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An Automated Process to Compute Density of Unknown Liquid (Organic Slurry) Using Brine as a Prototype

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Abstract: Experiments were carried out to determine the relationship between density of liquid (pure water) and compression of five springs supporting a 1000 Liter tank from beneath. The tank is meant to be an anaerobic digester for production of biogas. The springs constant were determined and were used to compute the densities of a fixed concentration of two unknown liquids (that of a fixed concentration of salt and the other had varying concentration). Results show that each of the five springs had different spring constants ranging from 62,177N/m or Kg/s.s to 167,048N/m or Kg/s.s. The average density of the liquid with fixed concentration of salt is 1118.24Kg/cu.m which compares excellently well with the density of pure water (1000Kg/cu.m). The unknown liquid with varying concentration of salt follows an exponential relationship $Y=3E-05e^{42.67x}$ and a correlation of 0.97, where Y stands for density of the fluid and X the corresponding extension of the spring. We have used the expression to predict the density of similar water of unknown concentration. Since methane gas production potential depends on water dilution ratio, it is expected that we can calibrate any digester tank to give direct readings of densities of bio-degradable material from mere displacement of the suspension springs.

Keywords: Anaerobic, Bio-degradable, Biogas, Correlation, Density, Methane Gas

1. Introduction

The need for an alternative source of renewable energy arises as a result of detrimental environmental effect associated with the use of non-renewable energy such as coal and petroleum. In a developing country like Nigeria over 80% of its population live in rural communities linked with the problem of epileptic power supply. The remedy to a renewable energy source is biogas production [1]. Biogas is a biofuel, made from organic material produced by living things, in contrast to fossil fuels such as coal, petroleum, or natural gas that comes from long-dead plants and microorganism. Biofuel included any solid, liquid, or gaseous fuel produced either directly from plants or indirectly from organic industrial, commercial, domestic, or agricultural wastes. In principle, burning biofuels add less carbon to the environment than burning fossil fuels because the carbon atoms released by burning biofuel already existed as part of the modern carbon cycle. Burning fossil fuels, on the other hand, always add extra carbon because the carbon they contain comes from a buried source that was not part of the modern carbon cycle. Carbon dioxide is the main greenhouse gas thought to contribute to global warming. Biofuels are seen as one way to reduce the amount of carbon dioxide gas added to the atmosphere. Biofuels produced, and used within the same country are a way to reduce dependence on foreign sources of oil and other fuels, providing energy security and an economic boost for agriculture and industry.

Biogas is a gaseous fuel obtained from waste fermentation, which is of interest in producing energy for electricity, cooking, heating, and biofuel for vehicles [2, 3]. Many operators of bio-digesters in the rural area use cow and other poultry waste mixed with water for slurry but unfortunately

cannot produce methane gas. Mainly, the ratio of water to solid biomass (density of slurry) affects the gas production potentials in a bio-digester. Excess of water or insufficient water in the slurry will not produce methane gas. Some literatures specify about 70% water as optimum for gas production [4]. Reason need for automation. By automating the process, this will allow a good agitation of the slurry that is inside the digestion tank and is placed on five springs with known spring constants to compute the ratio of mass of the slurry to its volume of water.

This work is directed to assist biogas producers to optimize the density or mixing ratio of slurry before loading the digester.

