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Dursun S, Ineson P, Frankland JC, Boddy L, (1993) Sulphite and pH effects on CO_2 evolution from decomposing angiospermous and coniferous tree leaf litters. *Soil Biology & Biochemistry* **25**, 1513-1525.

Ergas SJ, Schroeder E, Chang D, Scow K, (1994) Spatial distributions of microbial populations in biofilters. In: Proceedings of the *78th Annual Meeting and Exhibition of the Air and Waste Management Association*, pp. 19-24, Cincinnati, OH.

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Research Paper

Kinetic Modelling of a Landfill Anaerobic Digestion Temperature in Relation to Multiphase Flow Across Unsaturated Porous Waste Media

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Abstract: Because an engineered landfill gas production unit is a closed system where organic waste is buried and compacted, there is need to understudy the kinetics under which gas evolves thereof. In this study, models were developed for multiphase flow across unsaturated porous waste media, semi-saturated and saturated media in a prototype landfill system. The anaerobic digestion temperature regime was kinetically Modelled for low, intermediate, and high landfill gas pressures as well as mass flow rates. The gas transport was modelled based on one dimensional transient basic differential equation while the biochemical kinetics was modelled based on Monod's Equation. The models which were developed for anaerobic digestion temperature at mesophilic range of 305, 309, 313, 317 and 321 K were narrowed down to multiphase flow across unsaturated porous organic waste media. The average maximum landfill gas pressures at low, intermediate, and high-pressure zones within the landfill confinements were recorded as 10.87, 13.31, 15.3, 17.8 and 20.4 KPa for the aforementioned mesophilic temperature along between flow distance of 0.0 and 0.045 m. Similarly, maximum mass flow rate of 1E-07, 1E-06, 1E-05, 1E-03 and 1E-01 kg/s were obtained for landfill gas at the same mesophilic temperature range. This indicated that landfill temperature is proportional to the average kinetic energy of the landfill gas densities and particles. Therefore, constant increase in the landfill temperature scaled up the heat rate per unit area of the landfill, which in turn served as a catalyst for microbial breakdown of organic waste for the generation and acceleration of gas flow within the landfill confinements.

Keywords: *Landfill, Leachate, Landfill gas, organic waste, porous media, Temperature.*

Introduction

Zhang *et al*. (2021) established a one-dimensional gas transport model for gas response in a landfill with layered new and old waste. The variation of gas permeability with depth, the anisotropy ratio of gas permeability, and settlement caused by waste biodegradation was considered in the model. Stratification of the unsaturated and saturated zones were also considered by distinguishing the difference in gas saturation. The maximum gas pressure occurred in the old waste layer near the boundary between new and old waste layers in the earlier period, but eventually moved to the bottom of landfill in the later period. The anisotropy ratio was observed as a more sensitive parameter influencing the distribution of landfill gas pressure. Ikpe *et al*. (2020a) investigated the biothermal variations in MSW landfill based on computational modelling. The results revealed that an increases in the landfill temperature stimulated gas particle movement, tending also to increase the pressure of the landfill gas, thereby, accelerating the rate of decomposition and adding more momentum to the gas particles to enable it spread more quickly within the confined system. Orhorhoro *et al*. (2018) investigated the effects of landfill gas flow trajectories at three distinct temperature phases (cryophilic temperature 50-150k, mesophilic temperature: 200-300k and thermophilic temperature 300-400k). Conservation mass equation was derived for solid, liquid, and gaseous phase of the landfilled waste matrix. The results reveal that the rate of landfill gas generation is dependent on the increase in temperature and pressure within the landfill system, usually causing subsurface pressures in the landfill to be higher than either the atmospheric pressure or indoor air pressure. This correlates with the findings of Ikpe et al (2020b) from fuzzy modelling and optimization of anaerobic co-digestion process parameters for effective biogas yield from bio-wastes. Flow through waste solid matrix is usually considered as porous medium flow, generally simulated with Darcy's formulation (Bear, 1972), accounting also for capillary suction

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and varying hydraulic conductivity as a function of liquid phase saturation. Measurements of solid waste porosity ranged from 28% to 33.5% (Beaven & Powrie, 1995) effective porosity and from 57.7% to 72.9% (Staub *et al*., 2009) total porosity using laboratory scale tests). Once again, porosity of solid waste varies due to mechanical deformation and degradation. In the present study, however, a total porosity value of 50% was assumed to be constant in space and time. Kjeldsen and Fischer (1995) monitored the gas pressure in the old waste layer of Skellingsted landfill for 35 days, and results show that the variation of gas pressure in the landfill has a great influence on the composition of landfill gas. Gas pressure in Olinda and Louisiana landfills was measured for 3 and 5 days, and it was found that the measured pressure is influenced by fluctuations in atmospheric pressure (Spokas & Bogner, 1996; Bentley et al., 2003). Gebert and Groengroft (2006) found that the amplitude of the gas pressure measured in two gas collection wells in an old German landfill exhibits a linear correlation with the amplitude of atmospheric pressure. Zhang *et al*. (2019) observed the gas pressure in the newly filled municipal solid waste (MSW) layer of the Wuxi landfill for more than 500 days, with results showing that the gas pressure varies with time, showing a single peak curve. The stratification of new and old waste layers is constantly occurring in operating landfills (Lefebvre et al., 2000; Jang Kim, 2003). Gas breakthrough pressure and emission rate of unsaturated compacted clay were investigated by Chen et al. (2016), over a wide range of landfill gas pressures under various degrees of saturation, thicknesses, and degrees of compaction. Under a gas pressure of 10 kPa, a minimum of 0.4 m thick clay layer was able to prevent gas breakthrough at degree of saturation of about 60% or higher. Therefore, a thicker clay layer is required if clay degree of saturation is lower than 60%. For low degree of saturation (*i.e.,* 40%), degree of compaction had almost no influence on gas emission in the gas pressure range from 0 to 20 KPa. Therefore, gas breakthrough pressure of unsaturated compacted clay increased as the degree of saturation and thickness of clay increased. From the above report, several studies have been carried out on energy specific landfill system. However, this study is focused on the kinetic modelling of anaerobic digestion temperature regime in relation to multiphase flow across unsaturated porous waste media in a prototype landfill design framework.

Materials and Method

The 3D isometric landfill system was modelled using SOLIDWORKS 2018 software which is a solid modelling Computer Aided Design (CAD) as well as Computer Aided Engineering (CAE) tool that runs mainly on Microsoft Windows. The modelling steps started with 2D sketch, consisting of geometries such as arcs, points, conics, lines, splines and so on. Dimensions were added to the sketch to define the size and configuration of the geometry. Relations in the tool bar were used to define features such as parallelism, tangency, concentricity, perpendicularity among others. In the part assembly, sketches of individual parts were assembled together to form the intended solid model of the landfill system. The landfill data were obtained from a field prototype in the Faculty of Engineering, University of Benin, Nigeria. Materials used in the construction of the field prototype were used as a guide during selection of the landfill materials from SOLIDWORKS material library.

The landfill models as shown in Figure 1 and 2 incorporates all the functional materials needed for its operation. As shown in Figure 3, the gas extraction unit is modelled with four (4) cornered steel rods binned together with copper wire, and the annulus packed with granular materials (non-cancerous stone). Perforated gas extraction pipe is incorporated at the middle of the four (4) cornered steel rods to allow the flow and channelling of biogas generated from decomposing waste stream in the landfill to storage vessels. Borehole diameter for the gas extraction well is 0.20m while the gas extraction pipe diameter is 0.10m. Generally, landfill gas contains four major gases including CH_4, CO_2 N_2 and O_2 as well as moisture and other compounds in trace quantities, of which CH_4, (about 50-55%) and CO_2 (about 35-40%) accounts for the highest constituents. To obtain pure methane, which is the primary gas in a landfill gas, bio-filter is installed in the gas extraction pipe (see Figure 3) to purify and remove unwanted components from the raw landfill gas. The landfill model also incorporates perforated pipes buried horizontally (diameter of 0.10m and 0.40-0.50 m spacing) within the compacted waste layers and also within the granular layers (gravel layer) at the bottom of the landfill. The purpose is for transporting and channelling of leachate to a sizable trench (leachate collection sump) at a lower base of the landfill for extraction when necessary. The bottom and side walls of the system is modelled with bentonite clay (secondary liner) of low hydraulic conductivity ($1x10^{-7}$cm/s) to delay and control the rate of leachate percolation, while High Density Polyethylene (HDPE) liner (primary liner) is further modelled to align properly with the surface of the bentonite clay liner to further prolong water retention in the landfill. The HDPE material specification was thickness of 2mm as presented by Ikpe et al. (2019). The model also incorporates polypropylene geotextile mat or geomembrane filter placed on the surface of the granular layer to separate solid particles from liquid content of the waste during decomposition.

Specifications of this material as presented by Ikpe *et al*. (2020c) are melting point temperature of 30ºC, tensile strength between the range of 31.03-41.37MPa (ISO527), mass of 9613.75 g and thickness of 4.5mm. The waste permeability value was 3.x10-12m^2, porosity was 0.5, cover thickness was 0.3m, and the permeability of cover was 1x10-13m^2. In evens of the primary and secondary liner failure, ground water monitoring probes is also incorporated in the model to detect the presence of leachate in ground water. The above descriptions of the landfill models are presented in Figure 1 and 2.

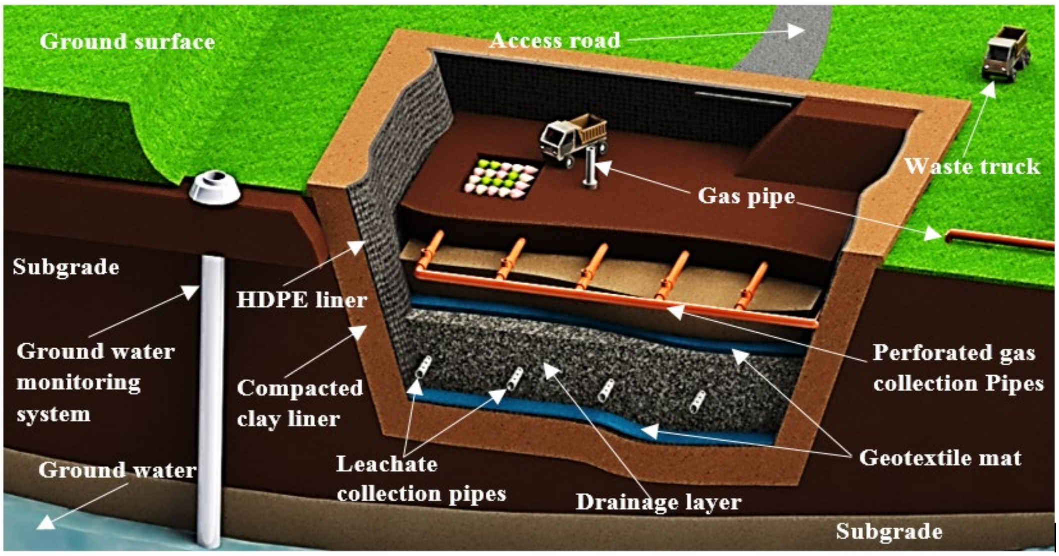


Figure 1. Cross sectional view of the landfill showing internal components

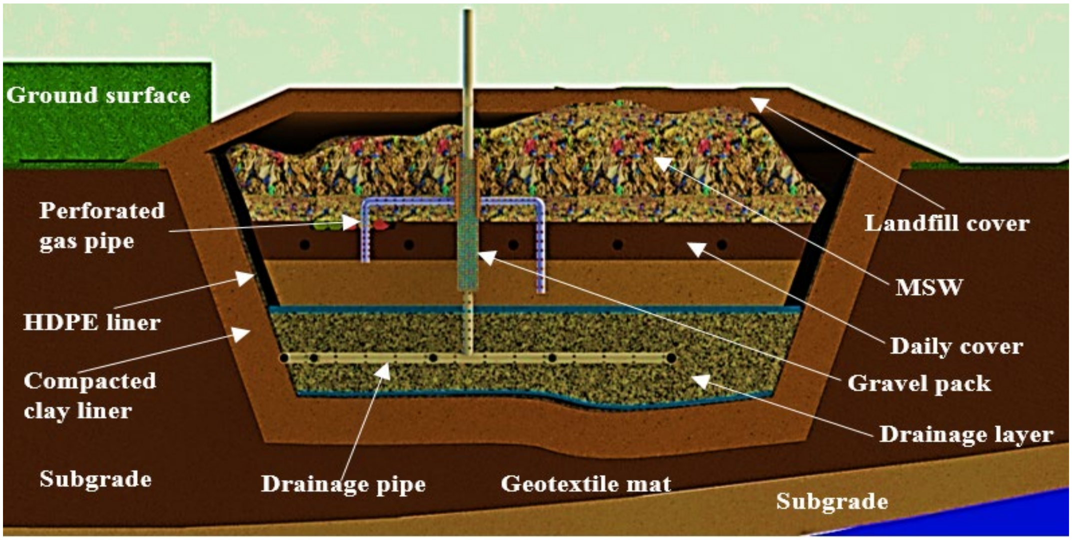


Figure 2. Cross sectional view of the landfill with MSW inside

The organic waste media was modelled for unsaturated, semi-saturated and saturated porous media using SOLIDWORKS 2018 software. The commercial CFD solver ANSYS Fluent 14.0 was used to simulate the complex anaerobic waste digestion-multiphase flow processes of the landfilled system at mesophilic temperature ranges of 305, 309, 313, 317 and 321 K. First-order spatial and temporal discretization was employed, while velocity-pressure coupling was achieved using ‘‘phase coupled SIMPLE’’ algorithm. The biochemical equations were computed implicitly while the flow model coupled with the biochemical process used the sink/source terms of the equations. Velocity magnitude for flow regimes across porous media generally low, therefore, convergence properties for all partial differential equations were computerised low, in order to achieve convergence when all velocity components, mass and energy accuracy attain values of 10^{-12}. The following main assumptions were applied for model development:

i. Gaseous phase flow in the landfilled solid waste matrix was described as unsaturated porous media multiphase flow.
ii. Solid waste matrix was assumed to be rigid (non-deformable).
iii. Flow was considered to be incompressible.
iv. Thermal equilibrium was assumed between solid waste and surrounding or contained fluids.
v. Biodegradable solid waste was assumed to be in fixed positions.
vi. Biodegradation was assumed to occur in the liquid phase.
vii. The pressure inlet boundary condition, which is mathematically described as a Dirichlet boundary condition for the relative pressure, was expressed as: $P_{inlet} = Pa$, where Pa is the relative pressure at the inlet. Similar boundary conditions were assumed for both the species mass transfer and temperature at inlet: C_{inlet} = Ca and $T_{inlet} = Ta$, where Ca and Ta represent the values of species concentration and temperature at the inlet.
viii. The pressure outlet boundary condition, which is a Dirichlet boundary condition for relative pressure, was assumed to be $P_{outlet} = Pb$, where Pb is the relative at the outlet. For the species mass transfer, zero flux boundary $\left(\frac{\partial C_{outlet}}{\partial n} = 0\right)$ condition was assumed. For the temperature, Dirichlet boundary condition applied was: $T_{outlet} = Tb$, where Tb is the temperature value at outlet.
ix. The impermeable rigid wall boundary condition, which is mathematically a Dirichlet boundary condition for the velocity assuming no-slip condition ($V_W = 0$ m/s). For the species mass transfer and temperature, zero flux boundary condition was applied: $\left(\frac{\partial C_W}{\partial n} = 0 \; and \; \frac{\partial h_W}{\partial n} = 0\right)$.

