INVESTIGATION OF THE PURIFICATION OF BIOGAS FROM DOMESTIC WASTES USING LOCAL MATERIALS IN NIGERIA

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Abstract: Purification of biogas from domestic wastes using local materials in Nigeria was investigated. A cylindrical filter made with transparent polyethenes outer casing was loaded with 250g of local materials separated and supported with local sponge to remove water vapour, carbon dioxide and hydrogen sulphide. A second filter which served as control set up was loaded with 250g standard reagents comprising of iron fillings and quicklime. The local materials used comprised of charcoal, potash, clay, iron ore and zeolite. The results obtained were analyzed for percentage composition of biogas and the activeness of the local materials. The results showed an improvement in methane from 68.05% to 73.88% with zeolite, 69.08% to 69.68% with Iron ore, 68.85% to 74.89% with charcoal, 68.88% to 76.08% with potash, and 69.05% to 71.13% with clay and 68.96% to 82.37% when all the local materials were used at the same time.

Keywords: Domestic wastes, Purification, Biogas, Percentage composition and Nigeria

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1. INTRODUCTION

The demand for energy in Nigeria is growing by the day. According to Africa Progress Report (2015), Nigeria has a human population estimated at 170 million and 95 million of the population relies on wood, charcoal and straw for energy. The need for exploring and exploiting new sources of energy which are renewable as well as environmental friendly cannot be overemphasized. Biogas technology offers an attractive platform to utilize certain categories of biomass for meeting our energy needs if it is properly harnessed (Adelekan and Adelekan, 2004; Bande, 2004). In Nigeria, various cellulosic biomasses (kitchen organic domestic wastes, cattle dung, agricultural waste etc.) are readily available and can be utilized in the production of biogas (Ofoefule and Uzodinma, 2009; Ebunilo et al., 2015). Biogas is comprised of methane (CH_4, about 45-75% by volume), carbon dioxide (CO_2, 25-55%), and other compounds including hydrogen sulphide (H_2S, present in concentrations from several hundred to a couple of thousand parts per million), water, and other trace gas compounds (Ayoub 2002). Methane is a powerful greenhouse gas if emitted into the atmosphere, but can also represent a valuable renewable energy source, with the potential to reduce greenhouse gas emissions when it is collected and substituted for fossil fuels. Biogas can be used directly to generate power, cook, etc., but the large volume of CO_2 produced with it reduces the heating value of the gas, increases compression and

transportation costs and limits economic usability (Kim, et al. 2004). Purification allows for a wider variety of uses, either for heat and electricity, or for vehicle fuels. For use as a fuel, purification to remove carbon dioxide (CO_2) and hydrogen sulphide (H_2S) is required, because H_2S corrodes vital mechanical components within engine generator sets and vehicle if it is not removed (Yuan and Bandosz, 2007). On the other hand, removing CO_2 increases the heating value and leads to a consistent gas quality, similar to natural gas (Appels et al., 2008). Although the hydrogen sulphide is present in small quantities in the biogas, the presence of H_2S usually prohibits the direct use of these gases because of its toxic properties, the formation of SO_2 upon combustion (acid rain), and the problems it (usually) gives in downstream processing (Maat et al., 2005). Beside, hydrogen sulphide is frequently encountered in the field of odour monitoring because of its high odorous power (Zaouak et al., 2012). The type and the amount of pollutants depend upon the biogas source and determine which cleaning and upgrading techniques are the most suitable for gas purification (Gamba and Pellegrini, 2013). Purified biogas provides reductions in GHG emissions as well as several other environmental benefits when used as a cooking fuel, vehicle fuel, lightening fuel etc. Hence there is need for proper purification of biogas. This research work is aim at the purification of biogas from domestic wastes using available local materials in Nigeria.

MATERIALS AND METHODS

MATERIALS

The following materials were used in this research work: Biogas gas mild steel digester with temperature and pressure gauge attached, gas chromatography analyzer, zeolite-$Na_{12}(Al_{12}Si_{12}O_{48}).27H_2O$, biomass (domestic wastes), montmorillonite clay $(Na,Ca)0.33(Al,Mg)2(Si_4O_{10})(OH)_2.nH_2O$, Iron ore/Haematite ($Fe_2O_3$), potash ($K_2CO_3$), quicklime (CaO), charcoal (C), Iron fillings (Fe), weighing scale, manual compressor, homemade scrubber with plastic, gas bottle, rubber hose. The quantity of local materials and control set up (i.e. Iron oxide and quicklime) were 250g each.

