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# Biogas production from an anaerobic pond treating domestic wastewater in Burkina Faso

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ABSTRACT

The production of biogas and its composition from an anaerobic pond treating domestic wastewater have been studied in the Sudano-Sahelian climate of Burkina Faso. The biogas production was measured from March 2010 to March 2011 using a floating static chamber, and the composition was analysed using a micro-gas chromatograph. The composition of biogas produced was relatively constant with time. The major component of the biogas by volume was $CH_4$ which accounted for an average of 80.5%, $N_2$ for 11.8%, $O_2$ for 5% and $CO_2$ for 2.5%. The mean areal production rates of biogas and methane respectively were 121 and 97 $L\,m^{-2}\,d^{-1}$. The mean methane production rates were 248 $L\,kg^{-1}$ COD removed and 588 $L\,kg^{-1}$ VSS removed. The average daily volume of biogas and its corresponding methane were 5.73 and 4.63 $m^3\,d^{-1}$, respectively, equivalent to a ratio of 7.3 $m^3$ $CH_4$ per capita-year. The conversion of this methane production to electricity could reduce the $CO_2$ equivalent greenhouse gas emission from petrol combustion. This study revealed that the conversion of an anaerobic pond to an anaerobic lagoon digester with the capture and reuse of biogas would be an interesting option for wastewater treatment in the warm conditions of Sudano-Sahelian climate of Burkina Faso.

*Keywords:* Anaerobic pond; Biogas; GHG emission; Methane; Burkina Faso; Wastewater stabilization pond

## 1. Introduction

Anaerobic ponds (APs) are usually the first type of pond used in series in a waste stabilization pond system [1]. They are recognized as highly efficient at removing organic carbon from wastewater, which is achieved by sedimentation of settleable solids and their subsequent anaerobic digestion in the resulting sludge layer [2]. As in other anaerobic systems, most of the biodegradable organic matter present in the AP is converted into biogas (comprised primarily of $CH_4$ and $CO_2$) which escapes to the atmosphere, contributing to greenhouse gas (GHG) emissions. However, with the question of long-term sustainability, different authors have emphasized the need for the implementation of integrated environmental protection systems that

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combine sewage treatment with the recovery and reuse of treatment by-products [3,4]. In the global effort to reduce GHG emissions, natural wastewater treatment is already ahead of the game [5]. This author also stated that "we need to use natural wastewater treatment and reuse systems not only to reduce the consumption of electrical energy and its associated GHG emissions, but—and more creatively—to generate electricity and capture carbon". This approach has a special appeal to developing countries, which confront serious environmental problems, such as lack of resources and electrical power [6]. This means that, out of the driving forces that traditionally have promoted wastewater treatment (removal of carbon, nutrients, and pathogens) additional advantages could include biogas recovery.

Thus, in Burkina Faso, APs have important potential application considering the advantageous warm climatic conditions that prevail and justify their utilization without the need for heating or covering as it is often the case in cold climate regions. Despite these advantages, AP have rarely been studied in Sahelian climate countries for biogas production. There is still need for some basic research mostly on the quality and the potential biogas yield of AP. The goal of this research was to determine the production of biogas and its composition from an anaerobic pond treating domestic wastewater in the Sudano-Sahelian climate of Burkina Faso, and the potential energy recovery, in order to optimize the process for future development of anaerobic digesters.

## 2. Methodology

### 2.1. Location and description of the site

This work was carried out at the experimental anaerobic stabilization pond system (12°22′45.5′′N, 1°30′09.3′′W) of the International Institute for Water and Environmental Engineering (2iE) in Ouagadougou, Burkina Faso. The plant treats the wastewater from the 2iE campus. The anaerobic pond was continuously in operation for 6 years. The anaerobic pond has a vertical geometry form of a truncated cone with an egg-shaped surface with a top surface of 84 $m^2$ at the water level and a bottom surface area of 9.5 $m^2$. Its total depth is 3.1 m with 0.5 m of free board and a wall slope of 2/3. Its effective depth is 2.6 m with a useful volume of 107 $m^3$. The site was characterized by the Sudano-Sahelian climate conditions with a long dry season (October to May) and a short rainy season (June to September) with a precipitation varying between 600 and 900 mm $yr^{-1}$. The maximum of rain was observed in August. The average temperature of the coldest month (January) was 24.8°C and the warmest (April) 33.6°C. The minimum air temperatures varied from 16°C in January to 26.5°C in April, and the maximum temperatures varied from 32°C in January to 42°C in April.