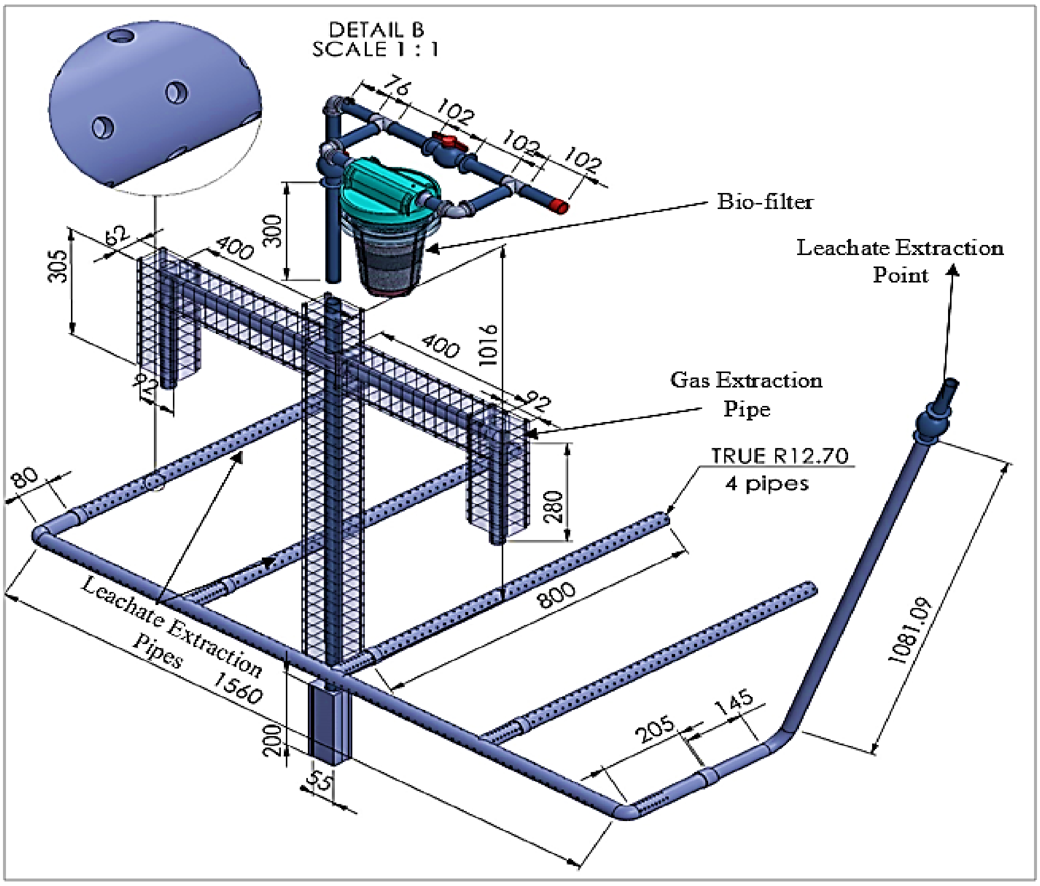


Figure 3. Layout of landfill leachate and gas extraction system

The kinetic modelling of anaerobic digestion temperature, mass flow rate and landfill gas pressure in relation to unsaturated porous media multiphase flow in a prototype landfill was achieved using the following properties in the gaseous, liquid and solid phases as well as the following flow parameters presented in Table 1.

Table 1. Landfill properties in the gaseous, liquid and solid phases with flow parameters

Properties of the gas Phase	**Minimum**	**Maximum**
Thermal conductivity (W/mK)	0.015	0.038
Specific heat capacity (KJ/kgK)	600	2100
Density Fluid (Kg/m^3)	0.282	0.840
Velocity (m/s)	0	2198.108
Velocity (X) (m/s)	-195.020	195.130
Velocity (Y) (m/s)	-28.893	2197.940
Velocity (Z) (m/s)	-201.483	202.130
Temperature (K)	280.96	-
Mach Number	0	7.23
Vorticity (1/s)	22.226	71927.174
Molecular viscosity (Kg/m s)	1.7894 x10^{-5}	1.7894 x10^{-5}
Viscosity of gas mixture (Pa.s)	1.54×10^{-15}	1.54×10^{-15}
Relative Pressure (Pa)	-82543.53	-
Properties of Solid Phase (MSW)	**Minimum**	**Maximum**
Density (Kg/m^3)	140.2	220.8
Thermal conductivity (W/mK)	0.3	3.5
Specific heat capacity (KJ/kgK)	1000	2200
Residual saturation	0.03	0.03
Permeability of soil	1.0×10^{-15}	1.0×10^{-15}
Properties of liquid Phase	**Minimum**	**Maximum**
Liquid material (leachate)	-	-
Density (Kg/m^3)	3.2	5.1
Thermal conductivity (W/mK)	0.200	0.600
Specific heat capacity (KJ/kgK)	1000	3000
Dynamic viscosity (Kg/m s)	0.001003	0.001003
Temperature (Fluid) (K)	280.96	
Flow parameters		
Flow vectors direction	Normal to face	
Volume flow rate	0.1000 m^3/s	
Viscous regime	Turbulent	
Turbulent intensity: 10%	10%	
Turbulent length scale	7% of the Hydraulic diameter	
Turbulent velocity scale	5% of the free steam velocity	

Tchobanoglous et al. (1993) described the kinetics of biodegradation in organic solid waste by the following chemical mass balance Equation 1.

$$C_aH_bO_cN_d + \frac{4a+b-2c-3d}{4}O_2 \xrightarrow{Biomass} aCO_2 + \frac{(b-3d)}{2}H_2O + dNH_3 \quad (1)$$

Where the constants *a, b, c* and *d* are chemical compositions of the waste. The values for these constants have been estimated in numerous studies (Iannelli et al., 2005; Mavridis and Voudrias, 2021; and Komilis et al., 2012). The chemical formula for bacterial growth is given by Equation 2 (Stegenta-Dabrowska et al., 2022; Nayagum et al., 2009). The corresponding chemical equation for the biomass decay is given by Equation 3.

$$5C_aH_bO_cN_d + (a-5d)NH_4^+ \xrightarrow{O_2} aC_5H_7NO_2 + (5b-20d+a-10c)H^+ + (5c-2a)H_2O \quad (2)$$

$$C_5H_7NO_2 + 3H_2O + H^+ \xrightarrow{O} 5/6C_6H_{12}O_6 + NH_4^+ \quad (3)$$

The kinetics of solid waste biodegradation and biomass production are connected with the relationship in Equation 4. Based on Monod's Equation, the biochemical kinetics in Equation 4 is expressed by the following relationship in Equations 5 and 6 (Qin et al., 2007; Lin et al., 2008; Higgins and Walker, 2001; Baptista et al., 2010).

$$S_s = \frac{dC_S}{dt} = \frac{S_B}{Y_S} = \frac{1}{Y_S}\frac{dC_B}{dt} \quad (4)$$

$$S_s = \frac{dC_S}{dt} = -k_m \frac{C_S}{k_S + C_S} C_B \quad (5)$$

$$S_s = \frac{dC_S}{dt} = -k' C_S \quad (6)$$

where S_S is the solid waste biodegradation rate, C_S is the concentration of biodegradable solid waste, t is the time, S_B is the biomass production rate, C_B is the biomass concentration in the waste stream, Y_S is the yield coefficient which connects kinetics of biodegradable solid waste and biomass, k_m is the maximum biodegradation rate in high biodegradable solids concentration and K_S is the half saturation constant for the solid waste. The factors that mostly influence the kinetics of biodegradation are temperature, moisture content in waste, particle size that prescribes the effective surface of solid matrix where biodegradation occurs, pH and so on (Baptista et al., 2010). Considering the aforementioned factors, Haug (1993) proposed the following equation:

$$S_s = \frac{dC_S}{dt} = -k' C_S = -k * k_{temp} * k_{mc} * k_{O_2} * k_{FAS} * k_{pH} * C_S \quad (7)$$

where k' is the effective/corrected biodegradation rate, k is the maximum biodegradation rate k_{temp} is the temperature correction function, k_{mc} is the moisture content correction function (dimensionless), kO_2 is the oxygen concentration correction function, k_{FAS} is the free air space correction function and kpH is the pH correction function. Based on the cardinal temperatures T_{min}, T_{max} and T_{opt}, Rosso et al (1993) originally proposed the correction function expressed in Equation 8:

$$k_{temp} = \frac{(T - T_{max}) * (T - T_{min})^2}{(T_{opt} - T_{min}) * [(T_{opt} - T_{min}) * (T - T_{opt}) - (T_{opt} - T_{max}) * (T_{opt} + T_{min} - 2T)]} \quad (8)$$

where T_{min} is the minimum acceptable temperature, T_{max} is the maximum acceptable temperature, T_{opt} is the optimum temperature for the biodegradation of organic feedstock and T is the actual temperature. The expression in Equation 8 was employed by both Sole-Mauri et al. (2007) and Mason (2009), in studies conducted on biodegradable volatile solids degradation profiles in composting process.

According to the mass conservation law, the net mass of gas flowing into and out of the unit body plus the mass of gas production equal to the variation of gas mass in the unit body, which can be expressed in Equation 9 (Zhang et al., 2021). For unsaturated flow, Navier Stokes Brinkman equations for ''Euler'' multiphase approach which is an extended Darcy's model for simulation of momentum conservation in each control volume (Fytanidis and Voudrias, 2014) is given by Equation 10.

$$-\left(\frac{\partial \rho_g V_x}{\partial x} dx + \frac{\partial \rho_g V_y}{\partial y} dy + \frac{\partial \rho_g V_z}{\partial z} dz\right) dt + \rho g Q G dx dy dz dt = \frac{\partial \rho g \varepsilon S_g dx dy dz}{dt} dt \quad (9)$$

$$\frac{\partial \varepsilon a_q \rho_q \vec{V}_q}{\partial t} + \nabla \varepsilon a_q \rho_q \vec{V}_q \vec{V}_q = -\varepsilon a_q \nabla P + \nabla \varepsilon \bar{\bar{\tau}} + \varepsilon a_q \rho_q \bar{g} - a_q^2 \frac{\mu_q}{k k_r} \vec{V}_q - \varepsilon a_q \nabla P_c \quad (10)$$

where ρ_g is the density of landfill gas, V_x, V_y and V_z are the volumes of landfill gas entering the unit body along directions O_x, O_y and O_z per unit time, ε is the total porosity of the medium, S_g is the gas saturation, a_q is the volume fraction of q phase, p_q is the density of q phase, $\vec{V}_q$ is the Darcy velocity of q phase (air of water), P is the static pressure, $\bar{\bar{\tau}}$ is the shear stress, g is the acceleration of gravity, μ_q is the dynamic viscosity of q phase, k is the intrinsic or saturated permeability of q phase, k_r is the formulation of relative permeability (dimensionless) derived by van Genuchten (1980). The capillary pressure term $\gamma a_q \nabla P_c$ is included only in the wetting phase (Mualem, 1976) where P_c is derived from van Genuchten (1980) formulation.

$$P_c = -\frac{\rho_w g}{\alpha}\left(\left(\frac{1}{S_e}\right)^{\frac{1}{\gamma}-1}\right)^{1/\beta} \quad (11)$$

where ρ_w is the aqueous phase density, α and β are the van Genuchten constants $\left(\gamma = 1 - \frac{1}{\beta}\right)$. Energy conservation equation for the kinetics of anaerobic digestion temperature regime is given by Equation (12).

$$\frac{\partial \varepsilon a_q \rho_q h_q}{\partial t} + \nabla \varepsilon a_q \rho_q h_q \vec{V}_q = \partial a_q \rho_q \frac{\partial P}{\partial t} + \varepsilon \bar{\bar{\tau}}_q : \nabla \vec{V}_q - \nabla \varepsilon q_q + S_q \quad (12)$$

Where h_q is the specific enthalpy of q phase and S_p is the sink/source term of energy. The heat exchange between the different phases is derived from Equation 13.

$$Q_{pq} = h_{pq}(T_p - T_q) \tag{13}$$

where Q_{pq} is the heat transfer across the phases, T_p is the temperature of p phase, T_q is the temperature of q phase and h_{pq} is the volumetric heat transfer coefficient between the phases p and q derived as a function of Nusselt number (Ranz & Marshall, 1952). One dimensional transient basic difference equation of gas transport in MSW matrix is given by Equation14. Equation 15 is the equation of one-dimensional transient difference scheme for gas transport in a landfill (Zhang et al., 2021).

$$\frac{K_{gz}}{u_g}\frac{\partial^2 P_g}{\partial z^2} + \frac{1}{u_g}\frac{\partial K_{gz}}{\partial z}\frac{\partial P_g}{\partial z} + \rho L_o \sum_{1=1}^{3} w_i \frac{AGi}{BGi}(t + D_{Gi})^{-\frac{1+D_{Gi}}{BGi}} - nS_g \left\{ \begin{array}{c} 1 + \frac{1}{e_0+1}\left[e_0 - C_c 1g\left(1 + \frac{t}{t_D}\right) + 1\right]\frac{A_{Gi}t}{B_{Gi}} e^{-\frac{t}{B_{GI}}} \\ + \frac{C_c}{(e_t+1)(t+t_D)1n\,10}\left[1 - A_{Gi} * B_{Gi}\left(-\frac{t}{B_{Gi}} e^{-\frac{t}{B_{Gi}}} + 1 - e^{-\frac{t}{B_{Gi}}}\right)\right] \end{array} \right\} = \frac{nS_g}{P_{atm}}\frac{\partial P_g}{\partial t} \tag{14}$$

$$f_{G1}\frac{P_{gk-1}^t - 2P_{gk}^t + P_{gk+1}^t}{h_z^2} + f_{G1}\frac{P_{gk+1}^t - P_{gk-1}^t}{2h_z} + f_{G3}\left(\rho L_o \sum_{1=1}^{3} w_i \frac{AGi}{BGi}(t + D_{Gi})^{-\frac{1+D_{Gi}}{BGi}} - \right) = f_{G4}\frac{P_{gk}^t - P_{gk}^{t-1}}{\tau} \tag{15}$$

where e_0 is the initial void ratio, e_t is the void ratio at time t, h_z is the step length in the vertical direction, τ is the step length of time, A_{Gi} is the parameter related to gas production rate, B_{Gi} is the time of peak gas production rate, D_{Gi} is the length of time that the waste has been degraded to produce gas. The liquid flow and landfill gas transportation in landfills are estimated according to the equations of mass conservation for leachate and landfill gas in Equations 16a and 16b.

$$\rho_w \frac{\partial}{\partial t}(nS) = \rho_w \nabla.\left[\frac{k_{iw}k_{rw}}{\mu_w}\nabla.(u_w + \rho_w g_z)\right] + f_w \tag{16a}$$

$$\frac{\partial}{\partial t}\left[\rho_g n(1 - S)\right] = \nabla.\left[\frac{k_{ig}k_{rg}}{\mu_g}\nabla.(\rho_g u_g + \rho_w g_z)\right] + f_g \tag{16b}$$

where: n is the porosity, S is the liquid saturation, *rw* and *rg* are the density of liquid and gas, *r* is the partial differential operator, k_{iw} and k_{ig} are the intrinsic permeability for liquid and gas, k_{rw} and k_{rg} are the relative permeability functions for liquid and gas phase which can be estimated via the van-Geunchten model (van Genuchten, 1980), μ_w and μ_g are the dynamic viscosities of liquid and gas, u_w is pore water pressure, u_g is pore gas pressure. The mass conservation equation for liquid phase (Equation 16a) and gas phase (Equation 16b) can be further expressed as shown in Equation 17 and 18. The governing equation of solute migration is expressed in Equation 19 (Liu et al., 2021).