1.1. The Need for Automation in Biogas Production

Climate change is one of the main environmental concerns of our time and significant attention is paid to the reduction and stabilization of the greenhouse gases concentration in the atmosphere. That can be achieved by the transfer from the fossil fuels to the renewable sources of energy, one of which is biofuel produced from biomass. Though, estimates of the biomass contribution to the future energy systems vary widely, importance of biomass as a sustainable energy source and significant increase of its use in the coming years is generally accepted [5, 6]. Biofuel Production is based on anaerobic conversion by microorganisms of complex organic substrates (i.e. cattle manure, food industry wastes, etc.) into the methane or ethanol, which are consequently used as energy sources. Anaerobic digestion is a complicated process depending upon a complex interaction between various groups of bacteria. A fine balance between these groups is necessary for successful digestion giving a large methane yield. The process conditions define the development of the digestion. In a situation of imbalance, an accumulation of hydrogen and other intermediates are likely to occur giving rise to inhibitions and metabolic shifts. Indeed, the entire process can stop totally if the imbalance is allowed to proceed. The following factors may lead to the process imbalance: hydraulic overloading, organic overloading, and the presence of inhibitory concentrations of toxic material in the reactor, e.g., heavy metals, ammonia, organic solvents, etc. several parameters are suggested to be important in the anaerobic digestion process including concentrations of hydrogen, carbon dioxide, methane, volatile fatty acids, ammonia, carbon/nitrogen ratio, pH and alkalinity. Established laboratory techniques such as HPLC, gas chromatography, etc. are capable of producing exhaustive information about media composition but analysis is often quite time-consuming, expensive, requires skilled personnel and hardly can be automated. Currently, chemical analysis of biomass from digesting tanks is performed in the laboratory few times a month and therefore gives no opportunity to correct the process. The principal means of controlling the biogas production process is still by feeding the reactor with appropriate type of raw material. Therefore, real time detection of the key substances in the biomass and monitoring of the changes in its compositions occurring during the process are paramount for the effective functioning of a digester. Analytical tools for the on-line process control remain relatively primitive up to date. It is worth nothing that lack of analytical instruments is a common problem for all biotechnological industry despite the fact that products worth billions of dollars are produced through fermentation processes annually. Lack of on-line sensors for the monitoring of the fermentation processes is commonly stressed [7, 8]. The only chemical parameters being routinely measured in the bioreactors are pH and pO_2 [9, 10]. Recently gas analyzers that may be used at-line for the detection of biogas (CO and CH_4), H_2, O_2 and CO_2 in the headspace of the bioreactor were suggested (Lema J. M., Punal A., Lorenzo A., Roca E., Hernandez C). Several analytical instruments were proposed for on-line monitoring of the fermentation processes and anaerobic digestion in particular. The most important are NIR spectroscopy and image-analysis. Both techniques are non-destructive, rapid and require no sample preparation, which make them quite attractive for the real-time process follow-up. Being non-contact techniques, both NIR and image analysis are devoid of such problems as contamination of the probe by broth compounds and sterilization. NIR spectroscopy is nowadays widely used in agricultural, food and pharmaceutical industries as quality control tool given those problems with instrumental drift and calibration stability are solved. Artificial vision or image analysis makes use of images collected using CCD or other type of camera. This is a new technique that has not yet been widely applied in the industry. Both NIR spectroscopy and image analysis require relatively complex statistical methods for the data processing and modeling especially in the case of image analysis. It should be noted that widely application of NIR in biotechnological industry is impeded by the complexity of analyzed media and the fact that only relatively high concentrations can be qualified using this technique [11, 12]. NIR and image analysis were demonstrated to be feasible for off-line and at-line monitoring of the anaerobic digestion process [13, 14]. One of the analytical instruments particularly suitable for the tasks of on-line or at-line process monitoring are chemical sensors. Not surprisingly, on-line probes that are used currently in bioreactors are chemical sensors, e.g., pH and pO_2 probes. Known advantages of the chemical sensors include the possibility to perform measurements in real time, easy automation of measurements and relative simplicity and low price of the required instrumentation [15]. However, practical application of the sensors for on-line measurements in bioreactors is limited by rather strict requirements that sensor should meet to be used for biotechnological process control. The common problems with on-line sensors are contamination and surface adsorption of organic matter from the reactor that lead to the drift or change of the response parameters (baseline and sensitivity). Furthermore, sensors should not require re- calibration for prolonged periods of time or re-calibration procedure should not compromise the process. Sensors should be able to measure substances of interest in the range of their variation during the process that

is to have adequate dynamic ranges and detection limits. Sensors should be able to endure sterilization procedure without deterioration of their performance. Sensors should possess sufficient selectivity towards measured substances to be capable of carrying out determination in the complex environment such as fermentation broth where several other compounds are present often in the high concentrations. Just a few of the commercially available sensors meet those stiff conditions and those are the ones already used in bioreactors as was described before. This work gives a short overview of system on chip array and discussed its application to the follow-up of the biotechnological process including biogas production.