### 2.2. Wastewater characterization

The quality of the influent and effluent of the anaerobic pond (based on composite samples) was analysed at weekly intervals for 6.5 years. In situ measurement of physical–chemical parameters (temperature, pH, dissolved oxygen) was made using specific probes of a multi-parameter (*multi 350i WTW*). Chemical oxygen demand (COD), suspended solids (SS), volatile suspended solids (VSS), sulphate and sulphide analyses were performed in accordance with Standard Methods [7]. Biochemical oxygen demand ($BOD_5$) was measured with a special apparatus (*Oxytop WTW*). Alkalinity expressed as $CaCO_3$ and volatile fatty acids (VFA) expressed as acetic acid were determined by an alkalimetric method using a two-stage sequential titration [8].

### 2.3. Biogas collection, sampling and analysis

The production of biogas was measured from March 2010 to March 2011 with four floating static chambers in *Plexiglas* adapted from the collectors described in a similar study on biogas production in Mediterranean climatic conditions [2]. The geometric form of the biogas collector is a half-sphere, with a bottom area of 0.2826 $m^2$. Fig. 1 shows a schema of the biogas collector. All the collectors were supported at the surface with floats and anchored with lines to the pond banks to prevent any disturbance by wind or rains. The collectors were opaque in order to stop UV penetration and prevent algal growth within the system [2]. Problems such as the increase in $O_2$ concentrations mentioned by several authors [9,10] were thus eliminated. The volume of the gas collected after 24 h was measured with a graduate scale established on each collector to calculate the daily biogas production rate. The reading of the biogas volume had an estimated accuracy of 6%.

The measurements of biogas production were done three times a month for one year. The four gas collectors were placed on the pond water surface at different locations, according to the bathymetry of sludge, in order to obtain an estimate of biogas production: two collectors in the middle (B and C), one near the entrance (A) and another near the outlet (D). Sludge distribution in the anaerobic pond and locations of biogas collectors are shown in Fig. 2. All biogas

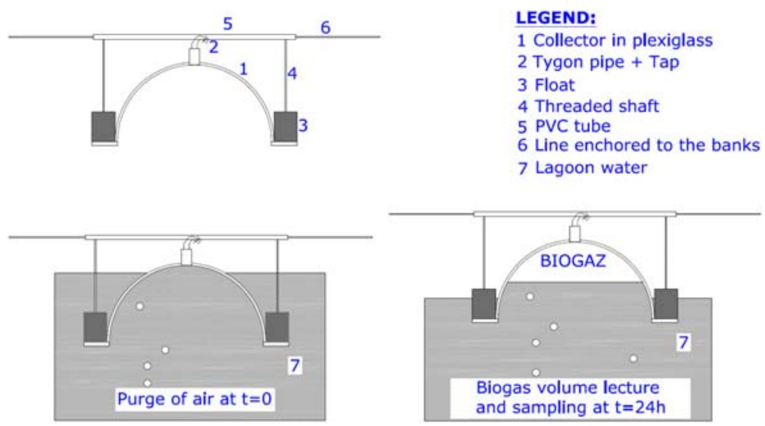


Fig. 1. Schematic view of the biogas collector.

production data were corrected to temperature 20˚C and pressure $10^5$ Pa.