$$-\rho_w n \frac{\partial S}{\partial s}\frac{\partial u_w}{\partial t} + \rho_w n \frac{\partial S}{\partial s}\frac{\partial u_g}{\partial t} + \rho_w S \frac{\partial_n}{\partial_t} = \rho_w \nabla.\left[\frac{k_{iw}k_{rw}}{\mu_w}\nabla.(u_w + \rho_w g_z)\right] + f_w \tag{17}$$

$$\rho_g n \frac{\partial S}{\partial s}\frac{\partial u_w}{\partial t} + \left[\frac{n(1-S)M}{RT} - \rho_g n \frac{\partial S}{\partial s}\right]\frac{\partial u_g}{\partial t} + \rho_g(1 - S)\frac{\partial n}{\partial t} == \nabla.\left[\frac{k_{ig}k_{rg}}{\mu_g}\nabla.(\rho_g u_g)\right] + f_g \tag{18}$$

$$nS\frac{\partial c_i}{\partial t} - nc_i \frac{\partial S}{\partial s}\frac{\partial u_w}{\partial t} + nc_i \frac{\partial S}{\partial s}\frac{\partial u_g}{\partial t} + c_i S \frac{\partial n}{\partial t} = -\nabla.(c_i v_w) + \nabla.(D_i \nabla c_i) + f_c^i \tag{19}$$

where s is the suction, u is the vertical displacement of a landfill, M is the molecular weight of landfill gas, R and T are the ideal gas constant and temperature, v_w is the fluid velocity of liquid, D_i are diffusion coefficients of volatile fatty acids and methanogen. Viscosity of the gas mixture can be expressed as a function of the viscosities of individual gases (Poling *et al.*, 2001), given by Equation 20. Durmusoglu (2002) expressed the mass balance equation for the liquid and gas phase relation given by equation 21 and 22. The settlement of waste stream in the landfill can be estimated based on vertical volumetric strain of MSWs which is expressed in Equation 23.

$$\varphi_{ij} = \frac{\left[1 + \left(\frac{\mu_i}{\mu_j}\right)^{1/2}\left(\frac{M_j}{M_i}\right)^{1/4}\right]^2}{\sqrt{8}\left(1 + \frac{M_i}{M_j}\right)^{1/2}} \tag{20}$$

$$nS_l\rho_l\beta\frac{\partial P_l}{\partial t}+\rho_l n\frac{\partial S_l}{\partial t}+\rho_l S_l\frac{\partial V_s}{\partial z}+\rho_l S_l\frac{\alpha^* Y}{\rho_s}=\frac{\partial}{\partial z}\left[\frac{\rho_l k_l}{\mu_l}\left(\frac{\partial \rho_l}{\partial z}-\rho_l g\right)\right] \quad (21)$$

$$n(1-S_l)\frac{\bar{M}}{\bar{R}\phi}\frac{\partial P_g}{\partial t}-\rho_g n\frac{\partial S_l}{\partial t}+\rho_g(1-S_l)\frac{\partial V_s}{\partial z}+\alpha^*\left(\frac{Y\rho_g(1-S_l)}{\rho_s}-1\right)=\frac{\partial}{\partial z}\left[\frac{\rho_g k_g}{\mu_g}\left(\frac{\partial P_g}{\partial z}-\rho_g g\right)\right] \quad (22)$$

$$\varepsilon_z(\sigma',t)=C_C'\log\frac{\sigma'}{\sigma_0'}+\left[\varepsilon_{dc}(\sigma_0')+(C_\infty'-C_C')\log\frac{\sigma'}{\sigma_0'}\right]\left(1-exp(-C_s t)\right) \quad (23)$$

$$\sigma'=\sigma_T-\left[Su_w+(1-S)u_g\right] \quad (24)$$

where: $\varepsilon_z(\sigma',t)$ is the vertical volumetric strain of MSWs having a filled age of t under the effective stress σ', C_C' and C_∞' are the compression ratios for placed fresh MSW and fully decomposed MSW, σ_T is the total stress, σ_0' is the pre-consolidation pressure, $\varepsilon_{dc}(\sigma_0)$, is the sum of ultimate volumetric strains of decomposition compression and mechanical creep under pre-consolidation pressure and C_S is the secondary compression rate constant. Based on the finite-line source theory, Zeng *et al*. (2002) proposed the analytical equation for temperature response in the ground as:

$$\theta(r,z,t)-\theta_0=\frac{q_l}{4\pi k}\int_0^H \frac{erfc\left(\frac{\sqrt{r^2+(z-h)^2}}{2\sqrt{\alpha t}}\right)}{\sqrt{r^2+(z-h)^2}}-\frac{erfc\left(\frac{\sqrt{r^2+(z+h)^2}}{2\sqrt{\alpha t}}\right)}{\sqrt{r^2+(z+h)^2}}dh \quad (25)$$

where H is the depth and *erfc* is complementary error function. Municipal solid waste is a porous medium with pore spaces between irregularly shaped solid grains. Analytical equations applicable to heat conduction in porous media is given by Equation 26 (Yang, 2016).

$$\begin{cases}(1-\emptyset)\rho_s c_s\frac{\partial\theta_s}{\partial t}=(1-\emptyset)\nabla.\ (k_s\nabla\theta_s)\\ \quad +(1-\emptyset)Q_s+h\left(\theta_f-\theta_s\right)\\ \emptyset\rho_f c_f\frac{\partial\theta_f}{\partial t}+\left(\rho_f c_f\right)q_f.\nabla\theta_f=\emptyset\nabla.\left(k_f\nabla\theta_f\right)\\ \quad +(1-\emptyset)Q_f+h\left(\theta_s-\theta_f\right)\end{cases} \quad (26)$$

where θ_s and θ_f are the solid and fluid temperatures, ρ_s and ρ_f are the densities of solid and liquid phases c_s and c_f are specific heat capacities of solid and liquid phases, k_s and k_f are heat conductivities, Q_s and Q_f are sources for liquid phases, $\emptyset$ is the landfill waste porosity and h is the exchange heat transfer coefficient. However, the constitutive equations for heat transfer in porous media is given by Equation 27 (Nield and Bejan, 2006).

$$\begin{cases}(1-\emptyset)\rho_s c_s\frac{\partial\theta_s}{\partial t}=(1-\emptyset)k_s\nabla^2\theta_s+h\left(\theta_f-\theta_s\right)+(1-\emptyset)Q_s\\ \emptyset\rho_f c_f\frac{\partial\theta_f}{\partial t}+\rho_f c_f q_f\,\nabla\theta_f=\emptyset k_f\nabla^2\theta_f-h\left(\theta_f-\theta_s\right)+\emptyset Q_f\end{cases} \quad (27)$$

The time measured since the first layer of waste was deposited in the landfill is given by Equation 28.

$$T=T_0+Y\frac{T_f}{D}+T_{g+}F_g \quad (28)$$

where *D* is the total landfill depth, T_0 is the time elapsed since the landfill was capped, T_f is the total time to fill the landfill, and T_s is the time for gas production to commence. The governing equation of landfill gas flow is given by Equation 29 while the landfill gas flow velocity (v_a) is given by Equation 30 (Feng et al., 2009).

$$\frac{\partial(n\rho_a S_a)}{\partial t}+\nabla(\rho_a v_a)=F_g \quad (29)$$

$$v_a=-\frac{kk_{ra}}{\mu_a}\left(\nabla P_a+\rho_a g\eta\right) \quad (30)$$

where ρ_a is the gas density, S_a is the gas saturation, F_g is the source phase, *k* is the intrinsic permeability, k_{ra} is the gas relative permeability.

Results and Discussion

Effective resistance to gas flow in landfill systems is caused by permeability ratios between the various medium layers and spacing between perforated cross-sections. A no flux boundary condition is equivalent to an additional layer of zero permeability and thus infinite ratios for all other layers. Compacted waste layers with very low permeability will result in singularity with no flux conditions. The two reliable control measures are experimental determination of permeability ratios and aperture density. The thermodynamics and flow kinetics in a landfill gas involves no excessive pressure or temperature, and low Reynolds and Mach numbers (Nec and Huculak, 2010). Most landfills are generally considered as landfills with a homogeneously unsaturated waste layer (Nastev et al., 2001; Lu et al., 2019) or a continuously placed waste layer (Li et al., 2012; Li et al., 2013). Since the voids in MSW landfills are not completely filled by the liquid phase, the presence of the gas phase reduces the volume of medium available for liquid flow in an unsaturated medium. When the gas and liquid phases flow together through a porous medium, saturations of the phases are less than unity ($S_l + S_g = 1$). The extent of waste compaction plays a vital role in the degree of saturation of waste in the landfill system. Hydraulic conductivities of the unsaturated, semi-saturated and saturated porous waste media were $1x10^{-7}$ m/s, $1x10^{-9}$ m/s and $1x10^{-12}$ m/s respectively as shown in Figures 4-6. The analysis mainly focused on multiphase flow across unsaturated porous waste media because, waste in landfill systems is rarely completely saturated since majority of the flow occur in the unsaturated phase above leachate table. Even in semi-saturated waste media, the formation of landfill gas creates bubbles of gas within the void space, indicating that the waste media is not fully saturated. However, in events where the organic waste media is completely saturated, gas becomes entrapped in the waste media, thereby, leading to clogging of internal gas extraction pipes and interruption in the gas flow rate.

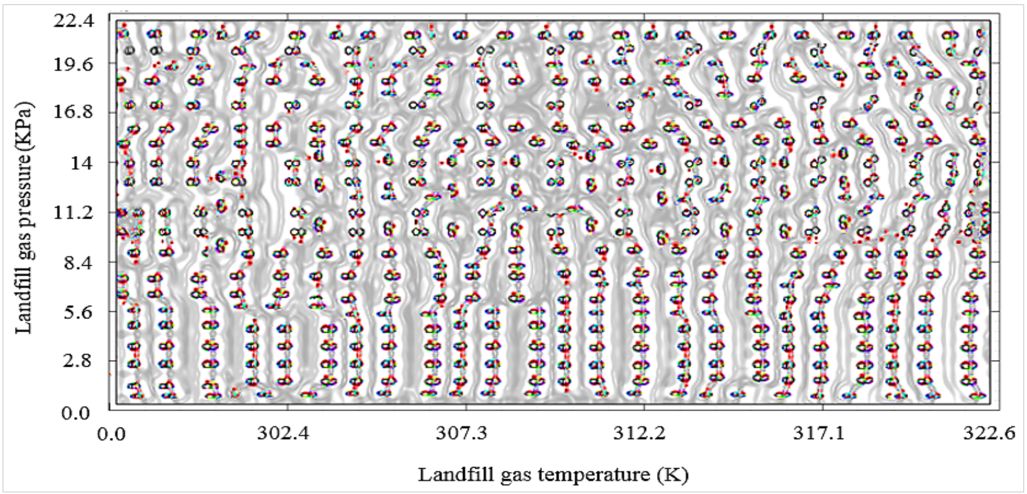


Figure 4. Unsaturated porous media with Hydraulic conductivity of $1x10^{-7}$ m/s

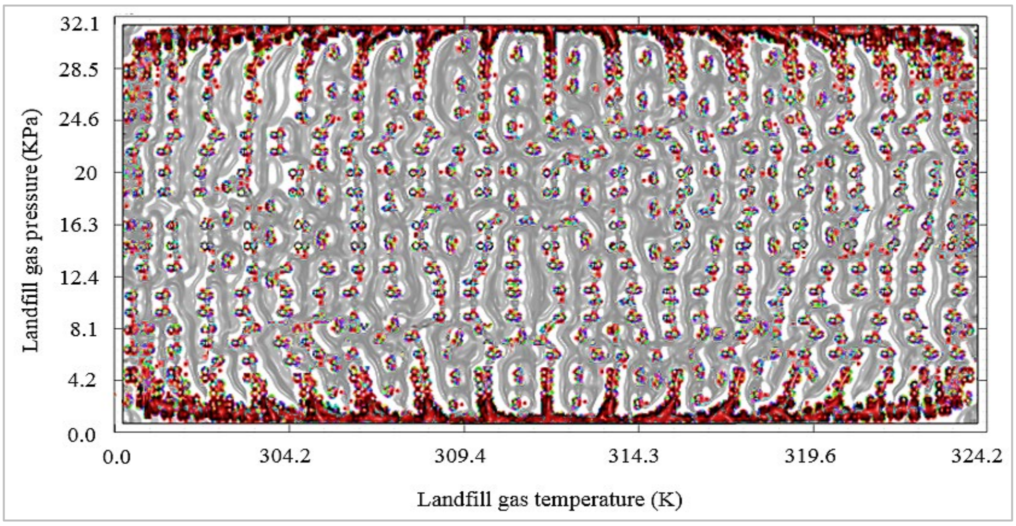


Figure 5. Semi-saturated porous media with hydraulic conductivity of $1x10^{-9}$ m/s

The white space indicated in Figure 4-6 signifies the pore spaces or drainage holes within the waste media. The said pore spaces are much in Figure 4, implying that the hydraulic conductivity ($1x10^{-7}$ m/s) of the waste media is low, but enough for leachate and landfill gas can adequately flow through. Compared to Figure 4, the pore space (represented by white colour or colourless portion) between the compacted wastes media in Figure 5 is less, implying that the hydraulic conductivity ($1x10^{-9}$ m/s) of the waste media is very low, but leachate and landfill gas can still manage to flow through but not adequately. The pore space (represented by white colour or colourless portion) between the compacted waste media in Figure 6 is barely seen, as the hydraulic conductivity ($1x10^{-12}$ m/s) of the waste media is extremely low, and leachate as well as landfill gas can hardly flow through. This indicates that the saturated porous media with hydraulic conductivity of $1x10^{-12}$ m/s looks non-porous, but not impervious, as such, the movement of leachate and landfill gas within the waste layers are almost but not completely restricted. Thus, a given landfill system operating under such condition is likely to fail in terms of not being able to give off gas as the other conditions in Figure 4 and 5 would. This can occur as a result of very low hydraulic conductivity within the waste media, hampering the pressure and mass flow rate of landfill gas and seeping tendency of the leachate into micro-pores and surrounding waste media within the system. This can also be due to clogging of the drainage systems or collapse of leachate transportation pipes as well gas channelling pipes, thereby, preventing the gas flow rate and leachate transport from functioning effectively. This may also take place due to the presence of excessive leachate in the system which can have a negative influence on microbial activities, thereby causing the organic substrate to soar or loose nutritional value for the microorganisms.

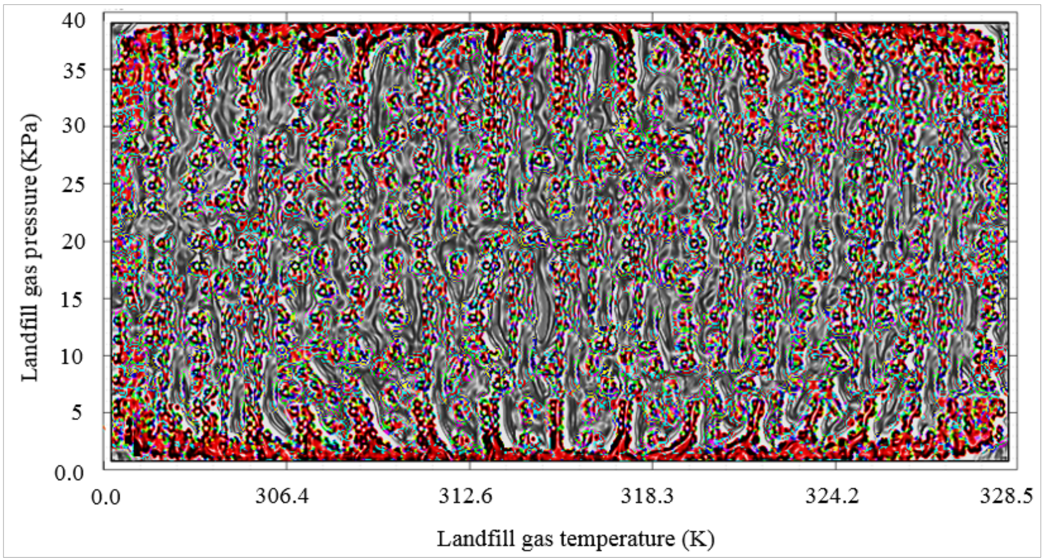


Figure 6. Saturated porous media with hydraulic conductivity of $1x10^{-12}$ m/s

Studies have also shown that high waste compaction may not be ideal for some landfills such as landfills with high moisture content or bioreactor landfill with leachate circulation, as it could be difficult for leachate to flow through the highly compacted waste layers that are more or less saturated and therefore causing pore pressure build-ups (Khalil *et al*., 2014). However, Buivid et al. (1981) noted that higher compaction under well-mixed static landfill condition yielded higher methane gas volume. Hydraulic conductivity of a saturated waste is defined by Darcy's law and has the same unit as that of velocity. Hydraulic conductivities obtained from the field design in this study were in the range of $4.7x10^{-6}$ and $1x10^{-2}$ m/s. Hydraulic conductivity of MSW reported in literature vary approximately between $1.7x10^{-4}$ and $2.0x10^{-4}$ m/s (Beaven and Powrie, 1995), $4.7x10^{-7}$ and $9.6x10^{-4}$ m/s (Chen and Chynoweth, 1995), $3.9x10^{-7}$ and $6.7x10^{-5}$ m/s (Burrows et al., 1997), $5.7x10^{-8}$ and $1.9x10^{-7}$ m/s (Jain et al., 2006). However, effective porosities obtained from the field design in this study was used to determine the degree of saturation for MSW in prototype landfill presented in this study, which were in the range of 41.2-73.6%. Effective porosities of MSW reported in literature vary approximately between 1.5 and 14.4% and total porosity between 45.5 and 55.5 % (Hudson et al., 2004), 47 and 57% (Zeiss, 1997), 48 and 51% (Olivier and Gourc, 2007), 45 and 62% (Stoltz & Gourc, 2007).