1.2. Biogas Production Process

The present energy crisis in Nigeria is disturbing and needs a practical, affordable and sustainable solution. Kerosene as the major source of domestic fuel for cooking among the rural communities is sold at 423.42 Naira per litre, cooking gas sold at 8,400 Naira per 12kg cylinder and this is expensive since large number of people cannot afford it regularly.

The use of this designed biogas digester in Nigeria, will have an advantage over dependence on expensive fossil fuels, thereby contributing positively to the economy. Also, it reduces sanitation risks of rural organic wastes and minimizes the negative environmental impacts caused by the use of fossil fuels. The work seeks to examine the benefit and the possibility of an alternative source of energy (biogas) using automation process.

Anaerobic Digestion is a natural process and is the microbiological conversion of organic methane in the absence of oxygen. The decomposition is caused by natural bacterial action stages. It takes place in a variety of natural anaerobic environment, including water sediment logged soils, natural hot springs, ocean thermal vents and the stomach of various animals e.g. (cow). The digested organic matter resulting from anaerobic digestion process usually called digestate.

First Stage: The degradation of complex organic matter from the waste by Hydrolytic bacteria, to produce simpler molecule such as long chain fatty acid, short chain peptides, amino acids e.t.c.

Second Stage: Acid forming bacteria act on the simple molecules to form volatile fatty acids (mainly ethanoic acid), ketones, CO_2 e.t.c.

Third Stage: Methane forming bacteria act on the volatile acids to form methane CO_2 and trace gases such as H_2S.

2. Materials and Method

2.1. Materials

A 1000 liter mixing tank which also serves as the digester was suspended on springs recycled from the shock absorbers of automobiles. Five springs were used to support the weight of the tank when filled with substrate and also to facilitate mixing of the slurry (figure 1). Proper mixing with adequate water is necessary to get an even paste and to predict using pre-determined model for the slurry the densities of organic materials.

Figure 1. *Mixing tank suspended on five springs.*

The following materials were used in determining the densities: Pure water, A bag of salt (19kg), 1000 Liter tank, Spiral spring as the base stand for the digester tank, Meter rule (1m long), Displacement measure equipment using programmable system on chip. Basic concept of Hooke's law expression was used to determine the relationship between density and extension of the spring.

The initial data of the spring was taken without water (empty), using the base stand as the point of reference. The tank was loaded with 19kg of sodium chloride (salt) then filled with water from 0 liter up to 800 liters. The data for the varying concentration of salty water was taken as dilution progressed. Subsequently the data for fixed concentration of salty water was taken as the tank was off-loaded accordingly.

Table 1. *Volume (m^3) and extension (m) measurements using pure water as fluid.*

Vol. of Water m^3	Extension X_1(m)	X_2(m)	X_3(m)	X_4(m)	X_5(m)
0.8	0.0387	0.0515	0.1105	0.1105	0.1060
0.7	0.3278	0.0492	0.0.0560	0.0912	0.0872
0.6	0.3320	0.0440	0.0500	0.0757	0.0680
0.5	0.3385	0.0380	0.0450	0.0580	0.0510
0.4	0.3448	0.0312	0.0360	0.0445	0.0345
0.3	0.3515	0.0250	0.0285	0.0307	0.0192
0.2	0.3595	0.0170	0.0245	0.0170	0.0045
0.1	0.3620	0.0090	0.0130	0.0035	0.0030

Table 2. *Volume (m^3) and extension (m) measurements using fixed concentration of salty water.*

Vol. of water m^3	Extension X_1(m)	X_2(m)	X_3(m)	X_4(m)	X_5(m)
0.8	0.0550	0.0580	0.0780	0.1340	0.1380
0.7	0.0520	0.0540	0.0780	0.1150	0.1210
0.6	0.0470	0.0470	0.0670	0.0940	0.0680
0.5	0.0380	0.0390	0.0610	0.0760	0.1000
0.4	0.0310	0.0310	0.0540	0.0600	0.0800
0.3	0.0250	0.0250	0.0470	0.0450	0.0660
0.2	0.0170	0.0190	0.037	0.0320	0.0340
0.1	0.0080	0.010	0.0270	0.0150	0.0170