The biogas from the collector was sampled in a *tedlar* bag and transported to the laboratory for analysis. The composition of the biogas in terms of $CH_4$, $CO_2$, $O_2$, $N_2$ and $H_2$ was determined using a micro-gas chromatograph (Micro-GC) type *Varian* 490-GC equipped with a thermal conductivity detector (TCD). The biogas analyser consists of a dual channel including a 10 m Molecular Sieve 5A PLOT (channel 1) with argon as a carrier gas and a 10 m PoraPLOT Q column channel (channel 2) with helium as carrier gas. The sample was pumped from a *tedlar* sampling bag through a sample line onto the adsorption tube with a sampling time of 30 s. The adsorption tube was set in "back flush" mode, and the "desorbed" sample components flow through a transfer line to the Micro-GC. The temperatures of the two columns were respectively 130˚C for the channel 1 and 60˚C for the channel 2. $CH_4$, $O_2$, $N_2$ and $H_2$ were analysed on channel 1 and $CO_2$ on channel 2. The gas analyser was calibrated with certified standard gases. Each biogas sample was analysed in triplicate. $H_2S$ concentrations were determined by bubbling the biogas in a solution of zinc acetate 0.1 M with the precipitated sulphide analysed according to Standard Methods [7].

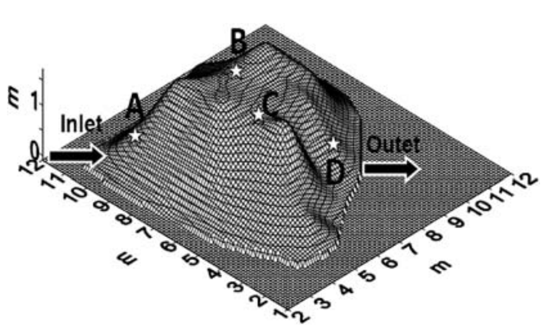


Fig. 2. Sludge distribution in the anaerobic pond and location of biogas collectors (A–D) (view in reverse).

Statistical analyses were done with XLSTAT software (v 2011 for windows). An ANOVA with Tukey's test was used to test significant differences between the 4 locations of biogas collectors in terms of biogas production at a significance level of $\alpha = 0.05$.

## 3. Results and discussion

### 3.1. Characteristics of influent and effluent, and removal efficiencies

Mean and standard deviation of influent and effluent characteristics for the anaerobic pond for 6.5 years of operation are listed in Table 1. The variation in some indicators between the raw influent and effluent reflects the anaerobic activity that occurred in the pond. Indeed, the effluent pH values were in general found lower than those of the influent values. The neutral pH at the effluent pond suggests that methanogenesis was occurring. Moreover, the increase in alkalinity in the effluent pond is indicative of bicarbonate production, and the increase in VFA as the end-product of anaerobic activity [11]. The decrease in sulphate and the increase in sulphide resulting from reduction of sulphate by sulphate-reducing bacteria were other indicators of anaerobic degradation in the pond [11,12]. The ammonia nitrogen concentration in the pond effluent was higher than that in the pond influent since ammonia nitrogen was released during the anaerobic breakdown of wastewater solids [13]. Moreover, the characteristics of the raw wastewater with regard to the ratio $COD/BOD_5 = 1.4$ showed that it was a domestic wastewater easily biodegradable [14].

Table 1
Influent and effluent characteristics of the anaerobic pond

| Parameter | Raw wastewater | | Effluent | | Number of samples |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| Temperature (°C) | 29.6 | 2.6 | 29 | 2.5 | 213 |
| pH | 7.5 | 0.5 | 6.9 | 0.3 | 213 |
| SS ($mg\,L^{-1}$) | 268 | 102 | 107 | 23.7 | 213 |
| VSS ($mg\,L^{-1}$) | 227 | 85 | 76 | 12 | 213 |
| COD ($mg\,L^{-1}$) | 583 | 175 | 228 | 91 | 213 |
| Dissolved COD ($mg\,L^{-1}$) | 198 | 65 | 99 | 50 | 213 |
| $BOD_5$ ($mg\,L^{-1}$) | 426 | 136 | 190 | 39 | 205 |
| Dissolved $BOD_5$ ($mg\,L^{-1}$) | 95 | 18 | 46 | 18 | 205 |
| Alkalinity ($mg\,CaCO_3\,L^{-1}$) | 321 | 59 | 452 | 68 | 104 |
| VFA ($mg\,ac.ac.\,L^{-1}$) | 65 | 22 | 120 | 18 | 104 |
| Sulphate ($mg\,S\text{-}SO_4\,L^{-1}$) | 23.6 | 2.1 | 6.1 | 4.6 | 48 |
| Sulphide ($mg\,S\,L^{-1}$) | 0.04 | 0.03 | 4.64 | 4.6 | 48 |
| Ammonia ($mg\,L^{-1}$) | 37.3 | 11 | 45.4 | 13.8 | 48 |
| Kjeldahl nitrogen ($mg\,N\,L^{-1}$) | 47.5 | 20.4 | 45.6 | 20.5 | 48 |