METHOD

The method involves removal of non-biodegradable materials from the biodegradable biomass. The biomass was reduced to smaller sizes by cutting it with knife. The biomass was mixed with water in a ratio of 1:2. The slurry in the digester was continuous stirred and left for anaerobic digestion to take place. The pressure gauge was continuously monitored for the production of biogas and flame test was immediately carried out once the pressure gauge indicates an increase. Formation of blue flame is a confirmation of proper production of biogas. At this stage the biogas produced is

evacuated for purification with local materials and control set up filter. The manual compressor is used to compress the

biogas for analysis.

RESULTS AND DISCUSSION

RESULTS

2Kg of biogas was evacuated for gas analysis to know the percentage composition of the constituents of biogas present.

0.5kg of biogas purified with local materials, control set up (quicklime and iron fillings) and raw biogas were analyzed

four times (separately for methane, carbon (IV) oxide, hydrogen sulphide and water vapour) for each quantity of biogas

evacuated. Same quantity of local materials and control setup reagents (250g) were used. This was done for all the

samples of local materials used in this research work. Table 1 show the results obtained with testing with sample A

while Table 2 shows the comparative analysis of average percentage (%) composition of methane (CH_4) after

purification with Sample A (Zeolite).

Table 1: RESULT OF TESTING WITH SAMPLE A

PERCENTAGE COMPOSITION OF BIOGAS FOR RAW BIOGAS AND PURIFIED BIOGAS												
TEST	BIOGAS MASS (kg)	RAW BIOGAS				BIOGAS PURIFIED WITH CONTROL SET UP				BIOGAS PURIFIELD WITH ZEOLITE			
		CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O
1	0.5	68.05	30.99	0.68	0.28	88.70	11.30	0.00	0.00	73.89	25.38	0.68	0.05
2	0.5	68.05	30.99	0.68	0.28	88.71	11.29	0.00	0.00	73.55	25.73	0.68	0.04
3	0.5	68.05	30.99	0.68	0.28	88.69	11.31	0.00	0.00	74.05	25.22	0.68	0.05
4	0.5	68.05	30.99	0.68	0.28	88.73	11.27	0.00	0.00	74.01	25.27	0.68	0.04

Table 2: Comparative analysis of average percentage (%) composition of methane (CH_4) after purification of Sample A

S/N	M_R	Mc	M_L	D_{CO2}	D_{H2O}
1	68.05	88.70	73.89	5.61	0.23
2	68.05	88.71	73.55	5.26	0.24
3	68.05	88.69	74.05	5.77	0.23
4	68.05	88.73	74.01	5.72	0.24
$\Sigma n=4$	$\Sigma X_R=272.20$	$\Sigma X_C=354.83$	$\Sigma X_L=295.50$	$\Sigma D_{CO2}=22.36$	$\Sigma D_{H2O}=0.94$
	A=68.05	A=88.71	A=73.88	A=5.59	A=0.235

Where;

D_{CO2} = Raw CO_2 – Purified CO_2 with local material= Quantity of CO_2 removed

D_{H2O} = Raw H_2O – Purified H_2O with local material = Quantity of H_2O removed

D_{H2S} = Raw H_2S – Purified H_2S with local material = Quantity of H_2S removed

n= Numbers of purification

Mc= Biogas purified with control set up

M_L= Biogas purified with local materials

M_R= Raw biogas

A= Average

But;

A= $\Sigma X/n$...4.1

Table 3 show the results obtained with testing with sample B while Table 4 show the comparative analysis of average

percentage (%) composition of methane (CH_4) after purification with Sample B (Iron ore-Haematite)

Table 3: RESULTS OF TESTING WITH SAMPLE B

PERCENTAGE COMPOSITION OF BIOGAS FOR RAW BIOGAS AND PURIFIED BIOGAS												
TEST	BIOGAS MASS (kg)	RAW BIOGAS				BIOGAS PURIFIED WITH CONTROL SET UP				BIOGAS PURIFIELD WITH IRON ORE-HAEMATITE			
		CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O
1	0.5	69.08	30.01	0.65	0.26	88.80	11.20	0.00	0.00	69.69	30.01	0.04	0.26
2	0.5	69.08	30.01	0.65	0.26	88.50	11.50	0.00	0.00	69.68	30.01	0.05	0.26
3	0.5	69.08	30.01	0.65	0.26	88.75	11.25	0.00	0.00	69.69	30.01	0.04	0.26
4	0.5	69.08	30.01	0.65	0.26	88.82	11.18	0.00	0.00	69.67	30.01	0.06	0.26