Table 3. *Volume (m^3) against extension (m) measurements using varying concentration of salty water.*

Vol. of water m3	Extension X_1(m)	X_2(m)	X_3(m)	X_4(m)	X_5(m)
0.1	0.0100	0.0110	0.0290	0.0170	0.0150
0.2	0.0170	0.0210	0.0380	0.0320	0.0310
0.3	0.0260	0.0280	0.0450	0.0440	0.0530
0.4	0.0360	0.0370	0.0540	0.0580	0.0640
0.5	0.0400	0.0430	0.0610	0.0760	0.0790
0.6	0.0460	0.0470	0.0670	0.0940	0.0960
0.7	0.0510	0.0530	0.0740	0.01150	0.1340
0.8	0.0550	0.0580	0.0780	0.01340	0.1380

2.2. Methodology

The steps used in order to compute the density of the unknown liquid are; determine all five spring constants K1 to K5 using fresh water. Measurement of volume (V_f) against extension (x) were collected. Using the known density of water $(1000kg/m^3)$ the volume is converted to mass of fresh water.

$$V_f \rho_f = M_f \quad (1)$$

$$V_f \rho_f g = F_f$$

Where, $x = extension$

$V_f = volume$ of fresh water

$M_f = mass$ of fresh water

$F_f = force$ exerted by fresh water

F_f is plotted against extension and the slope (F_f / x) is used to determine the spring constant. e.g. $K1 = slope = (F_f / x)$ in N/m or K_g / s^2.

Table 4. *Represent the data to determine the spring constant (K_1).*

Vol. of water cu.m	Mass of water=vol. of water * density of water Kg	Measured Length for X1 (m) M	Extension=initial length-final length M	Force = mg = mass of water*9.8 kg.m/s.s
0.8	800	0.3243	0.0387	7840
0.7	700	0.3278	0.0352	6860
0.6	600	0.3320	0.0310	5880
0.5	500	0.3385	0.0245	4900
0.4	400	0.3448	0.0182	3920
0.3	300	0.3515	0.0115	2940
0.2	200	0.3595	0.0035	1960
0.1	100	0.3620	0.0010	980

Table 5. *Represent the data to determine the spring constant (K_2).*

Vol. of water cu.m	Mass of water =vol. of water * density of water kg	Measured Length for X2 (m) M	Extension=initial length-final length m	Force = mg = mass of water*9.8 kg.m/s.s
0.8	800	0.3235	0.0515	7840
0.7	700	0.3258	0.0492	6860
0.6	600	0.3310	0.0440	5880
0.5	500	0.3370	0.0380	4900
0.4	400	0.3438	0.0312	3920
0.3	300	0.3500	0.0250	2940
0.2	200	0.3580	0.0170	1960
0.1	100	0.3660	0.0090	980

Table 6. *Represent the data to determine the spring constant (K_3).*

Vol. of water cu.m	Mass of water=vol. of water * density of water kg	Measured Length for X3 (m)	Extension=initial length-final length M	Force = mg = mass of water*9.8 Kg.m/s.s
0.8	800	0.3135	0.0595	7840
0.7	700	0.3170	0.0560	6860
0.6	600	0.3230	0.0500	5880
0.5	500	0.3280	0.0450	4900
0.4	400	0.3370	0.0360	3920
0.3	300	0.3445	0.0285	2940
0.2	200	0.3485	0.0245	1960
0.1	100	0.3600	0.0130	980

Table 7. *Represent the data to determine the spring constant (K_4).*

Vol. of water cu.m	Mass of water = vol. of water * density of water kg	Measured Length for X4 (m)	Extension=initial length-final length m	Force = mg = mass of water*9.8 kg.m/s.s
0.8	800	0.2805	0.1105	7840
0.7	700	0.2998	0.0912	6860
0.6	600	0.3153	0.0757	5880
0.5	500	0.3330	0.0580	4900
0.4	400	0.3465	0.0445	3920
0.3	300	0.3603	0.0307	2940
0.2	200	0.3740	0.0170	1960
0.1	100	0.3875	0.0035	980