Figure 7 depicts the landfill models for gas pressure and mass flow rate at inactive state. Therefore, gas pressure and mass flow rate values for these models at inactive state are zero. The landfilled waste media is still undergoing hydrolysis, the conversion of polymetric organic matter (polysaccharides, lipids, proteins) to monomers (sugar, fatty acids, amino acids) by hydrolases secreted on the waste media by microorganisms. Heat and leachate are integral part of hydrolysis process even as decomposition, gas production as well as flow across the porous media (Sikora, 2017). At the end of hydrolysis, the next process in the anaerobic digestion of landfill waste is known as acidogenesis. In this process, the products of hydrolysis are converted to non-gaseous short-chain fatty acids, alcohols, aldehydes and gases such as carbon dioxide and hydrogen. In the third stage known as acetogenesis, the non-gaseous products are further oxidized into hydrogen, carbon dioxide and acetate via syntrophic degradation process. The fourth stage is known as methanogenesis (methane formation stage) while acetogenesis and methanogenesis are closely connected in the last two stages, involving syntrophic associations between hydrogen-producing acetogenic bacteria and hydrogenotrophic methanogens.

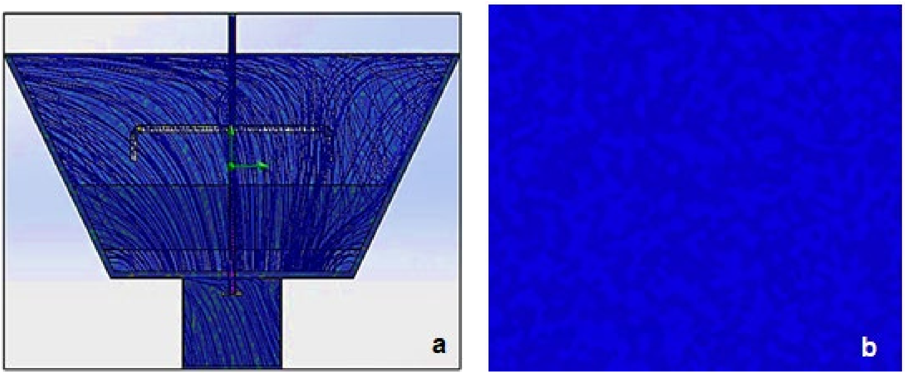


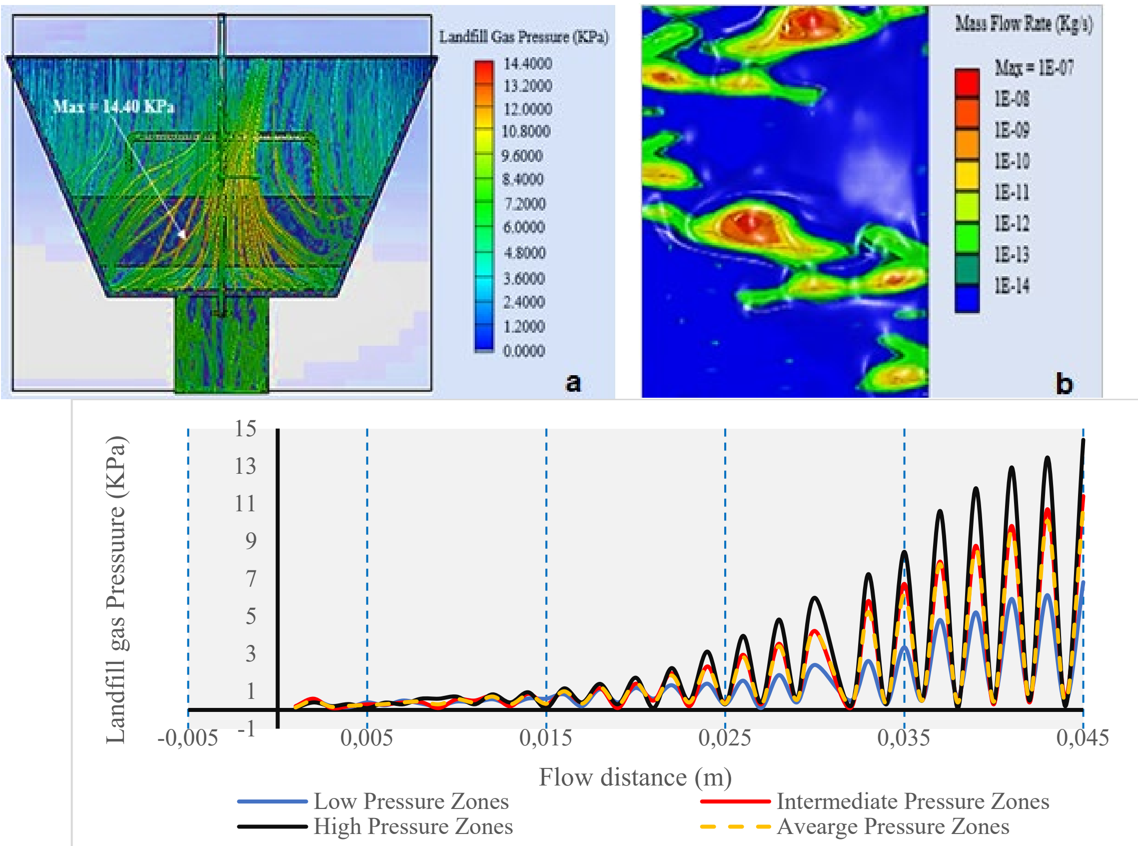
Figure 7. Models of landfill system at inactive state. **a.** Gas pressure**, b.** mass flow rate

The main classification of substrates for methane production includes splitting of acetate, CO_2 reduction with H_2 or formate and rarely ethanol or secondary alcohols as electron donors and reduction in methyl groups of methylated compounds such as methanol, methylated amines or methylated sulphides while methanogenic pathways with respect to each of these classifications include aceticlastic/acetotrophic methanogenesis, hydrogenotrophic methanogenesis as well as hydrogen dependent and hydrogen-independent methylotrophic methanogenesis (Hedderich and Whitman, 2006; Borrel et al., 2013). Acetate is a significant intermediate product in the process of anaerobic digestion of biodegradables to CH_4 and CO_2, as it can be directly converted to CH_4 and CO_2 via acetoclastic methanogens or syntrophically oxidize to H_2 and CO_2 (Schink & Stamms, 2006).

Landfill gas is the outcome of three processes including the evaporation of volatile organic compounds such as solvents, chemical and biological reaction between waste substrates as well as microbial activities particully methanogenesis. While the first two processes depend majorly on the waste characteristics, the dominant process in landfill systems is the third process where organic waste is broken down by anaerobic bacteria to produce biogas which comprises CH_4, CO_2 and traces of other compounds (Ebunilo *et al*., 2018; Ikpe *et al*., 2019). Despite the heterogeneity of landfilled waste matrix, the evolution of gas across unsaturated porous media maintains a specific kinematic pattern which involves flow from a region of saturated and semi-saturated porous media to a region of unsaturated porous media. It also involves flow from a region of higher temperature and pressure to a region of lower temperature and pressure. This is because, higher and optimum temperature accelerates organic waste decomposition for rapid production of landfill gas.

Figure 8a represents landfill gas pressure trajectories at anaerobic digestion temperature of 305K. The maximum landfill gas pressure at anaerobic digestion temperature of 305K is observed as 14.40 Kpa. The gas pressure trajectores shows the pressure flowing towards the peforatted holes on the gas extraction pipe and the upper section of the landfill which is not porous and not suturated by the upflowing gas. The upper section of the landfill (which can also be considered as a mini gas holder) and the gas extraction channels are completely empty and less saturated. Thus, landfill gas evolving from the anaerobic digestion process flows from high pressure regions to low pressure regions in the porous waste media and when saturated, flows upward to occupy the space at the upper section of the waste layer prior to evacuation. Figure 8b shows the mass flow rate of landfill gas at anaerobic digestion temperature of 305K, implying that with anaerobic digestion temperature of 305K, maximum mass flow rate of 1E-07 Kg/s is obtained. landfill gas due to the presence of other gases, the mass flow rate of landfill gas is decribed as a large number of different microscopic atomic or molecular particles (the mass densities are different because gases have different masses per particle) flowing in constant, rapid ramdom motion within the boundary walls of the landfill system. Hence, the density of landfill gas is described as the mass of gas occupying the landfill volume at a specified tempreyure and pressure. Mass flow rate of the gas particles intensify with higher pressures, causing the gas particles to undergo random elastic collisions with one anotherand with the boundary walls of the system.

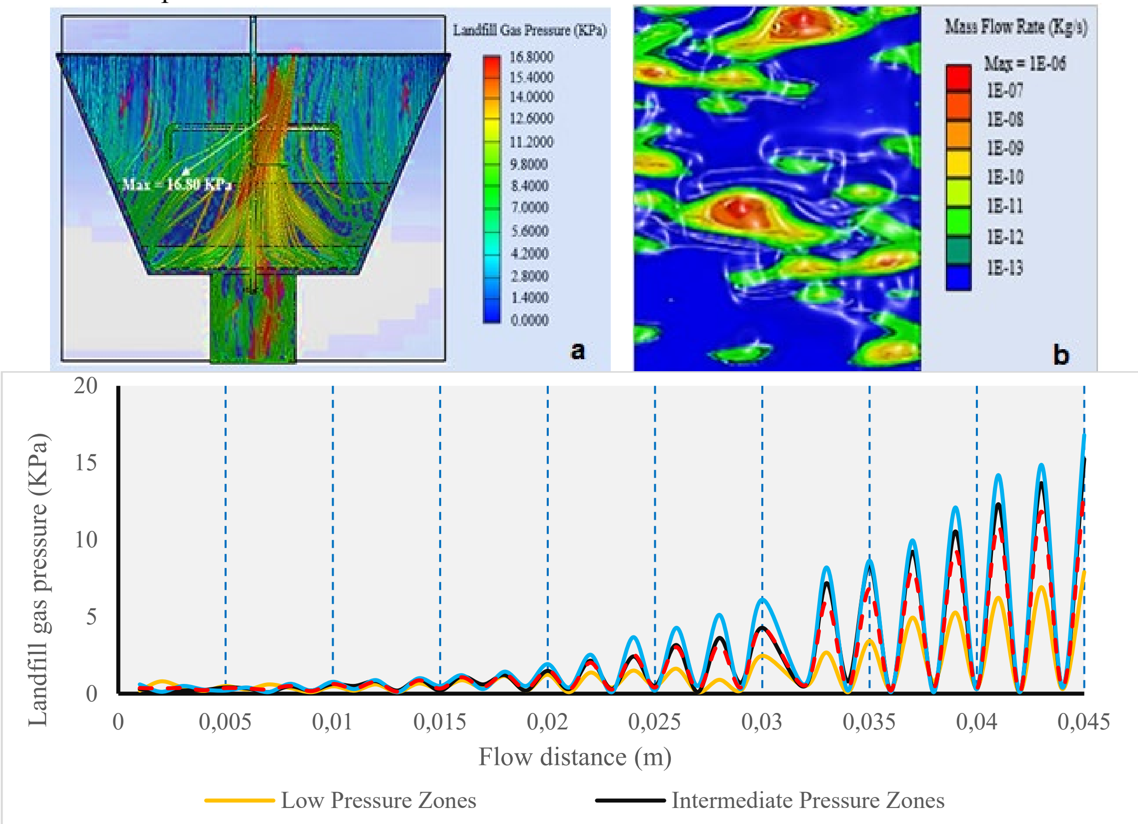
Figure 8c shows landfill gas pressure for various flow distances at landfill anaerobic temperature of 305 K. Maximum landfill gas pressure obtained at low, intermediate and high pressure zones within the landfill confinments were 6.81, 11.4 and 14.4 with an average of 10.87 KPa along maximum flow distance of 0.045 m.The plot indicates that the migration of landfill gas within the boudary walls of the system is characterized by brownian motion resulting from random movement of suspended gas particles in the landfill system. The pattern of motion is typically characterized by random fluctuations along a particles's position within sub-domain of the fluid (landfill gas) followed by a variational movement to another sub-domain. Each movement is followed by further fluctuations within the boundaries walls of the new enclosed volume. Consequently, direction of the force of atomic bombardment changes constantly, and at different intervals, the particles is hit moreon one side than another, resulting in random nature of the motion exhibited by the gas particles. As indicated by the plot in Figure 8c, the gas movement does not have a specific or preferencial direction of flow, and the parttern describes the landfill gas under thermal equilibrium, as the temperature within each domain and sub-domain is spatially uniform and temporally constant. In this context, the overall linear and angular momentum of the gas remains null over time. Therefore, the kinetic energies of the molecular brownian motions, alongside those of molecular rotations and vibrations sum up to the calorific component of the gas's internal energy.



c.

Figure 8. a. Landfill gas pressure at anaerobic digestion temperature of 305K, b. Mass flow rate at anaerobic digestion temperature of 305K, c. Plot of landfill gas pressure against the flow distance

Figure 9a represents landfill gas pressure trajectories at anaerobic digestion temperature of 309K. The maximum landfill gas pressure at anaerobic digestion temperature of 309K is observed as 16.80 Kpa. Figure 9b shows the mass flow rate of landfill gas at anaerobic digestion temperature of 309K, implying that with anaerobic digestion temperature of 309K, maximum mass flow rate of 1E-06 kg/s is obtained. Figure 9c shows landfill gas pressure for various flow distances at the same landfill anaerobic temperature of 309 K. The maximum landfill gas pressure obtained at low, intermediate and high pressure zones within the landfill confinments were 7.9, 15.24 and 16.8 with an average of 13.31 KPa along maximum flow distance of 0.045 m. The results indicate that the maximum landfill gas pressure and mass flow rate are higher at anaerobic digestion temperature of 309K than anarobic temperature of 305K reported previously. Similarly, the maximum landfill gas pressure obtained at low, intermediate and high pressure zones within the landfill confinments were also higher than those reported previously for anarobic temperature of 305K.