Table 4: Comparative analysis of average percentage (%) composition of methane (CH_4) after purification with Sample B

S/N	M_R	M_C	M_L	D_{H2S}
1	69.08	88.80	69.69	0.61
2	69.08	88.50	69.68	0.60
3	69.08	88.75	69.69	0.61
4	69.08	88.82	69.67	0.59
$\Sigma n=4$	$\Sigma X_R=276.32$	$\Sigma X_C=354.87$	$\Sigma X_L=278.73$	$\Sigma D_{H2S}=2.41$
	A=69.08	A=88.72	A=69.68	A= 0.603

Table 5 show the results obtained with testing with sample C while Table 6 show the comparative analysis of average

percentage (%) composition of methane (CH_4) after purification with Sample C (Charcoal)

Table 5: RESULTS OF TESTING WITH SAMPLE C

PERCENTAGE COMPOSITION OF BIOGAS FOR RAW BIOGAS AND PURIFIED BIOGAS												
TEST	BIOGAS MASS (kg)	RAW BIOGAS				BIOGAS PURIFIED WITH CONTROL SET UP				BIOGAS PURIFIELD WITH CHARCOAL			
		CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O
1	0.5	68.85	30.20	0.66	0.29	85.20	14.80	0.00	0.00	74.67	25.00	0.04	0.29

2	0.5	68.85	30.20	0.66	0.29	86.85	13.15	0.00	0.00	75.23	24.45	0.03	0.29
3	0.5	68.85	30.20	0.66	0.29	86.90	13.10	0.00	0.00	74.82	24.85	0.04	0.29
4	0.5	68.85	30.20	0.66	0.29	87.05	12.95	0.00	0.00	74.79	24.90	0.02	0.29

Table 6: Comparative analysis of average percentage (%) composition of methane (CH_4) after purification with Sample C

S/N	M_R	M_C	M_L	D_{CO2}	D_{H2S}
1	68.85	85.20	74.67	5.20	0.62
2	68.85	86.85	75.23	5.75	0.63
3	68.85	86.90	74.82	5.35	0.62
4	68.85	87.05	74.79	5.30	0.64
$\Sigma n=4$	$\Sigma X_R=275.4$	$\Sigma X_C=346.0$	$\Sigma X_L=299.51$	$\Sigma D_{CO2}=21.60$	$\Sigma D_{H2S}=2.51$
	A=68.85	A=86.50	A=74.89	A= 5.40	A= 0.628

Table 7 show the results obtained with testing with sample D while Table 8 show the comparative analysis of average

percentage (%) composition of Methane (CH_4) after purification with Sample D (Potash)

Table 7: RESULTS OF TESTING WITH SAMPLE D

PERCENTAGE COMPOSITION OF BIOGAS FOR RAW BIOGAS AND PURIFIED BIOGAS													
TEST	BIOGAS MASS (kg)	RAW BIOGAS				BIOGAS PURIFIED WITH CONTROL SET UP				BIOGAS PURIFIELD WITH POTASH			
		CH_4	$C0_2$	H_2S	H_20	CH_4	CO_2	H_2S	H_20	CH_4	$C0_2$	H_2S	H_20
1	0.5	68.88	30.18	0.64	0.30	84.50	15.50	0.00	0.00	76.46	23.10	0.27	0.17
2	0.5	68.88	30.18	0.64	0.30	85.20	14.80	0.00	0.00	76.45	23.08	0.26	0.21
3	0.5	68.88	30.18	0.64	0.30	86.50	13.50	0.00	0.00	75.96	23.58	0.28	0.18
4	0.5	68.88	30.18	0.64	0.30	86.80	13.20	0.00	0.00	75.43	24.10	0.27	0.20

Table 8: Comparative analysis of average percentage (%) composition of methane   (CH_4) after purification with Sample D

S/N	M_R	M_C	M_L	D_{CO2}	D_{H2S}	D_{H2O}
1	68.88	84.50	76.46	7.08	0.37	0.13
2	68.88	85.20	76.45	7.10	0.38	0.09
3	68.88	86.50	75.96	6.60	0.36	0.12
4	68.88	86.80	75.43	6.08	0.37	0.10
$\Sigma n=4$	$\Sigma X_R=275.52$	$\Sigma X_C=343.0$	$\Sigma X_L=304.30$	$\Sigma D_{CO2}=26.86$	$\Sigma D_{H2S}=1.48$	$\Sigma D_{H2O}=0.44$
	A=68.88	A=85.75	A=76.08	A=6.72	A=0.37	A=0.11