The average volumetric organic loading was calculated to be $205\,g\,BOD_5\,m^{-3}\,d^{-1}$ during the overall operating period of the anaerobic pond (365 PE). The mean removal efficiencies were 62.7% for COD, 57% for BOD, 53.5% for SS and 67% for VSS. The $BOD_5$ removal efficiencies were found slightly lower than reported literature values of 60–80% expected for AP in a tropical, warm-temperature climate condition such as Burkina [15]. This low performance is explained by the accumulation of sludge during continuous operation for more than six years. The sludge accumulation was estimated to be $41.3\,m^3$ in the AP, which reduced the hydraulic retention time from 3 to 2 days and impacted the performance of the pond [16].

### 3.2. Biogas production

The composition of biogas collected during the one-year monitoring period (144 samples) had an average composition by volume (as shown in Fig. 3) of 80.5% ± 1.4 methane (minimum 77.8%, maximum 82.4%), 11.8% ± 0.7 nitrogen (minimum 11.2%, maximum 13.6%), 5% ± 1.5 oxygen (minimum 2.2%, maximum 7.1%), 2.5% ± 0.9 carbon dioxide (minimum 1.4%, maximum 4.4%) and 0.2% of other gases ($H_2$, $H_2S$, etc.).

The values of methane content found in this study were in line with the findings of several authors, 83% methane in biogas from an anaerobic pond treating domestic wastewater in Mediterranean climatic conditions [2], 80% of methane in biogas from the AP covered with HDPE membranes in the Melbourne WSP system [17]. In comparison with a study done under the same climatic conditions on a full scale anaerobic pond (Kossodo WSP) treating the municipal wastewater of Ouagadougou, the biogas composition found in this study in terms of methane, nitrogen and carbon dioxide was similar to the municipal system; the dissolved oxygen content of 5%, however, was much higher than the value of less than 1% found in the municipal anaerobic pond [18]. The presence of oxygen in biogas could be explained by the wind-induced vertical mixing and wastewater flow rate that can deal the dissolution of atmospheric oxygen in the slightly aerobic surface water [19,20]. Moreover, the presence of oxygen in biogas collected during this research could also be related to the photosynthetic activity of algae that appeared on the anaerobic pond

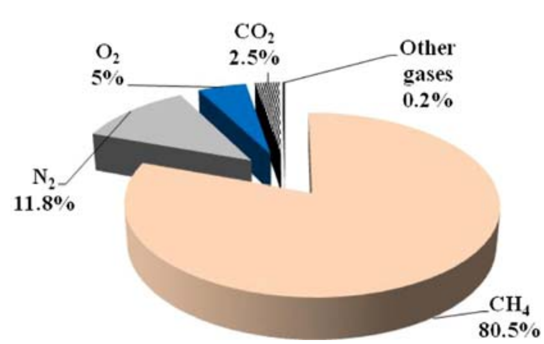

Fig. 3. Average composition of the biogas from 2iE anaerobic pond ($n = 144$).

during the holiday and rainy season where the pond operated with low organic loading rate and the crumbling of the sludge crust by rain allowing the development of aerobic zone at the surface layer of the pond. The percentage of $CO_2$ and $N_2$ found in the biogas of this study was similar to those reported by several authors [2,19]. The composition of biogas emanating from the bottom sludge in waste ponds is high in methane and nitrogen gas, low in carbon dioxide in contrast to the composition of biogas produced in separate sludge digesters which is typically 30–35% $CO_2$ and less than 5% $N_2$. As the biogas emerges through the overlying water column, $CO_2$ is converted to bicarbonate alkalinity [20].