Table 8. *Represent the data to determine the spring constant (K_5).*

Vol. of water cu.m	Mass of water = vol. of water * density of water kg	Measured Length for X5 (m)	Extension=initial length-final length M	Force = mg = mass of water* 9.8 kg.m/s.s
0.8	800	0.2680	0.1060	7840
0.7	700	0.2758	0.0872	6860
6	600	0.2950	0.0680	5880
0.5	500	0.3120	0.0510	4900
0.4	400	0.3285	0.0345	3920
0.3	300	0.3438	0.0192	2940
0.2	200	0.3585	0.0045	1960
0.1	100	0.3600	0.0030	980

Determine the fixed concentration of salty water using the result. Salty water was unloaded from the tank and the volume (V_s) was measured along with its extension (X).

From,

$$F = KX = mg$$

$$M_s = \frac{KX}{g} \quad (2)$$

Where,

M_s = mass of salty water,

X = extension of spring,

K = spring constant

g = gravitational constant

We used the expression in (2) to compute the mass of salty water Ms.

Table 9. *Represent the data to determine the density of fixed concentration of salty water using (K_1).*

Vol. of water cu.m	Measured Length for X2 M	Extension=initial length-final length M	Mass of liquid=(k2/g)*X2 kg
0.8	0.317	0.058	5017.754184
0.7	0.321	0.054	5081.069694
0.6	0.328	0.047	5191.871837
0.5	0.336	0.039	5318.502857
0.4	0.344	0.031	5445.133878
0.3	0.350	0.025	5540.107143
0.2	0.356	0.019	5635.080408
0.1	0.365	0.010	5777.540306

Table 10. *Represent the data to determine the density of fixed concentration of salty water using (K_2).*

Vol. of water cu.m	Measured Length for X1 M	Extension=initial length-final length M	Mass of liquid = (k1/g)*X1 kg
0.8	0.308	0.055	5250.08
0.7	0.311	0.052	5301.217143
0.6	0.316	0.047	5386.445714
0.5	0.325	0.038	5539.857143
0.4	0.332	0.031	5659.177143
0.3	0.338	0.025	5761.451429
0.2	0.346	0.017	5897.817143
0.1	0.355	0.008	6051.228571

Table 11. *Represent the data to determine the density of fixed concentration of salty water using (K_3).*

Vol. of water cu.m	Measured Length for X4 (m) M	Extension=initial length-final length M	Mass of liquid=(k4/g)*X4 kg
0.8	0.257	0.134	1695.255918
0.7	0.276	0.115	1820.586122
0.6	0.297	0.094	1959.10898
0.5	0.315	0.076	2077.842857
0.4	0.331	0.06	2183.384082
0.3	0.346	0.045	2282.32898
0.2	0.359	0.032	2368.081224
0.1	0.376	0.015	2480.218776

Table 12. *Represent the data to determine the density of fixed concentration of salty water using (K_4).*

Vol. of water cu.m	Measured Length for X3 (m) m	Extension=initial length-final length M	Mass of liquid=(k3/g)*X3 Kg
0.8	0.295	0.078	4385.47602
0.7	0.295	0.078	4385.47602
0.6	0.306	0.067	4549.002245
0.5	0.312	0.061	4638.198367
0.4	0.319	0.054	4742.26051
0.3	0.326	0.047	4846.322653
0.2	0.336	0.037	4994.982857
0.1	0.346	0.027	5143.643061

Table 13. *Represent the data to determine the density of fixed concentration of salty water using (K_5).*

Vol. of water cu.m	Measured Length for X5 m	Extension = initial length-final length m	Mass of liquid=(k5/g)*X5 kg
0.8	0.236	0.138	1497.323673
0.7	0.253	0.121	1605.181735
0.6	0.274	0.1	1738.418163
0.5	0.294	0.08	1865.31
0.4	0.308	0.066	1954.134286
0.3	0.326	0.048	2068.336939
0.2	0.34	0.034	2157.161224
0.1	0.357	0.017	2265.019286

From the graph of mass against its volume; we determine the density of the salty water.

i. A fixed mass of Salt was loaded into the tank and diluted with clean water. The slope of its graph of mass against volume was used to determine the density of the salty liquid.
ii. A fixed mass of salt was continuously diluted and the extension of the spring recorded. The concentration was plotted against extension and curve fitting was performed to fit the data set.
iii. Repeat steps (i-ii) for specific organic slurry and use the result in step (iii) to predict the density of unknown organic substance.