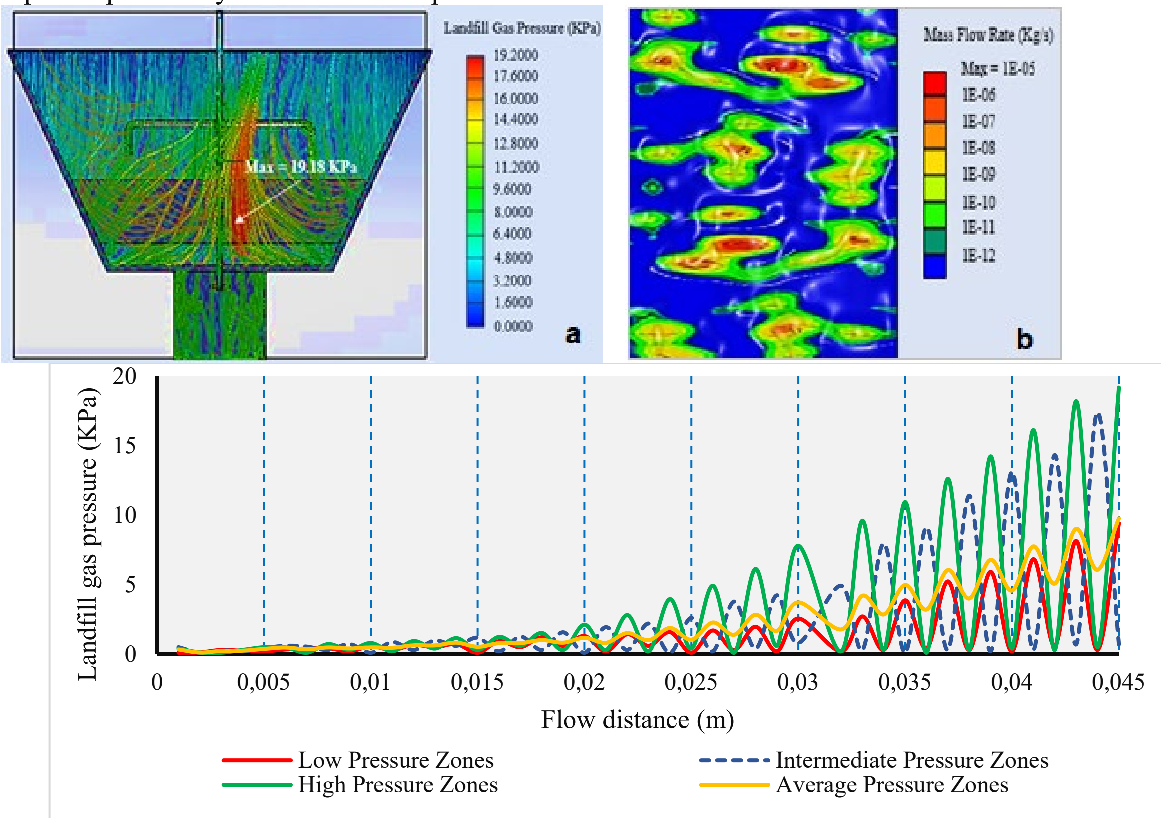


c.

Figure 9. a. Landfill gas pressure at anaerobic digestion temperature of 309K, b. Mass flow rate at anaerobic digestion temperature of 309K, c. Plot of landfill gas pressure against the flow distance

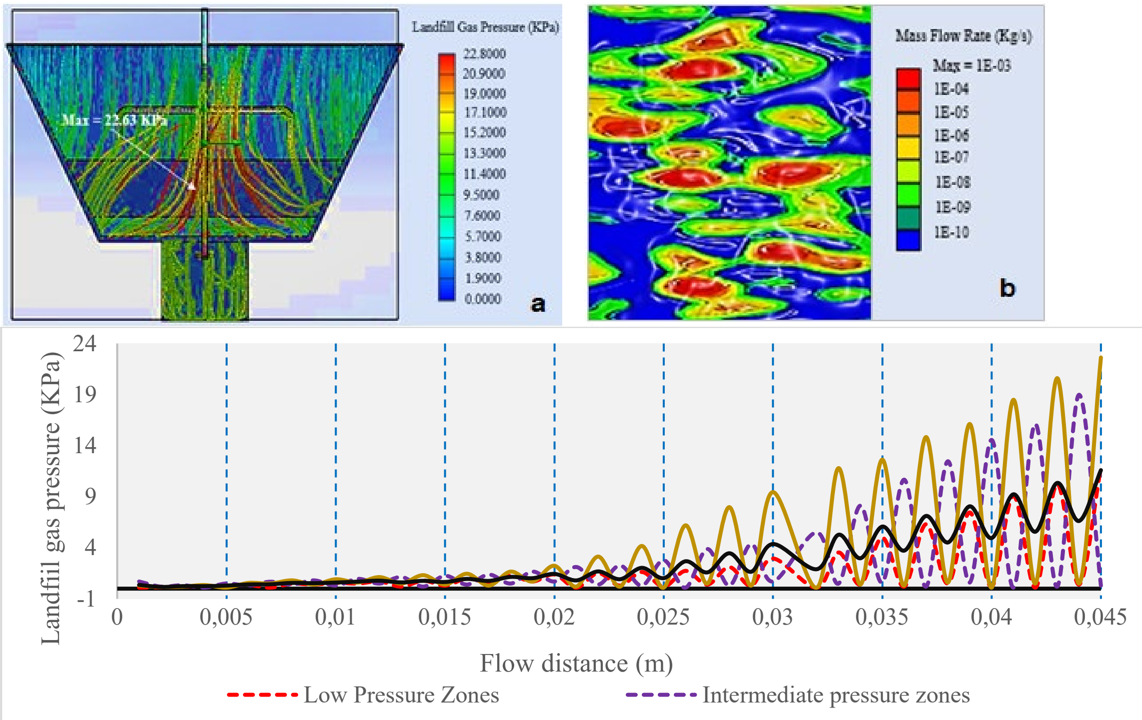
Figure 10a represents landfill gas pressure trajectories at anaerobic digestion temperature of 313K. The maximum landfill gas pressure at anaerobic digestion temperature of 313K is observed as 19.20 Kpa while a maximum mass flow rate of 1E-05 Kg/s was obtained at anaerobic digestion temperature of 313K in Figure 10b. Landfill gas pressure for various flow distances at landfill anaerobic temperature of 313K is shown in Figure 10c, where maximum landfill gas pressure at low, intermediate and high pressure zones within the landfill confinments were recorded as 9.42, 17.4 and 19.18 with an average of 15.3 KPa along maximum flow distance of 0.045 m. The results indicate that the maximum landfill gas pressure and mass flow rate are higher at anaerobic digestion temperature of 313K than anarobic temperature of 309K reported previously. Similarly, the maximum landfill gas pressure obtained at low, intermediate and high pressure zones within the landfill confinments were also higher than those reported previously for anarobic temperature of 309K.

Figure 11a represents landfill gas pressure trajectories at anaerobic digestion temperature of 317K. At anaerobic digestion temperature of 317K, the maximum landfill gas pressure was observed as 22.80 Kpa while the maximum mass flow rate of 1E-03 Kg/s was obtained at anaerobic digestion temperature of 309K in Figure 11b. Landfill gas pressure for various flow distances at anaerobic temperature of 317K is shown in Figure 11c, indicating maximum landfill gas pressure at low, intermediate and high pressure zones within the landfill confinments as 11.87, 18.98 and 22.63 with an average of 17.8 KPa across 0.045 m maximum flow distance. From the results aforementioned, maximum landfill gas pressure and mass flow rate are higher at anaerobic digestion temperature of 317K than anarobic temperature of 313K reported previously. Similarly, the maximum landfill gas pressure obtained at low, intermediate and high pressure zones within the landfill confinments were also higher than those reported previously for anarobic temperature of 313K.



c.

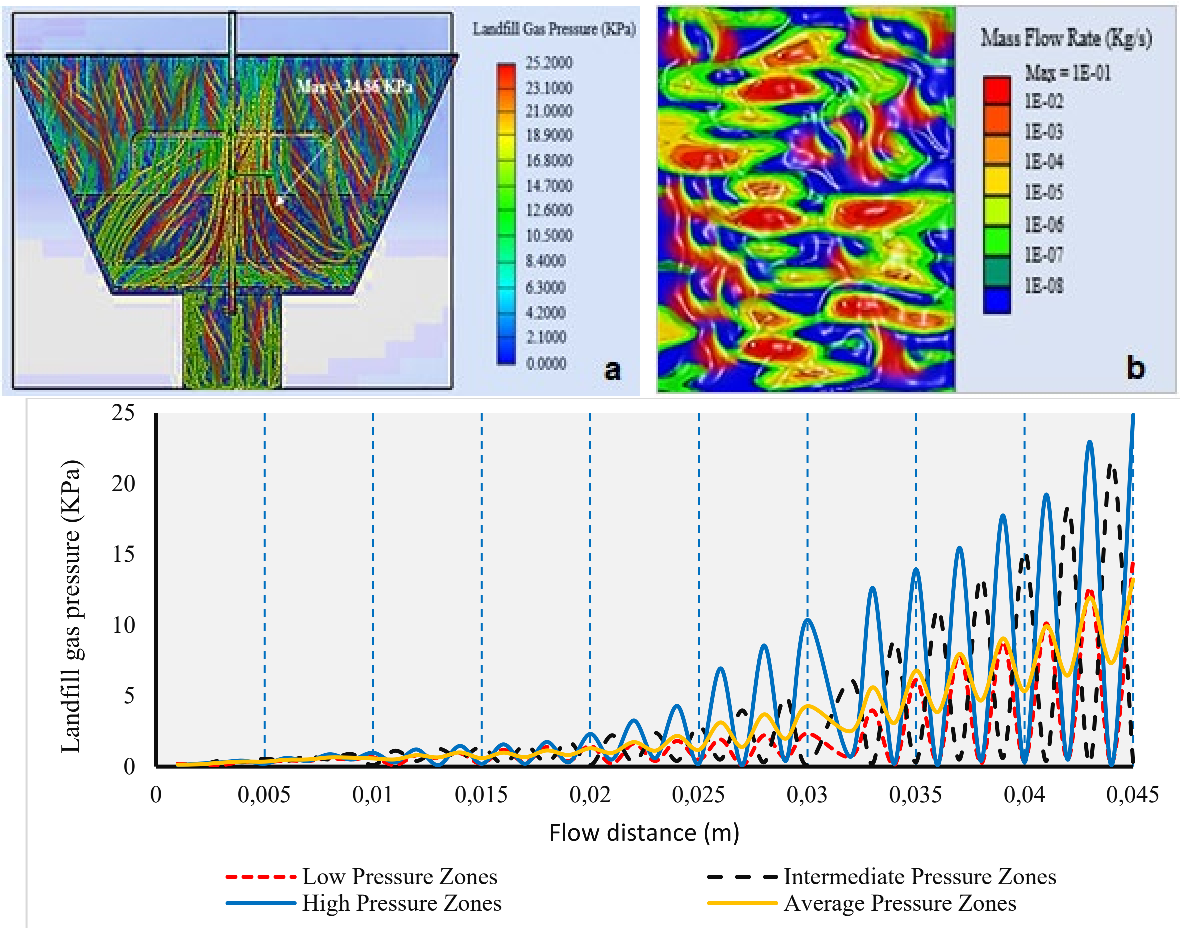
Figure 10. a. Landfill gas pressure at anaerobic digestion temperature of 313K, b. Mass flow rate at anaerobic digestion temperature of 313K, c. Plot of landfill gas pressure against the flow distance



c.

Figure 11. a. Landfill gas pressure at anaerobic digestion temperature of 317K, b. Mass flow rate at anaerobic digestion temperature of 317K, c. Plot of landfill gas pressure against the flow distance

Figure 12a represents landfill gas pressure trajectories at anaerobic digestion temperature of 321K. At anaerobic digestion temperature of 321K, the maximum landfill gas pressure was observed as 25.20 Kpa while the maximum mass flow rate of 1E-01 Kg/s was obtained at anaerobic digestion temperature of 309K in Figure 12b. Landfill gas pressure for various flow distances at anaerobic temperature of 321K is shown in Figure 12c, indicating maximum landfill gas pressure at low, intermediate and high pressure zones within the landfill confinments as 14.71, 21.63 and 24.86 with an average of 20.4 KPa along 0.045 m maximum flow distance. From the results aforementioned, maximum landfill gas pressure and mass flow rate are higher at anaerobic digestion temperature of 321K than anarobic temperature of 317K reported previously. Similarly, the maximum landfill gas pressure obtained at low, intermediate and high pressure zones within the landfill confinments were also higher than those previously mentioned for anarobic temperature of 317K.



c

Figure 12. a. Landfill gas pressure at anaerobic digestion temperature of 321K, b. Mass flow rate at anaerobic digestion temperature of 321K, **c.** Plot of landfill gas pressure against the flow distance

Conclusion

In this study, the kinetics of anaerobic digestion temperature regime in relation to multiphase flow across unsaturated porous organic waste media in a prototype landfill design framework was successfully modelled. It was observed that moles of the landfill gas per unit flow rate were much with higher pressures compared to lower pressures which only had few moles of gas per unit flow rate. This is because at higher pressure, mass flow rate of the landfill gas increases significantly, and in the process carries a large number of gas particles which represents mole density of the landfill gas flowing per unit area across the unsaturated porous waste media. Findings from this study also reveal that multiphase flow of landfill gas is a function of the temperature and heat distribution rate across the unsaturated porous waste media. Therefore, optimum temperature within the landfill system accelerates the rate of heat distribution and microbial activities (breaking down of organic substrate) for proper decomposition of organic fraction of waste within each layer in the landfill system. Although semi-saturated and saturated porous waste media was not fully analysed in this study, it is deduced from the models developed that landfill gas pressure and mass flow rate in the unsaturated media is higher than both parameters in semi-saturated and saturated porous waste media. However, landfill gas pressure and mass flow rate in the semi-saturated media is higher than both parameters in the saturated porous waste media which appears to be almost impervious. Hence, engineered landfill system designed for gas production should be managed as unsaturated porous media for effective gas recovery.

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Research Paper

Analysis and Evaluation of a Developed Municipal Solid Waste Shredding Machine for Okada Community, Nigeria

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Abstract: Nigeria generates more than 32 million tons of solid waste annually, out of which only 20–30% is collected and disposed in an open dump site. Besides, reckless disposal of solid waste has led to blockage of sewers and drainage networks and choking of water bodies. More so, the problem of solid waste management has become one of the nation's most serious environmental problems. In this research work, analysis, and evaluation of a developed municipal solid waste shredding machine for Okada community, Nigeria was carried out. The shredding machine was developed and evaluated for performance using individual waste components. Parameters such as efficiency, shredding time, and machine throughput capacity were determined using food waste, paper waste, plastic, and nylon waste. Furthermore, the composition and analysis of the solid waste stream in the Okada community was carried out. The density, moisture content, and volume of municipal solid waste were determined. The values obtained were used to determine the daily amount of municipal solid waste generated in the Okada community. Load Count Analysis techniques were used to determine the volume of municipal solid waste generated daily. From the experimental results obtained, shredding techniques for solid waste treatment were most suitable for the Okada community. Besides, it was determined that food waste, with 28.0%, and plastic and nylon, with 21.0%, have the highest percentage composition of municipal solid waste generated in the Okada community. It was also revealed that food waste has the highest quantity of properly shredded waste (48.89 kg), and this was followed by paper waste, with a mass of 47.85 kg properly shredded. Furthermore, it was revealed from the research work that 3,027.6 kg of municipal solid waste will be generated daily in the Okada community. Besides, the developed machine was efficient because in each of the tests and evaluations of individual waste components, the efficiency obtained was above 80%.

***Keywords**: Municipal Solid Waste; Treatment; Shredding Machine; Waste Composition; Machine Efficiency; Okada Community*

Introduction

Solid waste, as the name implies, simply means a leftover or already used item waiting for reuse or disposal (Titus & Anim, 2014; Orhorhoro *et al.,* 2017). The volume of solid waste generated daily is largely dependent mainly on two factors, namely: the population in any given area and the consumption pattern of the inhabitants of such an area (Portelinha *et al.,* 2022). As reported by the United Nations (UN), the world population is expected to rise from the current 7.3 to 8.5 billion by 2030 and thus increase to 9.7 billion by 2050 if no specific control measures are properly adopted (Mavropoulos, 2010; Hoornweg *et al.,* 2014), with developing countries such as Nigeria and other sub-Saharan African countries having the highest share. Also, about 97% of this growth is expected to take place in Asia and Africa due to their increased population and industrialization (UNWPE, 2016). According to the United Nations' habitat watch, African city populations will triple over the next 40 years (UNDP, 2010). More so, African cities are already inundated with slums, a phenomenon that could triple urban populations and spell disaster, unless urgent actions are initiated. Regrettably, Africa and Asian countries have the least capability to absorb the associated waste increase. Nigeria's population already exceeds 200 million and is not decreasing, despite soaring energy needs, while the resulting massive wastes pose health and environmental hazards due to improper management.