Daily areal biogas production at locations A–D is shown in Fig. 4 in a box and whisker plot. At location A, situated near the entrance area, the mean rate recorded was $110\,L\,m^{-2}\,d^{-1}$ (minimum 21, maximum 222). In the middle area, the mean rate of biogas production recorded was $188\,L\,m^{-2}\,d^{-1}$ (minimum 89, maximum 322) at location B and $183\,L\,m^{-2}\,d^{-1}$ (minimum 87, maximum 288) at location C. At location D situated near the outlet, it was recorded at $99\,L\,m^{-2}\,d^{-1}$ (minimum 20, maximum 210). In order to find significant differences between the locations related to the rates of biogas production, an ANOVA test was carried out ($\alpha = 0.05$). The biogas production rates in the middle areas (B and C) were significantly higher than those in the inlet area (A) and outlet area (D) ($t$-test; $p < 0.0001$). However, there were no significant differences between the rate production in locations A and D ($t$-test; $p = 0.867$). Likewise, there were also no significant differences in biogas production rates between the locations B and C ($t$-test; $p = 0.989$).

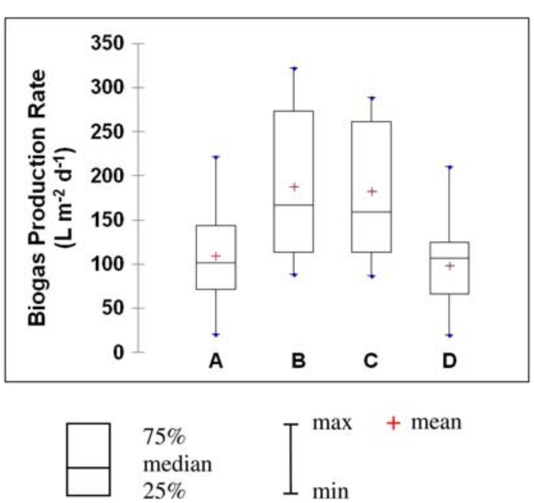


Fig. 4. Box and whisker plots of areal biogas production rates at locations A–D.

The mean biogas production rate in the middle of the anaerobic pond was calculated to be $185.6\,L\,m^{-2}\,d^{-1}$ (minimum 88, maximum 303). The high rate of biogas production in the middle area was in line with the significant biogas bubbling observed during the monitoring periods. It is concluded that sludge accumulation and distribution in the pond explain the differences observed between the rates of biogas production at the four locations within the anaerobic pond. We attribute the high production rates of biogas in the middle area to the greater accumulation of sludge.

This spatial evolution of biogas production rates in the anaerobic pond of 2iE contrasts with that observed in a similar study on full-scale municipal anaerobic pond in Ouagadougou [18]. The differences observed are due to the sludge distribution in ponds. Indeed, in the case of the full-scale anaerobic pond, which is configured as a rectangular geometric form, the maximum sludge accumulation was found near the inlet, while the anaerobic pond in this research, configured in a vertical geometric form of a truncated cone, favoured maximum accumulation of sludge in the middle area (Fig. 2).