Table 9 show the results obtained with testing with sample E (Clay) while Table 10 show the comparative analysis of

average percentage (%) composition of Methane (CH_4) after purification with Sample E (Clay)

Table 9: RESULTS OF TESTING WITH SAMPLE E

PERCENTAGE COMPOSITION OF BIOGAS FOR RAW BIOGAS AND PURIFIED BIOGAS												
TEST	BIOGAS MASS (kg)	RAW BIOGAS				BIOGAS PURIFIED WITH CONTROL SET UP				BIOGAS PURIFIELD WITH CLAY			
		CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O
1	0.5	69.05	30.00	0.66	0.29	88.60	11.40	0.00	0.00	70.70	28.55	0.66	0.09
2	0.5	69.05	30.00	0.66	0.29	88.50	11.50	0.00	0.00	71.62	27.65	0.66	0.07
3	0.5	69.05	30.00	0.66	0.29	88.85	11.15	0.00	0.00	70.91	28.35	0.66	0.08
4	0.5	69.05	30.00	0.66	0.29	88.70	11.30	0.00	0.00	71.29	27.95	0.66	0.10

Table 10: Comparative analysis of average percentage (%) composition of methane (CH_4) after purification with Sample E

S/N	M_R	M_C	M_L	D_{CO2}	D_{H2O}
1	69.05	88.60	70.70	1.45	0.20
2	69.05	88.50	71.62	2.53	0.22
3	69.05	88.85	70.91	1.65	0.21
4	69.05	88.70	71.29	2.05	0.19
$\Sigma n=4$	$\Sigma X_R=69.05$	$\Sigma X_C=354.65$	$\Sigma X_L=284.52$	$\Sigma D_{CO2}=7.68$	$\Sigma D_{H2O}=0.82$
	A=69.05	A=88.66	A=71.13	A=1.92	A=0.205

Table 11 show the results obtained with testing with sample F (potash, charcoal, clay, zeolite and Iron ore) while Table

12 show the comparative analysis of average percentage (%) composition of methane (CH_4) after purification with

Sample F (potash, charcoal, clay, zeolite and Iron ore).

Table 11: RESULTS OF TESTING WITH SAMPLE F

PERCENTAGE COMPOSITION OF BIOGAS FOR RAW BIOGAS AND PURIFIED BIOGAS												
TEST	BIOGAS MASS (kg)	RAW BIOGAS				BIOGAS PURIFIED WITH CONTROL SET UP				BIOGAS PURIFIELD WITH, POTASH, CHARCOAL, CLAY, ZEOLITE AND IRON ORE			
		CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O	CH_4	CO_2	H_2S	H_2O
1	0.5	68.96	30.08	0.67	0.29	88.05	14.95	0.00	0.00	82.42	17.53	0.02	0.03
2	0.5	68.96	30.08	0.67	0.29	87.85	13.50	0.00	0.00	81.90	18.08	0.01	0.01
3	0.5	68.96	30.08	0.67	0.29	88.98	11.50	0.00	0.00	82.20	17.79	0.00	0.01
4	0.5	68.96	30.08	0.67	0.29	88.94	11.10	0.00	0.00	82.95	17.05	0.00	0.00

Table 12: Comparative analysis of average percentage (%) composition of Methane after purification   with Sample H

S/N	M_R	Mc	M_L	D_{CO2}	D_{H2S}	D_{H2O}
1	68.96	88.05	82.42	12.55	0.65	0.26
2	68.96	87.85	81.90	12.00	0.66	0.28
3	68.96	88.98	82.20	12.29	0.67	0.28
4	68.96	88.94	82.95	13.03	0.67	0.29
$\Sigma n=4$	$\Sigma X_1=275.84$	$\Sigma X_1=353.82$	$\Sigma X_2=329.47$	$\Sigma D_{CO2}=49.87$	$\Sigma D_{H2S}=2.64$	$\Sigma D_{H2O}=1.11$
	A=68.96	A=88.46	A=82.37	A=12.47	A=0.663	A=0.28