3. Results

Table 14 is a summary of results from experiments to determine the spring constant values for the five springs. The slopes of the graphs are the spring constants and all the five springs showed excellent correlation coefficient between 0.9961 and 0.9799. The springs constant are different for the five springs. This results to unbalanced force acting on the tank and causing it to tilt sideway as the tank is loaded with water.

Table 14. *Summary of fitting linear regression for determined spring constant for liquid of known density.*

	K1	K2	K3	K4	K5
Slope (N/m)	167,048	155,123	145,687	64,644	62,177
Intercept (N)	993.87	726.52	1280.90	926.52	1507.90
Correlation Coefficient	0.9887	0.9844	0.9849	0.9961	0.9799

Table 15 is a summary of result from experiments to determine the density of a fixed concentration of salty liquid using the value of the spring constant in table 14. The slope of the graphs is the density of the liquid, and all the five springs showed excellent correlation coefficients between 0.9969 and 0.9809. The density of the liquid determined separately has close value between 1102.4 kg/m^3 and 1170.9 kg/m^3.

Table 15. *Summary of fitting linear regression for determined density of unknown liquid with fixed concentration of salty water.*

	K1	K2	K3	K4	K5
Slope (kg/cu.m)	1,170.9	1,102.4	1,113.2	1,096.7	1,108
Intercept (kg)	6,132.8	5,871.9	5,211.6	2,387.4	2,607
Correlation coefficient	0.9885	0.9957	0.9809	0.9969	0.9949

Figure 2, is the graph of the extension of the springs against its loading with salty water of known concentration during continuous dilution. A logarithm function fitted has a correlation coefficient of 0.97 and follows the relationship $Y=3E\text{-}05e^{42.67x,}$ where Y stands for density of the fluid and X the corresponding extension of the spring. We have used the expression to predict the density of similar fluids of unknown concentration.

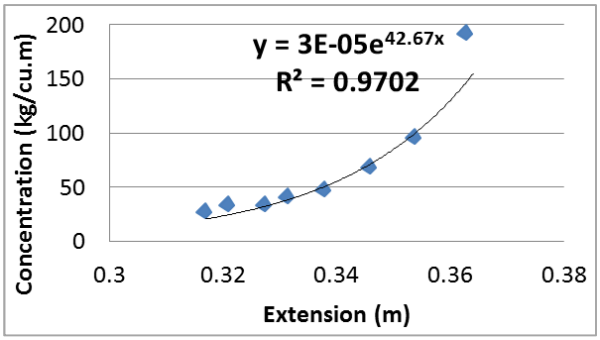

Figure 2. *Graph used to fit a functional relationship for the computation of densities of liquid of varying concentration.*

4. Discussion

From the results the average density of the salty liquid with fixed concentration is 1118.24kg/cu.m which is higher than that of fresh water (1000kg/cu.m). Density compares the heaviness of solids per unit volume in a fluid. From the graph of varying concentration the exponential profile can be used to compute the density of the organic slurry. If the same slurry material is used, the functional relationship between concentrations and spring extensions may be embedded into the microcontroller to give direct read-out of densities during mixing of the slurry. A good mixing ratio will maximize the gas production potentials of the organic material used.

5. Conclusion

The research results in this work have made it possible to have direct readings of densities of material (bio-degradable) from mere displacement of the suspension springs. The calibration should be addressed to make system on chip widely applicable for routine analysis. However, we believe that wider use of system on chip as process analytical tool in the biotechnological industry including biogas production. Since methane gas production potential depends on water dilution ratio, I hope that biogas producers will use this process to optimize mixing ratio before loading the digester for efficient gas production.

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