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According to research, solid waste is generated and dumped indiscriminately in Nigeria due to poor standard implementation, posing environmental and public health risks (Igbinomwanhia *et al.,* 2012; Orhorhoro *et al.,* 2021; Orhorhoro *et al.,* 2022; Oyebanji *et al.,* 2022). Nigeria generates more than 32 million tons of solid waste annually, out of which only 20–30% is collected and disposed of in an open dump site (Owamah *et al.,* 2015). Besides, reckless disposal of solid waste has led to blockage of sewers and drainage networks and choking of water bodies. Most of the waste is generated by households and, in some cases, by local industries. The poor waste management in Nigeria towns is as a result of laws on waste management not been enacted by state and local government council, the careless disposal of generated waste by the Okada population and the inefficient collection and disposal of waste by the contractors in charge of the truck operator (Owamah *et al.,* 2015).

There are many artisans and traders who litter the immediate surroundings. Improper collection and disposal of solid waste is leading to an environmental catastrophe as the country currently lacks adequate budgetary provisions for the implementation of integrated waste management programs across the states (Omole and Alakinde, 2013). The standard of solid waste treatment/management in Nigeria is at its lowest with poor documentation of waste generation rates, inefficient storage and collection systems, and the under-utilization of disposal sites (Kadafa *et al.,* 2012). Nigeria's urban cities are today struggling to clear heaps of solid waste from their environment. Thus, strategic centres of attraction in Nigeria are now taken over by the messy nature of unattended heaps of solid waste emanating from the society. Likewise, city officials appear unable to combat unlawful dumping of solid waste, which is a clear violation of the clean air and health ethics in our environmental sanitation laws and regulations in Nigeria. Solid waste management is the most pressing environmental challenge faced by urban and rural areas of Nigeria. Irrespective of policies and regulations, solid waste management in the country is assuming alarming proportions with each passing day. No wonder, out of the 36 states and the Federal Capital Territory (FCT), only a few have shown a considerable level of resolve to take proactive steps in fighting this scourge, while the rest have merely paid lip service to issues of waste management, indicating a huge lack of interest in developing the waste sector (Hoornweg and Bhada-Tata, 2012).

For instance, Lagos State, the commercial hub of Nigeria, is the second fastest growing city in Africa and the seventh fastest in the world. The latest reports estimate its population to be more than 21 million, making it the largest city in all of Africa. With a per capita waste generation of 0.5 kg per day, the city generates more than 10,000 tons of urban waste every day (Benjamin *et al.,* 2014). Despite being a model for other states in the country, municipal solid waste management is a big challenge for the Lagos State Waste Management Agency (LAWMA) to manage. Hence, the need to engage the services of private waste firms and other franchisees to reduce the burden of waste collection and disposal. One vital issue is the delayed collection of household solid waste. In some cases, the waste is not collected until after a week or two; consequently, the waste bin overflows and litters the surroundings (Benjamin *et al.,* 2014). Improper waste disposal and a lack of reliable transport infrastructure mean that collected waste is soon dispersed to other localities. Another undesirable practice is overloading collection trucks with 5-6 tons of waste in order to reduce the number of trips; this has prompted calls by environmental activists to persuade the relevant legislature to conform to modern waste transportation standards (Igbinomwanhia, *et al.,* 2011). The government at the federal level, as a matter of urgency, needs to revive its regulatory framework that will be attractive for private sectors to invest in waste collection, recycling, and reusing. The environmental health officer's registration council of Nigeria should do well to intensify more efforts to monitor and enforce sanitation laws as well as regulate the activities of the franchisees on good sustainable practices. Thus, there is an urgent need to develop a system that can treat generated solid waste.

Solid waste treatment refers to the activities required to ensure that waste has the least practicable impact on the environment; it is the use of physical, chemical, biological, or thermal technologies to reduce the volume, toxicity, and/or mobility of waste (Batista *et al.,* 2021, Khan *et al.,* 2021; Pheakdey *et. al,* 2022). Now, the waste management and treatment situation in Nigeria currently requires a concerted effort to sensitize the public on the need for proper disposal of solid waste. Furthermore, officials should be well trained in professionalism, service delivery, and ensuring that other states in the country have access to quality waste managers who are within their reach and can advise them on the best approach to managing their waste prior to collection. The problems of inadequate solid waste management are enormous and require urgent attention. Therefore, there is a need to exploit all available options that will ameliorate the situation. The use of a machine for solid waste treatment will contribute positively to the country's waste management crisis and at the same time reduce the effect of increased waste generation in Nigeria.

Material and Method

Composition and Analysis of Solid Waste Stream

This is probably the most significant characteristic affecting the proper disposal or recovery of material and energy from the waste stream. The composition of a solid waste stream can vary considerably from one form to another, i.e., it contains both physical and chemical composition. Information on the properties of solid waste is important in evaluating management programs and plans. The research which ascertains the treatment method best applicable in Okada community will be determined by the physical composition of the solid waste stream and not by its chemical composition. Chemical composition is only important in the consideration of incineration as an alternative processing and energy recovery option. The information and data on the physical composition of solid wastes include identification of the individual components that make up industrial and municipal solid wastes, the density of solid wastes, and the moisture content.

Sample collection and Analysis

The segregation of solid waste was done at the site of generation. The procedure applied in the segregation of solid waste and analysis is outlined below.

i. A 100 kg weighted sample of solid waste was taken from dumpsites, bins and other areas like the Old Boys' Hostel environment of Igbinedion University, Okada.
ii. A specific weighed quantity of solid waste. In this case, 1 kg was taken from the 100 kg weighed sample and separated into its individual components.
iii. The same process of segregation was applied to the remaining 99 kg.
iv. The various segregated constituents were placed in a container of known volume, in this case, 0.5. The wet mass (initial mass of waste constituent prior to drying) was measured using a spring balance while the volume of each waste constituent was measured using a volumeter. The result was noted.
v. The degree of composition of the waste constituent in comparison to the total waste was determined mathematically from the wet mass of the segregated components.
vi. The degree of composition, volume, and mass of each of the waste constituents were determined and noted.

On sampling the waste stream at the dumpsite at Okada community, the following categories and segregations of waste were observed:

i. Bio-degradable solid wastes, which include kitchen waste, vegetables, fruit, flowers, leaves from the garden, paper, and leather.
ii. Non-biodegradable waste that can be further classified.
   a. Recyclable wastes such as plastics, paper, glass, metal, and rubber tin cans are recyclable.
   b. Paints, chemicals, bulbs, spray cans, batteries, and shoe polish are examples of toxic waste.

Determination of Density and Moisture Content of Waste Sample

The density of municipal solid waste is given by Equation (1)

$$Density\ of\ waste\ sample = \frac{Mass\ of\ waste\ sample\ (kg)}{Volume\ of\ waste\ sample\ (m^3)} \quad (1)$$

The moisture content of municipal solid waste is expressed as the moisture content per unit of dry material. The dry waste is generated by bio-drying. The wet mass moisture content is expressed as shown in Equation (2).

$$M(\%) = \frac{W-D}{W} \times 100 \quad (2)$$

where,
M (%) = Percentage moisture content
W = Initial mass of sample
D = Mass of sample after drying
The waste with the highest mass determines the treatment method best applicable to Okada.

Estimation of Municipal Solid Waste Generated in the Study Area

The method used to determine the volume of waste generated in a day in this research is called load-count analysis. In this method, the quantity of municipal solid waste is determined by recording the estimated volume of each truckload of waste collected in the generation area (Okada) in a day. Equation (3) is used to determine the volume of waste generated.

$$V_{TL} = L_T \times B_T \times H_T \quad (3)$$

where,
V_{TL} = Volume of truck load of municipal waste (m^3)
L_T = Length of truck (m^3)
B_T = Breadth of truck (m^3)
H_T = Height of truck (m)

Detailed Designed and Description of the Machine

The shredding machine is comprised of the frame, motor, pulley, bearing, shaft, shredding chamber, and castrol wheels. The shredding chamber is mounted on the frame. Inside it is an HSS cutting blade propelled by a motor which drives a system of pulleys and bearings connected to the blade. The rotation of the blade generates heat, which, in combination with its sharp ends, induces the size reduction action of the machine. An outlet on the drum is provided for collection of the shredded waste. The shredding force is the force required to successfully shred the municipal solid waste samples to the desired sizes and is calculated from Equation (4) (Khurmi & Gupta, 2013).

$$F_s = ma \quad (4)$$

where,
F_s = Shredding force
m = mass of municipal solid waste + mass of shredding chamber (kg)
a = g (m/s^2)

To know the torque required to shred the municipal solid waste samples, it has become necessary to determine the shredding torque. The shredding torque is given by Equation (5) (Khurmi & Gupta, 2013).

$$T_s = F_s r \quad (5)$$

where,
F_s = Shredding force
T_s = Required torque (Nm)
r = Radius from axis of rotation to point of application of force (m)

The velocity ratio for belt drive is the ratio between the velocity of the driver and the follower (driven). It may be expressed mathematically as(Khurmi & Gupta, 2013):

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (6)$$

where,
d_1 = Diameter of the driver (m)
d_2 = Diameter of the follower (m)
N_1 = Speed of the driver (m)
N_2 = Speed of the driven

Length of the belt that passes over the driver in one minute is given by;

$$\pi d_1 N_1 \quad (7)$$

Similarly, length of belt that passes over the follower in one minute is given by,

$$\pi d_2 N_2 \quad (8)$$

Since the belt passes over the driver in one minute is equal to the length of the belt that passes over the follower in one minute

Therefore;

$$\pi d_1 N_1 = \pi d_2 N_2 \quad (9)$$

Therefore,

$$\frac{N_2}{N_1} = \frac{d_1}{d_2} \quad (10)$$

The required velocity is given by Equation (11) (Khurmi & Gupta, 2013).

$V = \frac{\pi DN}{60}$ (11)

The power requires to shred the grass is given by Equation (12) (Khurmi & Gupta, 2013).

$P = FV$ (12)

The centre to centre distance between driver and driven pulley is given by Equation (13)

$C = 2D_1 + D_2$ (13)

where,

D_1 = Diameter of the driver (m)

D_2 = Diameter of the driving (m)

C= Centre to centre distance between driver pulley and driven pulley

The belt length can be obtained as given by Equation (14) (Khurmi & Gupta, 2013)

$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1+D_2}{4C}$ (14)

The equation is expressed as follow (Khurmi and Gupta, 2005):

$\alpha = 180 \pm 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right)$ (15)

where,

α_1 = Angle of lap for driver pulley (rad)

α_2 = Angle of lap for driven pulley

C = Centre to centre distance between driving pulley and driven pulley

The belt tension can be calculated as follow (Khurmi & Gupta, 2013)

$2.3log\left(\frac{T_1}{T_2}\right) = \mu\alpha$ (16)

where,

α = Angle of wrap of an open belt

μ= Coefficient of friction

T_1= Tension in the tight side of the belt

T_2= Tension in the slack side of the belt

Also;

$P = (T_1 - T_2)V$ (17)

where,

P = Belt power (watts)

V = Belt speed (m/sec)

T_1 and T_2 are tension on the tight and slack sides respectively (N)

The shaft diameter is determined as follow;

Let;

τ = Shear stress induced due to twisting moment, and

σ_b = Bending stress (tensile or compressive) induced due to bending moment.

According to maximum shear stress theory, the maximum shear stress in the shaft Khurmi & Gupta, 2013),

$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$ (18)

But,

$\sigma_b = \frac{32M}{\pi d^3}$ (19)

$\tau = \frac{16T}{\pi d^3}$ (20)

Substituting Equation (20) and (19) into Equation (18) (Khurmi & Gupta, 2013)

$\tau_{max} = \frac{1}{2}\sqrt{(\frac{32M}{\pi d^3})^2 + 4(\frac{16T}{\pi d^3})}$ (21)

Thus,

$\tau_{max} = \frac{\pi d}{16}[\sqrt{M^2 + T^2}]$ (22)

Also,

$\frac{\pi}{16} \times \tau_{max} \times d^3 = [\sqrt{M^2 + T^2}]$ (23)

$T_e = [\sqrt{M^2 + T^2}]$ (24)

The expression $\sqrt{M^2 + T^2}$ is known as the equivalent twisting moment and is denoted by Te. The equivalent twisting moment may be defined as that twisting moment which, when acting alone, produces the same shear stress as the actual twisting moment. Table 1 shows the component parts, material used, and justification.

Table 1. Machine Parts, Materials Used and Justification

S/N	Component part	Material used	Justification
I	Shredding/Crunching Chamber	Mild steel sheet	Readily available It undergoes plastic deformation Does not wear easily
ii	Shaft	Stainless Steel	Does not wear easily during operation High tensile strength Ability to resistance corrosion Ability to withstand shear and compressive force.
Iii	Frame	Mild steel angle bar	Readily available Does not wear easily It undergoes plastic deformation
v.	HSS Cutting Blade	Stainless steel	Toughness and strength Corrosion resistance
vi.	Bearing	High Carbon Steel	Resistance to wear and corrosion, hard, tough and has high strength
vii.	Pulley	Cast Iron	Tough, hard, low cost and has high strength
viii.	Angle bar	Mild steel (Low carbon steel)	Ability to withstand shear and compressive force.
Ix	V-belt	Fibre reinforced rubber	It is strong, flexible, and durable It has a high coefficient of friction

Figure 1 shows the picture of the developed solid waste treatment machine installed in the Department of Chemical Engineering, Igbinedion University, Okada, Nigeria.

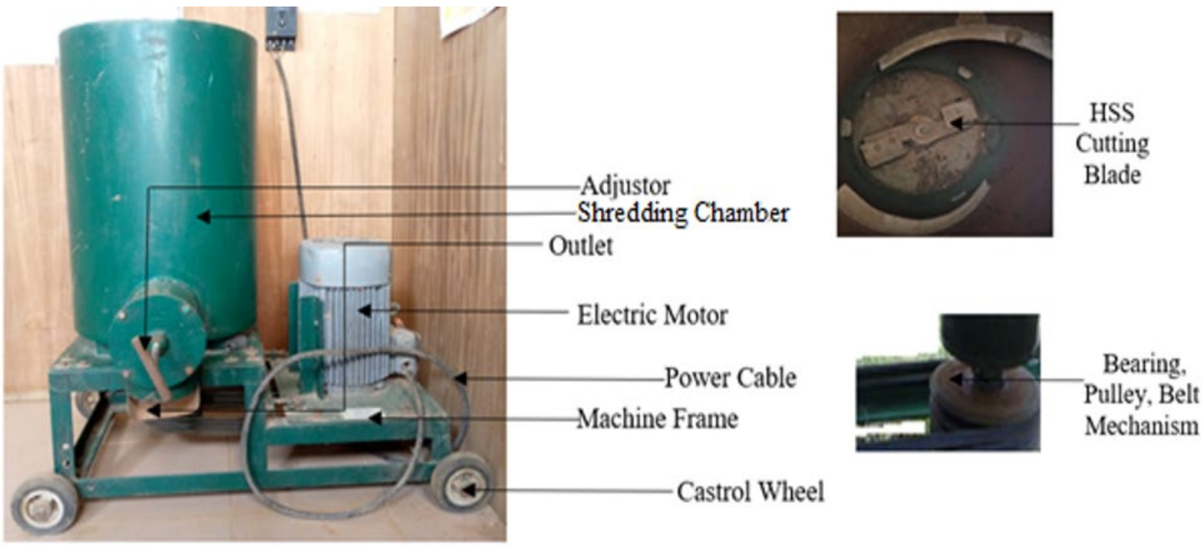

Figure 1. Picture of Developed Solid Waste Treatment Machine Installed in Department of Chemical Engineering, Igbinedion University, Okada, Nigeria

Results and Discussion

The treatment of municipal solid waste in Okada community was investigated during this research work. This was achieved by the segregation of the waste and carrying out a detailed analysis of the waste. From the experimental results obtained, a method of treatment most suitable for Okada was selected. Table 2 shows the results of the individual components, mass, volume, and degree of composition of waste.