DISCUSSION

Table 1 shows the results obtained when zeolite is used in the purification of biogas. The constituents of raw biogas, biogas purified with control set up (quicklime and iron fillings) and with zeolite as obtained is tabulated in Table 2. The results show that the constituent of hydrogen sulphide (H_2S) was constant though the percentage composition of methane (CH_4), carbon (1V) oxide (CO_2) and water vapour (H_2O) change. The constant in percentage composition of the hydrogen sulphide (H_2S) shows that zeolite was unable to purified hydrogen sulphide. Also, close observation of the raw biogas, biogas purified with zeolite and the sample of biogas purified with control set up show that there was a gradual increase in the percentage composition of methane. On the other hand, the percentage compositions of carbon dioxide and water were decreasing. The increase in the percentage composition of methane confirmed the removal of impurities from the biogas while the decrease in the compositions of carbon dioxide and water vapour confirms purifying ability of zeolite. This goes in line with the work of Kucic (2010). He reported that zeolite has the ability to absorbe carbon dioxide and water vapour. Comparative analysis of average percentage (%) composition of methane after purification with zeolite shows an improvement in percentage composition of methane from 68.05% to 73.88% and an average of 5.59% of carbon (1V) oxide (CO_2) and 0.235% of water vapour (H_2O) were removed (Table 2).

The result obtained using Iron ore (Haematite) in purification of biogas is shown in Table 3. The composition of methane gas (CH_4) and hydrogen sulphide (H_2S) gas were affected with the sample purified with Iron ore. The methane gas increases though the rate of increase is negligible and this has to do with the fact that the hydrogen sulphide (H_2S) only present in biogas as traces (Ayoub, 2002). There were no visible changes in the percentage composition of carbon dioxide (CO_2) and water vapour (H_2O) purified with Iron ore. The constant values of carbon dioxide (CO_2) and water vapour (H_2O) confirmed that Iron ore was unable to purify carbon dioxide (CO_2) and water vapour (H_2O). Comparative

analysis of average percentage (%) composition of methane after purification with Iron ore shows slight improvement (i.e. 69.08%-69.68%) and an average of 0.603% of hydrogen sulphide (H_2S) was removed (Table 4).

The result obtained with charcoal is shown in Table 5. The improvement in the quantity of methane produced when compared to the quantity obtains after evacuation (raw biogas) implies that charcoal has the ability to purify biogas. On the other hand, the values of water vapour (H_2O) of the sample of biogas purified with charcoal and raw biogas were the same and that simply shows that charcoal was unable to remove water vapour (H_2O). A close look at the comparative analysis of average percentage (%) composition of methane after purification with Sample C showed an improvement in percentage composition of methane from 68.85% to 74.89% and an average of 0.628% of hydrogen sulphide (H_2S) and 5.40% of carbon (1V) oxide were removed (CO_2) (Table 6).

The purification ability of potash is tabulated in Table 7. The results obtained show that potash has the ability to purify biogas though the potency of it purification ability is highest in carbon dioxide when compare to hydrogen sulphide (H_2S) and water vapour (H_2O) respectively. This was responsible for the increase in the quantity of biogas obtained after purification since more of carbon dioxide was removed. Comparative analysis of average percentage (%) composition of methane after purification with potash showed improvement (i.e. 68.88%-79.08%) in percentage composition of methane and an average of 6.72% of carbon (1V) oxide (CO_2), 0.11% of water vapour (H_2O) and 0.37% of hydrogen sulphide (H_2O) were removed (Table 8). Comparison of results of raw biogas and biogas sample purified with clay (Table 9) confirmed slight change in the percentage composition of methane (CH_4), carbon (1V) dioxide (CO_2) and water vapour (H_2O). The change in the composition of biogas shows the purification ability of clay in carbon dioxide (CO_2) and water vapour (H_2O) hence the slight increase in the percentage composition of the methane. However the percentage composition of hydrogen sulphide (H_2S) remains unchanged. This implied that clay did not have the ability to purify hydrogen sulphide (H_2S). Comparative analysis of average percentage (%) composition of methane after purification with clay shows slight improvement (i.e. 69.05%-71.13%) in percentage composition of methane but this was lower than the percentage composition of sample of biogas purified by potash (i.e. 68.88%-76.08%: Table 8). In other word, potash has a better purifying ability than clay. An average of 1.92% of carbon (1V) oxide (CO_2) and 0.205% of water vapour (H_2O) were removed (Table 10).

Table 11 shown the results when all the local reagents were used together (i.e. zeolite, iron ore, charcoal, potash and clay). The quantity of methane generated after purification with the local materials was closed to the one obtained with

control set up. The comparative analysis of average percentage (%) composition of methane after purification shown that the percentage composition of methane obtained with control set up and local reagents were closed and an average of 12.47% of carbon (1V) oxide (CO_2), 0.28% of water vapour (H_2O) and 0.663% of hydrogen sulphide (H_2S) were removed (Table 12).