The annual time series of the biogas production rates at the four locations of measurement (A, B, C and D) and the pond water temperature during the one-year monitoring period are shown in Fig. 5. Considering the pond water temperature variation from 22.3℃ in the cold period to 32.4℃ in the warm period, with an average of 28℃, it can be concluded that the anaerobic pond operated in mesophilic conditions. The high production rates were recorded during the warm period (March to May 2010) with an average pond water temperature of 31.5℃; a decrease in biogas production rate occurred during the rainy season (June to September 2010). This decrease can be explained by the dilution effect of the rainwater entering the pond and also by the low organic loading rate

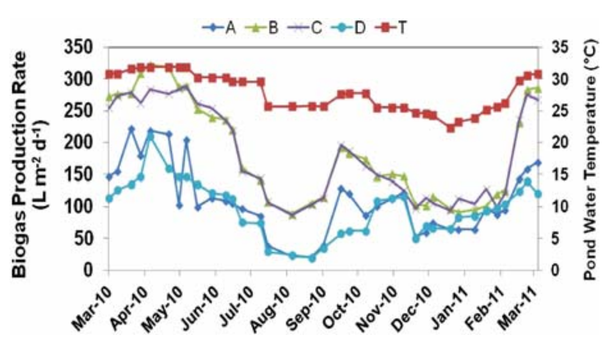


Fig. 5. Time series of biogas production rates at locations A–D.

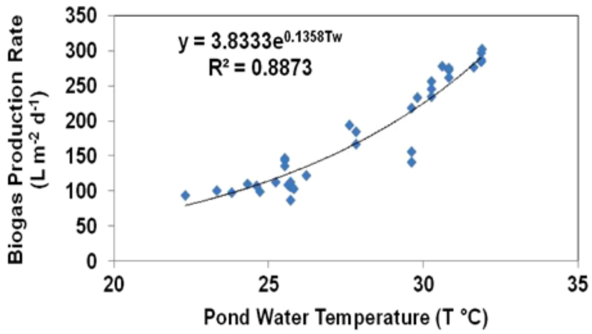


Fig. 6. Biogas production vs. pond water temperature.

in this period corresponding to the holiday period on the 2iE campus. A slight increase in the rate of biogas production in the month of October 2010 was characterized by a warming period (27.8°C). The lower production rate occurred during the dry, cold period (November 2010 to February 2011) with an average pond water temperature of 24.6°C. The variation in the biogas production rate is in line with the fact that it is influenced by the organic loading rate and water temperature [21] in addition to other environmental parameters such as rain effects.

Measurements of the biogas production rates ($R_{\text{biogas}}$ in $\text{L}\,\text{m}^{-2}\,\text{d}^{-1}$) were correlated (i) with the pond water temperature ($T_w$ in °C) with exponential Eq. (1) (Fig. 6), and (ii) with the monthly ambient air temperature ($T_a$ in °C) with exponential Eq. (2) based on the mean biogas production rates recorded at the middle of the pond (locations B and C).

$$R_{\text{biogas}} = 3.8333 \times e^{0.1358 T_w} (r^2 = 0.8873; n = 36) \quad (1)$$

$$R_{\text{biogas}} = 2.7515 \times e^{0.1398 T_a} (r^2 = 0.858; n = 36) \quad (2)$$

Similar temperature dependence was reported by several authors in Portugal [11], in France [2] and in Burkina Faso [18]. These relationships result from the sensitivty of methanogenic archaea whose activity decreases at low temperature [2].

Taking into account the geometric form of the 2iE anaerobic pond and the distribution of sludge, we have determined a surface called "active surface area" where the production of biogas is very significant. The active surface area of biogas production was determined to be 47.5 $\text{m}^2$, of which 19 $\text{m}^2$ at the inlet and outlet area and 9.5 $\text{m}^2$ at the middle area of the pond. The average annual biogas production and its methane content were calculated considering the specific production of gas in each location of measurement, multiplied by the corresponding area. On this

Table 2
Mean and standard deviation (SD) of biogas production rates from experimental anaerobic pond at 2iE WSP plant (March 2010–2011)

