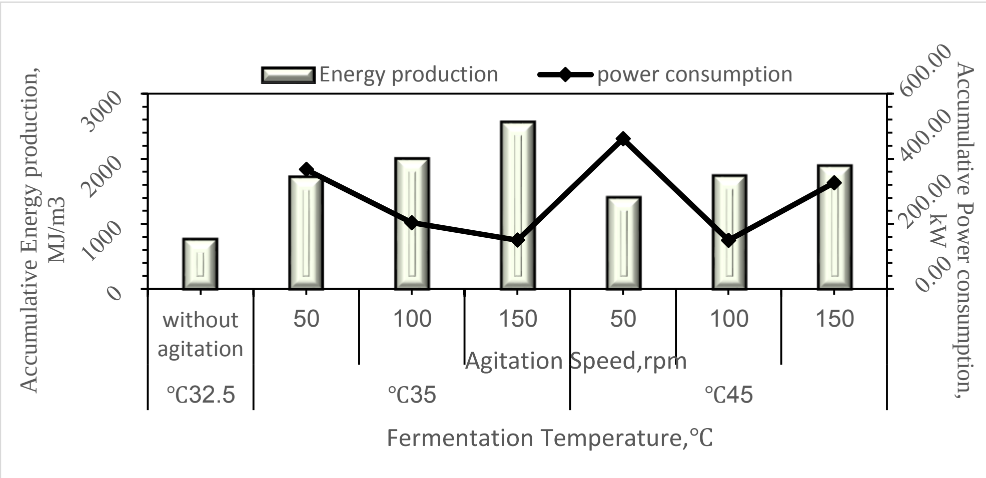


**Figure (10):** Comparison between power consumption and energy production at different treatments.

## Conclusion

The experiment was carried out to study the influence of different fermentation temperature and agitation speed on the biogas quality and productivity. The treatments under study are fermentation temperatures (control, 35 and 45 °C) and three agitation speeds (50, 100 and 150 rpm) pH, TSS, and VSS of slurry were determined. Biogas yield and component are also studied. The obtained results can be summarized as follows:

pH of slurry was ranged from 5.83 to 7.47 for all treatment. The TSS and VSS of slurry decreases with increasing fermentation temperature, agitation speed and retention time. The best fermentation temperature for biogas production was 35°C, the highest value of accumulated biogas yield was 261.83 $m^3$ per ton TS was found at a fermentation temperature of 35°C. The biogas yield increases with increasing agitation speed. The methane yield increased gradually until it reached the peak after 30 day for control and 20 day for 35 and 45 °C fermentation temperature and then decreased until it reached day 60. The methane yield increases with increasing agitation speed. the highest value of $CO_2$ yield was 19.18 $m^3$ per ton TS was obtained from 45°C fermentation temperature, while the lowest value of $CO_2$ yield was0.08 $m^3$ per ton TS was obtained at a fermentation temperature of 35°C, also, the $CO_2$ yield increases with increasing agitation speed. The highest value of $H_2S$ yield was 3.21 $m^3$ per ton TS was obtained from 45°C fermentation temperature.

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**أثر حرارة التخمر وعملية التقليب على انتاجية وجودة الغاز الحيوي**

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الهدف الرئيسي من الدراسة هو دراسة تأثير درجة حرارة التخمر وسرعة التقليب على إنتاج وجودة الغاز الحيوي. لتحقيق ذلك، تمت دراسة تأثير كلا من درجات حرارة التخمر عند (٣٢.٥و ٣٥ و٤٥ درجة مئوية) وسرعات تقليب عند (٥٠ و١٠٠ و١٥٠ لفة في الدقيقة) على بعض خصائص السماد الناتج عن التخمر وإنتاجية كلا من الغاز الحيوي والميثان وثاني أكسيد الكربون وكبريتيد الهيدروجين. أظهرت النتائج أن درجة الحموضة في السماد المنتج تراوحت من ٥.٨٣ إلى ٧.٤٧ لجميع المعاملات. كما ان قيمة المواد الصلبة الكلية والمواد الصلبة المتطايرة للسماد الناتج عن التخمر تنخفض مع زيادة درجة حرارة التخمر وسرعة التقليب وزمن الاستبقاء. كانت أفضل درجة حرارة تخمر لإنتاج الغاز الحيوي هي ٣٥ درجة مئوية، وكانت أعلى قيمة للإنتاج التراكمي للغاز الحيوي216.83 متر مكعب لكل طن. كما زاد العائد من الغاز الحيوي مع زيادة سرعة التقليب عند نفس درجة الحرارة. كما زاد ناتج الميثان تدريجياً حتى وصل إلى الذروة بعد ٣٠ يومًا عند ٣٢.٥ و٢٠ يومًا لكلا من درجة حرارة تخمر٣٥ و٤٥ درجة مئوية ثم بدأت في الانخفاض حتى وصلت إلى ٦٠ يومًا. وكانت أعلى قيمة لإنتاج ثاني أكسيد الكربون 19.18متر مكعب لكل طن تم الحصول عليها عند ٤٥ درجة مئوي، في حين أن أدنى قيمة لعائد ثاني أكسيد الكربون كانت 0.08متر مكعب لكل طن عند درجة حرارة ٣٥ درجة مئوية. كما كانت أعلى قيمة لكبريتيد الهيدروجين كانت 8.33 متر مكعب للطن وذلك عند درجة حرارة ٤٥ درجة مئوية.