CONCLUSION

This study sets out to investigate the purification of biogas using local materials shows that impure biogas can be purified with potash, clay, iron ore, zeolite and charcoal. The results obtained show that zeolite, charcoal, potash and clay have the ability of removing carbon dioxide from biogas (CO_2). The analysis shows that water vapour (H_2O) in biogas can be removed with zeolite, potash and clay. Also, the hydrogen sulphide (H_2S) that has effect of forming acidic rain if not properly remove from biogas was removed with Iron ore and the result equally shows that potash can partially remove hydrogen sulphide (H_2S) though not as active as Iron ore. The percentage composition analysis of biogas before and after purification with zeolite shows an improvement of methane from 68.05% to 73.88% with zeolite, 69.08% to 69.68% with Iron ore, 68.85% to 74.89% with charcoal, 68.88% to 76.08% with potash, 69.05% to 71.13% with clay , 68.88% to 76.70% with Iron ore and potash used together, 68.58% to 79.54% with Iron ore, potash and charcoal used together and finally 68.96% to 82.37% with zeolite, potash, clay, charcoal and Iron ore all used together.

REFERENCES

Africa Progressive Report (2015). Business day: World Economic Forum (WEF), South Africa, Saturday 05, December, 2015

Adelekan B.A. and Adelekan, I.O. 2004. Health Implications of Household Energy Use in Selected Nigerian Towns, Nigerian Journal of Renewable Energy, Sokoto Energy Research Centre. Vol. 12, Nos. 1 & 2, 2004, pp 138-146

Appels L., Baeyens J., Degreve J., Dewil R. (2008). Principles and potential of the anaerobic digestion of waste-activated sludge, Progress in Energy and Combustion Sci., 772 – 777

Ayoub M. E. (2002). An Educational Biogas Prospect in Tolkarm, Msc thesis, supervisor Dr.Muneer Abdoh, Dr.Abdellatif Mohamed, Najah national University

Bande Y.M. (2004). Biogas production from sewage, a thesis submitted to post graduate school, Bayero University, Kano, pp 6-25

Ebunilo P.O., Aliu S.A., Orhorhoro E.K. (2015). Performance Study of a Biogas Pilot Using Domestic Wastes from Benin Metropolis; International Journal of Thermal & Environmental Engineering Volume 10, No. 2 (2015), 135-141

Gamba S., Pellegrini L. (2013). Biogas Upgrading: Analysis and Comparison between Water and Chemical Scrubbings, chemical Engineering Transactions, 32, 1273-1278, DOI: 10.3303/CET1332213

Kim S., Kim H.T. (2004). "Optimization of CO_2 absorption process with MEA solution." Carbon Dioxide Utilization for Global Sustainability 153: 429-434 Kohl, A. L., and Riesenfeld, F. C. (1979). Gas Purification, 3d ed. – Ed., Gulf Pub. Co., Book Division, Houston

Kucic D., Kopcic N., Cosic N., Vukovic M., Briski F. (2010). Sorption of exhaust gases, CO_2 and NH_3, during biodegradation of solid waste in reactor system. University of Zagreb, Faculty of Chemical Engineering and Technology, Department of Industrial Ecology, Marulicev trg 19, 10 000 Zagreb, Croatia

Maat H., Hogendoornb J.A., Versteeg G.F., (2005). The removal of hydrogen sulphide from gas streams using an aqueous metal sulphate absorbent. part 1. The absorption of hydrogen sulphide in metal sulfate solutions, separation and purification technology, 43, 183–197

Ofoefule A.U and Uzodinma E.O. Biogas production for blends of cassava (manihot utilissima) peels with some animal wastes. International Journal of Physical Sciences Vol.4 (7), pp. 398-402, 2009. Available online at http://www.academicjournals.org/IJPS.ISSN 1992-1950 (C), 2009 Academic Journals

Yuan W. X. and Bandosz T. J. (2007). Removal of Hydrogen Sulphide from Biogas on Sludge- Derived Adsorbents. Fuel, 86(17-18), 2736-2746

Zaouak O., Ben Daoud A., Fages M., Fanlo J.L. and Aubert B., (2012). High Performance Cost Effective Miniature Sensor for Continuous Network Monitoring of H2S, Chemical Engineering   Transactions, 30, 325-330, DOI: 10.3303/CET1230055