| Biogas production rates | Mean | Min | Max | SD | *n* |
|---|---|---|---|---|---|
| Areal biogas production rate ($\text{L}\,\text{m}^{-2}\,\text{d}^{-1}$) | 121 | 36 | 212 | 57 | 36 |
| Biogas production rate ($\text{L}\,\text{kg}^{-1}$ COD added) | 192 | 57 | 370 | 81 | 36 |
| Biogas production rate ($\text{L}\,\text{kg}^{-1}$ $BOD_5$ added) | 262 | 78 | 504 | 110 | 36 |
| Biogas production rate ($\text{L}\,\text{kg}^{-1}$ VSS added) | 488 | 146 | 940 | 206 | 36 |
| Biogas production rate ($\text{L}\,\text{kg}^{-1}$ COD removed) | 307 | 92 | 590 | 129 | 36 |
| Biogas production rate ($\text{L}\,\text{kg}^{-1}$ $BOD_5$ removed) | 459 | 137 | 882 | 193 | 36 |
| Biogas production rate ($\text{L}\,\text{kg}^{-1}$ VSS removed) | 728 | 217 | 1,400 | 307 | 36 |

Table 3
Mean and SD of methane production rates from experimental anaerobic pond at 2iE WSP plant (March 2010–2011)

| Methane production rates | Mean | Min | Max | SD | *n* |
|---|---|---|---|---|---|
| Areal methane production rate ($\text{L}\,\text{m}^{-2}\,\text{d}^{-1}$) | 97 | 28 | 0.189 | 41 | 36 |
| Methane production rate ($\text{L}\,\text{kg}^{-1}$ COD added) | 155 | 45 | 302 | 66 | 36 |
| Methane production rate ($\text{L}\,\text{kg}^{-1}$ $BOD_5$ added) | 212 | 61 | 411 | 90 | 36 |
| Methane production rate ($\text{L}\,\text{kg}^{-1}$ VSS added) | 395 | 114 | 367 | 168 | 36 |
| Methane production rate ($\text{L}\,\text{kg}^{-1}$ COD removed) | 248 | 72 | 481 | 105 | 36 |
| Methane production rate ($\text{L}\,\text{kg}^{-1}$ $BOD_5$ removed) | 371 | 107 | 720 | 157 | 36 |
| Methane production rate ($\text{L}\,\text{kg}^{-1}$ VSS removed) | 588 | 170 | 1,142 | 250 | 36 |

Table 4
Biogas production in anaerobic pond from this research compared to those reported in the literature

| Waste type | Reactor type | Loading rate | | | HRT | Temperature | | Biogas | | Methane rate | | | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $kg\,COD\,m^{-3}\,d^{-1}$ | $kg\,BOD\,m^{-3}\,d^{-1}$ | $kg\,VSS\,m^{-3}\,d^{-1}$ | day | Air (°C) | Pond (°C) | $L\,m^{-2}\,d^{-1}$ | $\%CH_4$ | $L\,m^{-2}\,d^{-1}$ | $L\,kg^{-1}$ CODa | $L\,kg^{-1}$ BODa | $L\,kg^{-1}$ VSSa | $L\,kg^{-1}$ CODr | $L\,kg^{-1}$ BODr | $L\,kg^{-1}$ VSSr | |
| Domestic | AP | 0.187 | 0.139 | 0.076 | 1.5 | 24.8–33.6 | 22–32 | 121 | 80.5 | 97 | 155 | 212 | 395 | 248 | 371 | 588 | This research |
| Domestic | AP | 0.376 | 0.237 | 0.066 | 6.5 | 24.8–33.6 | 22–32 | 103 | 78.5 | 81 | 74 | 119 | 419 | 115 | 185 | 619 | [18] |
| Domestic | AP | 0.118 | 0.083 | 0.043 | 4.6 | 6.0–24 | NA | 49 | 83 | 41 | 107 | 158 | 305 | NA | 526 | 551 | [2] |
| Domestic | AP | NA | 0.17 | NA | 5.07 | 17–25 | NA | 45 | 71 | 31 | NA | NA | NA | 145 | NA | NA | [11] |
| Domestic | AP | NA | 0.043 | 0.032 | 6.3 | NA | 20 | NA | 86 | NA | NA | NA | 200 | NA | NA | NA | [20,23] |
| Dairy | AP | NA | 0.010 | 0.017 | 118 | 2.0–27 | 8.0–22 | 30 | 80.3 | 23 | NA | 900 | 540 | NA | 1.110 | 690 | [24] |
| Piggery | AP | NA | 0.300 | 0.150 | 36 | 2.0–27 | 9.0–23 | 780 | 72 | 530 | NA | 460 | 810 | NA | 730 | 1.050 | [24] |
| Domestic | TSUAR | 0.76 | NA | NA | 2 | 14–24 | NA | NA | 77 | NA | NA | NA | NA | 250 | NA | NA | [25] |
| Manure | CAP | NA | NA | 0.0125 | 343 | 13.5 | NA | NA | 66.7 | NA | NA | NA | 263 | NA | NA | NA | [13] |