Table 2. Results of individual components, mass, volume, and degree of composition of municipal solid waste in Okada community

Individual Components	Wet Mass (Kg)	Degree (°)	Volume(m^3)	Dry Mass (Kg)
Food Waste	28.40	102.24	0.10	8.50
Paper	13.00	46.80	0.15	12.20
Glass	5.60	20.16	0.03	5.60
Plastic And Nylon	20.50	73.80	0.30	20.50
Textiles	6.30	22.68	0.10	5.70
Garden Trimming	5.90	21.24	0.06	2.40
Leather	1.30	4.68	0.01	1.20
Wood	10.60	38.16	0.04	8.50
Metals	1.30	4.68	0.01	1.30
Tin Cans	5.60	20.16	0.06	5.60
Rubbish (Mixed)	1.50	5.40	0.01	1.30
Total	100	360	0.87	72.80

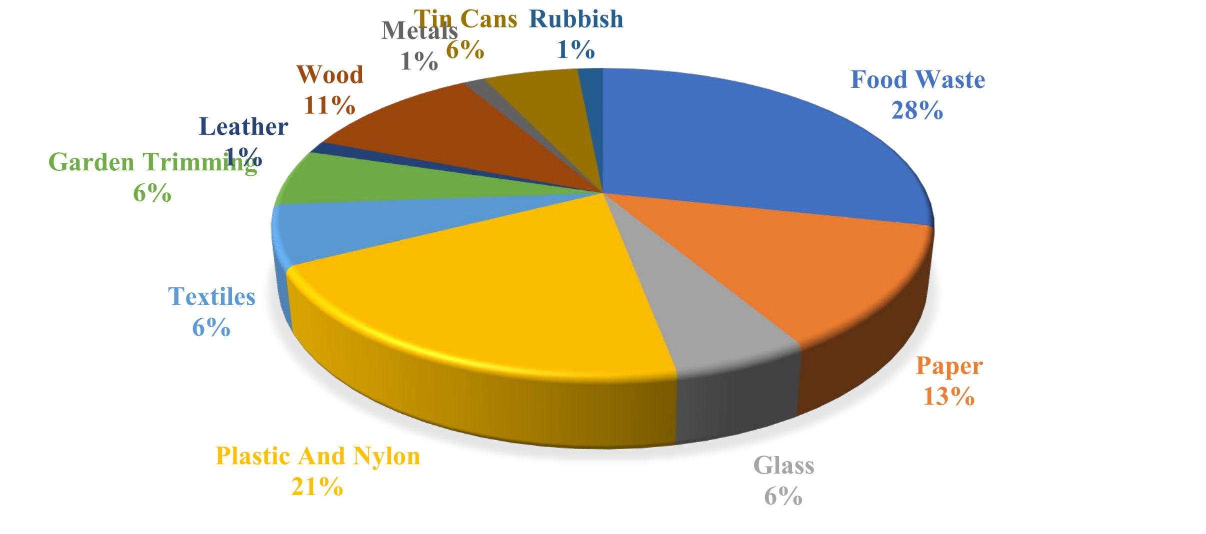

Figure 2. Composition of solid waste in Okada community, Nigeria

As depicted in Figure 2 and Table 2, food waste, with 28%, and plastic and nylon, with 21.0%, have the highest percentage of municipal solid waste generated in Okada metropolis. Other wastes, such as textiles, tin cans, and garden trimmings, account for a smaller proportion of the disposed waste. Thus, the best municipal solid waste treatment in this region is shredding via physical and mechanical techniques of solid waste treatment. Shredding is the process of transferring a force amplified by mechanical advantage through a material made of molecules that bond together more strongly, and resist deformation more, than those in the material being crushed do (Kumar, 2013; Orhorhoro *et al, 2016b*). According to Orhorhoro *et al.* (2017), food waste is highly biodegradable and, when reduced in size by shredding, can be co-digested for biogas production. The various sizes of particles are major factors that can either reduce or increase the hydraulic retention time (HRT) of an anaerobic digestion (AD) system. More so, shorter hydraulic retention times improve biogas yields (Orhorhoro *et al, 2016a*). The size of food waste has direct effects on its decomposition, and this calls for food waste particle reduction by shredding (Ajji & Rhachi, 2013). Reduction of food waste size leads to an increased surface area for microbes, ultimately improving the efficiency of the digester. The shredding operation is a size reduction operation for plastic waste before it is pelletized and extruded into useful consumer end products. To evaluate the performance of the developed shredding machine, 50 kg each of food waste, plastic and nylon waste, and paper waste were used to test the machine. The machine throughput capacity, shredding time, and efficiency were determined, and the results compared. Table 3 shows the results of the performance evaluation of the shredding machine. The particle size of the product obtained from the shredding of the LDPE pure water bags measured about 10 mm. This end product could make up 40-

60% of the recycled content of a new LDPE (Low density polyethylene) product, reducing the environmental nuisance caused by plastic waste.

Table 3. Result of the performance evaluation of the shredding machine

Individual Components	M_1 (kg)	M_2 (kg)	T (Sec)	Eff. (%)	MTC (kg/sec)
Food waste	50	48.89	320	97.78	0.156
Plastic and Nylon Waste	50	40.21	435	80.42	0.115
Paper Waste	50	47.85	395	95.70	0.127

The machine through-put capacity is calculated from Equation (25).

$$MTC = \frac{M_1}{T} \tag{25}$$

The efficiency is given by Equation (26)

$$Eff. = \frac{M_2}{M_1} \times 100 \tag{26}$$

where,
M_1 = Mass of municipal solid before shredding
M_2 = Mass of properly shredded municipal solid waste
The moisture content of total waste stream was determined using Equation (27).

$$Moisture\ content\ of\ total\ waste\ stream = \frac{Total\ wet\ mass - Total\ dry\ mass}{Total\ wet\ mass} \times 100$$

$$\frac{100 - 72.8}{100} \times 100 = 27.2\ \%$$

Table 3 shows the results of selected components of municipal solid waste before and after proper shredding. It was revealed that food waste has the highest quantity of properly shredded waste (48.89 kg), and this was followed by paper waste with a mass of 47.85 kg properly shredded. However, plastic and nylon waste have the smallest mass of properly shredded particles, but this was not an indication of the machine be efficient because in each of the test carried out, the efficiency of the machine were 97.78 % for food waste shredding, 95.70 % for paper waste shredding, and 80.42 % for plastic and nylon waste shredding as shown in Figure 4. In all cases, the efficiency was above 80 % and this was an indication that the machine perform very well.

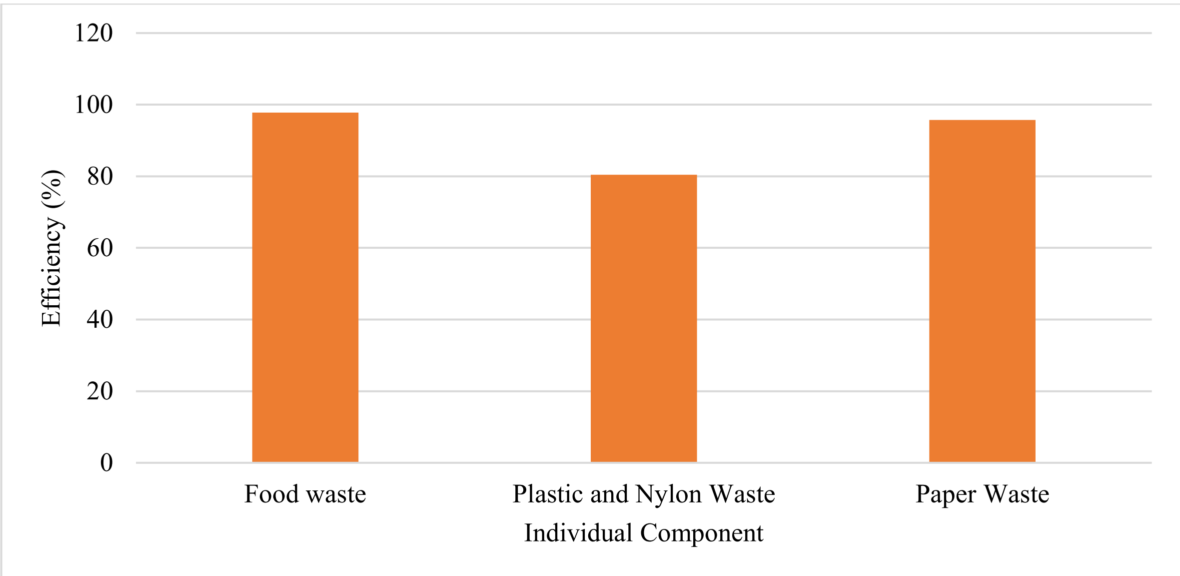

Figure 4. Efficiency of the shredding machine

The result of the machine throughput capacity of the shredding machine, which is the rate at which the mass of municipal solid waste goes through the process per unit time (shredding time), is shown in Figure

5. The outcome of the test revealed a good value of throughput capacity for the shredding machine, and this further affirmed that the machine is efficient and reliable.

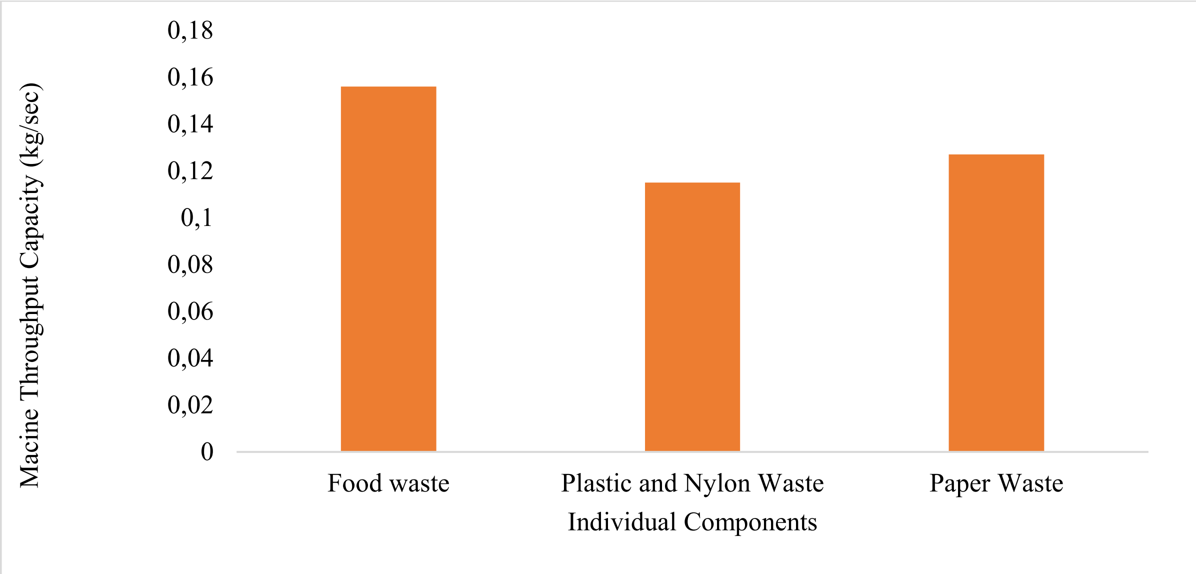

Figure 5. Machine throughput capacity of the shredding machine

Table 4 shows the results of the density and moisture content of individual components of municipal solid waste in the Okada community. As shown in Table 4, food waste has the highest percentage moisture content as expected and metal, glass, paper, plastic and nylon waste have the least moisture content. Thus, shredded food waste and garden trimming can be further processed to generate environmentally friendly and renewable biogas energy, whereas shredded non-biodegradable municipal solid waste with a low moisture content can be processed further using gasification, pyrolysis, incineration, and other methods.

Table 4. Result of the density and moisture content of individual component of municipal solid waste in Okada metropolis

Individual Components	Wet Mass (Kg)	Volume(m^3)	Density (Kg/m^3)	Moisture content, % by mass (m^3)
Food Waste	28.40	0.10	290	70
Paper	13.00	0.15	85	6
Glass	5.60	0.03	195	2
Plastic And Nylon	20.50	0.30	65	2
Textiles	6.30	0.10	65	10
Garden Trimming	5.90	0.06	100	60
Leather	1.30	0.01	160	10
Wood	10.60	0.04	240	20
Metals	1.30	0.01	320	2
Tin Cans	5.60	0.06	90	3
Rubbish (Mixed)	1.50	0.01	130	15
Total	100	0.87	1740	200
Average	9.091	0.079	158.18	18.18

The density and volume of municipal solid waste were determined as 1740 kg/m^3 and 0.87 m^3, respectively, and this value was used to calculate the expected mass of municipal solid waste generated in Okada community using Equation (27). The result revealed that 3,027.6 kg of municipal solid waste will be generated daily in the Okada community.

$$Mass\ of\ generated\ waste\ per\ day = Density\ of\ waste \times Volume\ of\ waste \times trips\ per\ day \quad (27)$$

$$Mass\ of\ generated\ waste\ per\ day = 1740 \times 0.87 \times 2 = 3{,}027.6\ kg$$

Conclusion

Solid waste generation, composition, treatment, disposal and its effects were reviewed in this research work. The poor waste management in the study area is as a result of laws on waste management not having been enacted by the state and local government councils. From the research results obtained, it was revealed that food waste has the highest quantity of properly shredded waste (48.89 kg), and this was followed by paper waste, with a mass of 47.85 kg properly shredded. However, plastic and nylon waste have the smallest mass of properly shredded particles, but this was not an indication of the machine's efficiency because in each of the tests carried out, the efficiency of the machine was 97.78 % for food waste shredding, 95.70 % for paper waste shredding, and 80.42 % for plastic and nylon waste shredding. In all cases, the efficiency was above 80%, and this was an indication that the machine was performing very well. The outcome of the test also revealed a good value of throughput capacity for the shredding machine, and this further affirmed that the machine is efficient and reliable. After proper observation and careful analysis of the various methods of storage, collection, and efficient treatment and disposal methods of municipal solid waste, I therefore conclude that the most environmentally friendly step to take in treating the generated waste in Okada community is to recycle the plastic waste, compost the organic food waste via anaerobic digestion process, and the remaining waste component can be compacted and landfilled.

Conflict of Interest: *The authors declare no conflict of interest.*

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Research Paper

The Evolution of the Biogas Potential of the Lakes Region, Türkiye by Years: Comparison at Provincial Level

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Abstract: The energy shortage in Europe in 2022, especially the problems related to natural gas, has revealed how important energy is in today's world. For this reason, energy saving and renewable energy are considered to be the most important issues in the world. Biogas energy is a valuable and renewable energy source that is developing in use and production. Gases originating from organic matter, called biogas, can be obtained through many different sources. One of them is animal manure, which consists of organic matter. In this study, the theoretical biogas potential of the provinces of Antalya, Afyonkarahisar, Burdur, Denizli, Isparta, and Konya was determined. In the study, an average of 2092686 tons/year of manure has been generated for these provinces between 2016-2020. An average of $677.18x10^6$ m^3/year biogas potential was determined from the waste. The average energy equivalent is 8.73 GJ.m^3/year. If electrical energy is obtained from animal manure, the electrical energy potential per capita for the years used in the study was determined as approximately 159 kWh/person/year. It has been understood that the average per capita electrical energy supply will have the biomethane potential to meet the parts of Isparta (3.9%), Antalya (0.7%), Burdur (7.8%), Afyonkarahisar (11.7%), Konya (4.4%)) for the provinces in the Lakes Region.