HRT = Hydraulic retention time; NA = not available.

basis, the mean areal biogas production rate was $121\,L\,m^{-2}\,d^{-1}$ (ranging from 36 to 212) and the areal methane production rate was $97\,L\,m^{-2}\,d^{-1}$ (ranging from 28 to 189). Biogas and methane conversion ratios are summarized respectively in Tables 2 and 3.

The results obtained in this study (mean values) are compared to those reported in the literature (Table 4). The mean of biogas production rate ($121\,L\,m^{-2}\,d^{-1}$) in this study was two and half times higher than the rate of 49 and $45\,L\,m^{-2}\,d^{-1}$, respectively reported from full-scale anaerobic ponds both treating domestic wastewater under Mediterranean climatic conditions [2,11]. Likewise, the average methane production rate of $97\,L\,m^{-2}\,d^{-1}$ was higher than the values of 41 and $31\,L\,m^{-2}\,d^{-1}$ measured under Mediterranean climatic conditions [2,11] and the value of $49\,L\,m^{-2}\,d^{-1}$ measured in Columbia under tropical climatic conditions [22].

The methane production rates based on organic loading are higher than the values reported under Mediterranean climatic conditions [2,11] and in California [20,23]. The differences observed could be explained by the warmer conditions prevailing in the Sahelian climatic region, increasing the rate of anaerobic digestion within the pond. In comparison with the study on biogas and methane production in a municipal anaerobic pond under the same climatic conditions [18], it appears that the production rates based on COD and BOD added or removed found in the pond of 2iE (treating only domestic wastewater) were higher than the results obtained on anaerobic pond treating municipal wastewater (industrial wastewater in addition to domestic), while the rates based on VSS added or removed were similar.

From the average quality of biogas (with 80.5% for methane content), the mean annual emission of methane from the 2iE anaerobic pond was $4.63\,m^3\,CH_4\,d^{-1}$ equivalent to $7.3\,m^3$ $CH_4$ per capita-year, two times higher than the value of $3.3\,m^3$ $CH_4$ per capita-year found from an anaerobic pond operating under Mediterranean climatic conditions [2]. These results demonstrate the efficiency of anaerobic digestion in the Sudano-Sahelian climate. There is a great potential for the sustainable application of anaerobic wastewater treatment if efforts could be made to capture and reuse the biogas to generate electricity that could be sold; there is also potential to sell carbon credits to help finance other sanitation projects.

## 4. Conclusions

One-year monitoring of biogas production in an anaerobic pond treating domestic wastewater under the Sudano-Sahelian climate of Burkina Faso showed the following:

- The biogas production is high with a high content of methane (averaged at 80.5%).
- The warm conditions that prevailed in the Sahelian climate favour the production of the biogas with high rates averaged to $121\,L\,m^{-2}\,d^{-1}$ for areal biogas production and $97\,L\,m^{-2}\,d^{-1}$ for areal methane production.
- Biogas production is positively correlated with monthly ambient air and pond water temperatures by two exponential equations useful for designers to predict biogas production in AP.
- The annual mean methane production rate was $248\,L\,kg^{-1}\,COD_{removed}$ and $588\,L\,kg^{-1}\,VSS_{removed}$.

It can be stated that anaerobic wastewater treatment could constitute a viable option in Sahelian countries considering their advantageous climatic conditions. Biogas capture and reuse would increase the economic feasibility of sanitation projects through electricity generation from biogas and the marketing of carbon credits.

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