Keywords: *Biogas, Lakes Region, Methane, Electricity*

Introduction

Industrialization steps and social-economic development policies in countries increase the need for energy. Energy is needed in many areas such as heating, industry, and transportation in all areas of life. Fossil resources such as coal and oil are mainly used to meet the energy demand (Yenigün *et al.,* 2021; Seyitoğlu & Avcıoğlu, 2021). These resources have an important share in the world's energy supply. However, these resources are not sufficient to meet the demand and cause environmental problems such as air pollution, global warming, and acid rain. Today, while researchers are trying to develop new technologies for the efficient use of these resources, they are also working on the use and evaluation of renewable energy, which can be considered unlimited in terms of environmental resources. Renewable energy sources are alternative energy sources that reduce foreign dependency on energy and prevent the instability of prices. In this respect, alternative and renewable energy sources are very important (Abbas *et al.,* 2017). Global environmental and energy policies emphasize the need to increase the share of renewable resources and increase the efficiency of energy conversion facilities and aim to develop advanced solutions for the renewal of existing facilities and power generation (Baldinelli *et al.,* 2017). One of the renewable energy sources that have gained importance in recent years is biomass energy. Biomass energy makes important contributions to the prevention of environmental pollution and reducing the greenhouse effect. Biogas is a colorless, flammable, and high-heat fuel type that is formed as a result of the decomposition of organic materials in an airless environment (Kadam & Panwar, 2017; Polat Bulut & Topal Canbaz, 2019). With the production of biogas from food and animal waste, environmental pollution can be reduced and the residues after biogas production can be converted into a valuable organic fertilizer (Seyitoğlu & Avcıoğlu, 2021; Polat Bulut & Topal Canbaz, 2019). In Turkey, incentives are given within the scope of renewable energy systems and it is aimed to supply 30% of the total electrical energy needs from renewable energy sources by 2023. In line with this target, when it is desired to increase the rate of electric energy production and reach the target of zero-emission in 2053, the importance to be given to biogas production emerges (Atelge, 2021). Looking at the world in general, Türkiye is in an important position in the field of agriculture and animal husbandry. Biogas constitutes an important energy source potential due to the high agricultural lands, animal potential, and

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the population interested in agriculture and animal husbandry in the country. Biogas is among the important alternative energy sources originating from the anaerobic digestion of all kinds of organic matter. Biogas enables the production of energy and organic fertilizer from organic waste materials. Animal manure is one of the most widely used organic materials in biogas production (Kumaş & Akyüz, 2021). Türkiye is among the rich countries in terms of biogas potential and animal waste capacity. Although there is a significant amount of animal waste capacity, there is not enough benefit from this waste. The livestock sector in Türkiye has not yet reached the desired levels (Tınmaz Köse, 2017; Kumaş *et al*., 2019). Different measures are taken all over the world to reduce greenhouse emissions during fertilizer storage and processing. Techniques such as biogas energy, manure cooling, and ventilation are among these measures. Biogas production by anaerobic digestion is one of the important technologies in reducing greenhouse gas emissions from manure management (Kumaş & Akyüz, 2021). There are many studies in the literature on biogas production. Kalayci *et al.* (2019) evaluated biogas production from animal waste amounts in Kırklareli province. The biogas potential of animal waste amounts was determined based on districts of Kırklareli in 2018. It has been calculated that 2093331 tons of animal waste are generated annually in the region and that 81506.628 m^3 of biogas can be obtained (Kalayci *et al.,* 2019). Khalil *et al* (2019) examined the potential of biogas that can be produced from Indonesia's animal waste. It has been determined that approximately 9597.4 Mm^3/year of biogas energy can be produced depending on the waste and 1.7×10^6 kWh electricity can be produced annually if biogas energy is used (Khalil *et al.,* 2019). Çağlayan (2020) studied the biogas potential consisting of bovine and ovine animal waste in the Eastern Anatolia region. While calculating the biogas potential for each province separately, it was determined that the highest potential of 14 provinces was the province of Van with 539,167 kg m^3/day. The lowest was determined as Tunceli province with 78.135 kg m^3 /day (Çağlayan, 2020). Melikoğlu and Menekşe (2020) created a model for estimating the biomethane production potential from cattle and sheep waste. In the study, it was stated that cattle and sheep assets will reach 18.7 million and 39.2 million in 2026. Accordingly, they estimated that 1.99 billion m^3 and 0.15 billion m^3 of biomethane could be produced from cattle and sheep, respectively (Melikoğlu & Menekşe, 2020). Çalışkan and Tümen Özdil (2021) determined the biogas potential that can be obtained from animal waste by using the number of animals in different regions of Turkey for the years 2007-2019. It was stated in the study that the total available biogas for the relevant year range contained 76.448×10^6 m^3 methane and its heating value was 2339296×10^6 MJ (Çalışkan &Tümen Özdil, 2021). Aksüt et al., (2022), determined the biogas potential that can be obtained from the animal wastes of Tokat province. For 2021, the amount of waste due to animal presence was determined as 245988 tons of solid waste and the biogas potential was 49 million m^3. The energy equivalent of biogas has been calculated as 292.000 MWh (Aksüt *et al.,* 2022). Işık and Yavuz (2022) determined the biogas potential for the province of Bingöl by using different animal species for the years 2015-2020. In the study, it was determined that the biogas potential is 36.5 million m^3 in 2020 and that 171.4 GWh electrical energy and 171449 x 10^6 kcal /m^3 heat energy conversion can be obtained with this potential (Işık & Yavuz, 2022).

In this study, biogas energy potential was calculated by taking into account the different manure collectability rates for different animal species in the lakes region of Türkiye. In the study, the numbers of animals obtained from the Turkish Statistical Institute were used for different animal species for the years 2016-2020. Changes according to years and comparisons of provinces were made. In addition, the equivalent of obtainable biogas production was determined.

Materials and Method

Afyonkarahisar, Antalya, Burdur, Denizli, Isparta and Konya provinces are located in the Lakes Region of Türkiye. The main income source of the provinces in the region is based on agriculture and animal husbandry. Konya ranks first in Türkiye in terms of cattle, second in sheep and goats, third in laying hens and fourth in turkey. Approximately 75% of the population living in Konya is engaged in agriculture and animal husbandry. 40% of Burdur's economy consists of animal husbandry activities based on milk production and plant production that supports animal husbandry. Although agriculture is Denizli's primary source of income, the cattle breeding and poultry sector have also developed in the province. The main income source of Afyon is agriculture and animal husbandry. Animal husbandry has developed in Afyon due to its wide pastures. In terms of livestock, it comes after Konya, Ankara, Sivas, Kars, and Ağrı. Animal husbandry has developed in Afyon due to its wide pastures. In terms of livestock, it comes after Konya, Ankara, Sivas, Kars, and Ağrı. Animal husbandry also has a very important place in Isparta and its region. Animal husbandry in the form of family businesses is quite common. Although animal husbandry is an economic activity that is not very common in Antalya, small ruminants breeding is common in the villages of the Central district. Poultry farming is a common economic activity (Anonim, 2022). In this study, the amount of waste and biogas potential of the Lakes Region, Türkiye for the years 2016-2020 were calculated depending on the number of cattle (dairy and beef cattle), small ruminants (sheep and goat), hoofed (horse, donkey, mule) and poultry (turkey, goose, duck, meat and laying hen). In addition, the amount of methane that can be produced from the biogas potential and the heat and electrical energy equivalents depending on this amount were calculated. Animal numbers for different animal species were obtained from the Turkish Statistical Institute. The number of animals for the relevant years is given in Table 1 (TUIK, 2022).

Table 1. Number of Animals

Year	Animal Type	Afyonkarahisar	Antalya	Burdur	Denizli	Isparta	Konya
2016	Cattle	320582	160946	198644	242389	147788	752533
	Small Ruminants	768078	1141951	437867	588517	466436	2088454
	Hoofed	5268	4206	1620	3409	2880	8705
	Poultry	17401182	511860	171558	4274741	421582	12494818
2017	Cattle	374417	174002	208936	264097	133654	868551
	Small Ruminants	895946	1131915	400272	616815	418653	2134897
	Hoofed	5452	3913	1562	2958	2633	8396
	Poultry	19111645	535509	201629	5026908	392773	15637818
2018	Cattle	391507	185833	222843	292086	145012	921572
	Small Ruminants	949973	1245651	410449	703754	491550	2252461
	Hoofed	5391	3753	1073	2678	2485	8232
	Poultry	19687110	530582	205813	5456579	445574	13470742
2019	Cattle	416500	192037	217165	293655	150959	927082
	Small Ruminants	1045000	1273635	410055	699302	537493	2459960
	Hoofed	5186	3445	926	2399	2531	7991
	Poultry	16456029	567134	238346	5603910	311884	13218994
2020	Cattle	437259	190687	213798	307093	149110	946144
	Small Ruminants	1235046	1312814	365044	740663	585259	2843229
	Hoofed	4922	2903	519	1617	2404	5496
	Poultry	16893961	558646	270392	5693485	226702	11234107

Table 2. Biogas Energy Parameters

Livestock Category	Mass	Manure Amount	Solid Matter Content in Manure		Volatile Solids Content in Manure		Biogas Efficiency	Manure Recovery Rates*
	kg head^{-1}	kg head^{-1} day^{-1}	%	kg head^{-1} day^{-1}	%	kg head^{-1} day^{-1}	m^3 kg^{-1}	%
Cattle (Dairy)	550	47.30	14.00	6.62	83	5.50	0.3	50
Cattle (Non-Dairy)	391	22.68	14.70	3.33	85	2.82	0.3	50
Buffalo	380	22.30	14.70	3.28	85	2.78	0.3	50
Sheep	48.5	1.94	27.50	0.53	84	0.45	0.2	13
Goat	38.5	1.58	31.70	0.50	73	0.37	0.2	13
Horse	377	19.23	31.70	6.10	67	4.07	0.3	29
Ass and Mule	130	6.63	31.70	2.10	67	1.40	0.3	29
Poultry (Broiler)	0.9	0.08	25.90	0.02	77	0.02	0.51	99
Poultry (Layer)	1.8	0.12	25.00	0.03	75	0.02	0.51	99
Turkey	6.8	0.32	25.50	0.08	76	0.06	0.51	26
Duck and Goose	2.7	0.30	28.20	0.08	61	0.05	0.51	22

In commercial animal holdings, animals are usually kept in a closed environment. For this reason, all fertilizers produced in enterprises operating in this way can be collected. However, it is not always possible to keep animals raised on small-scale farms or in rural areas in a closed environment. In animal husbandry carried out in such environments, animals generally spend their time in open areas such as pasture areas. For this reason, most of the fertilizers are stored in the field and it is difficult to collect them. Collectible fertilizer rates were used in many academic studies for Turkey; 50% for bovine animals, 13% for ovine animals, and 99% for poultry. In the study, the values given in Table 2 were used for the theoretical biogas calculation (IPCC, 2006). In addition, the CH_4 content in 1 m^3 biogas is 60%, the CH_4 heating value in 1 m^3 biogas is 21.48 MJ/m^3, and the electrical potential of 1m^3 biomethane is accepted as 2.09 kWh(Ersoy & Uğurlu, 2020).

Results and Discussion

According to the animal numbers data obtained from TUIK, there are cattle (1822882), small ruminants (5491303), hoofed (26088), and poultry (35275741) animals in the region in 2016. Considering the change in the number and type of animals in 2020 compared to 2016, there was an increase in cattle and small ruminants, while there was a decrease in hoofed and poultry. The calculated amount of manure for the years 2016-2020 depending on the number of animals is given in Figure 1. According to Figure 1, it is seen that the amount of manure has increased over the years. While the amount of manure was 1846x10^6 kg in 2016, this amount increased to 2213 x10^6 kg in 2020. Considering the total amount of available manure on a provincial basis, Konya has the highest value with 4294x10^6 kg, while Antalya has the lowest value with 850x10^6 kg.

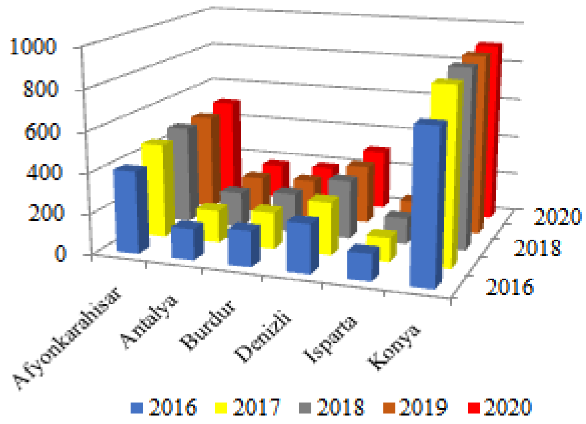

Figure 1. ManureAmount (10^6 kg.year^{-1})

Depending on the amount of available manure, the theoretically calculated biogas production potential covering the years 2016-2020 on a provincial basis is given in Figure 2. When the total biogas production potential for the years 2016-2020 is evaluated, the highest contribution was made in dairy cattle, while the least contribution was made in buffalo species. Dairy cattle are followed by laying hens. The highest contribution to the total biogas production on a provincial basis was obtained from Konya (1375x$10^6$$m^3$), while the least contribution was made from the province of Isparta (192x$10^6$$m^3$). The reason for the high potential of Konya province can be shown as the excess number of animals. Being the largest province in Turkey in terms of the area directly affects the number of animals and thus the potential for biogas energy. Konya province is followed by Afyonkarahisar (846x$10^6$$m^3$), Denizli (447x$10^6$ m^3), Burdur (277x$10^6$$m^3$), Antalya (248x$10^6$$m^3$), and Isparta(192x$10^6$$m^3$), respectively. The biomethane potential distribution for the years 2016-2020 depending on the amount of biogas is given in Figure 3. The biomethane potential, which was (360x10^6 m^3) in 2016, increased by 17.6% and reached (424x10^6 m^3) in 2020. Compared to 2016, there was an increase of 12.14 percent in 2017, 17.10% in 2018, and 16.52 percent in 2019. The order of the biogas potential based on provinces, from most to least, is Konya, Afyonkarahisar, Denizli, Burdur, Antalya, and Isparta.

The evolution of the amount of heat that can be obtained from methane over years is given in Figure 4 and the amount of electrical energy is given in Figure 5. The total electricity potential from animal manure, covering the years 2016-2020, has been determined as approximately 4.3 billion kWh per year. While the total amount of electrical energy for 2016 was 0.76 billion kWh, this amount was calculated as 0.89 billion kWh for 2020. While Konya's total electrical energy amount is 1.7 billion kWh, this amount is followed by Afyonkarahisar with 1.06 billion kWh. The least amount of electrical energy was Isparta with 0.24 billion kWh. The total amount of heat energy for the years 2016-2020 has been calculated as 43.64 GJ. The order of the total heat amount by provinces is Konya(17.72 GJ), Afyonkarahisar (10.90 GJ), Denizli (5.75 GJ), Burdur (3.57 GJ), Antalya (3.19 GJ) and Isparta (2.48 GJ).

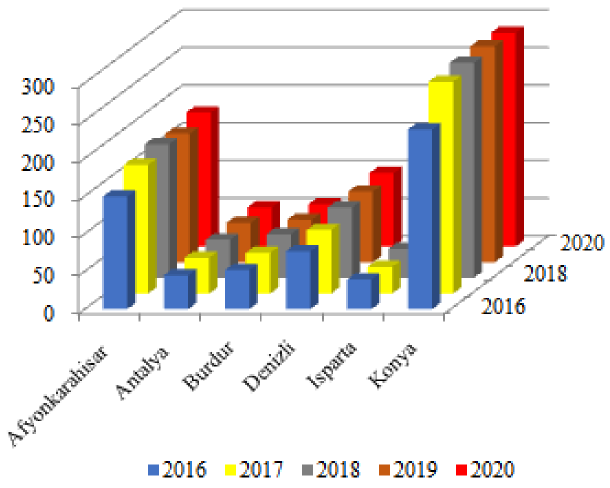

Figure 2. Biogas Amount ($10^6 m^3.year^{-1}$)

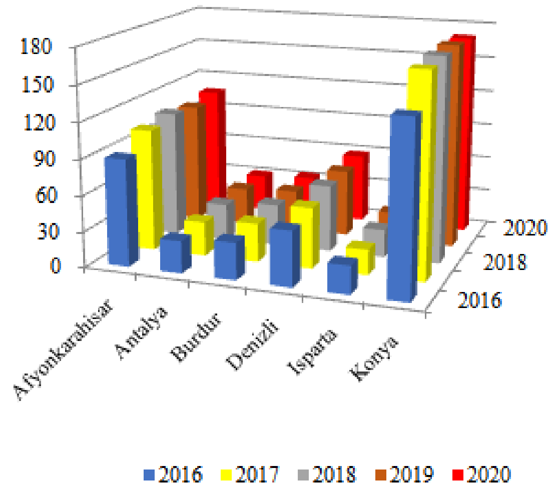

Figure 3. Amount of Methane ($10^6 m^3.year^{-1}$)

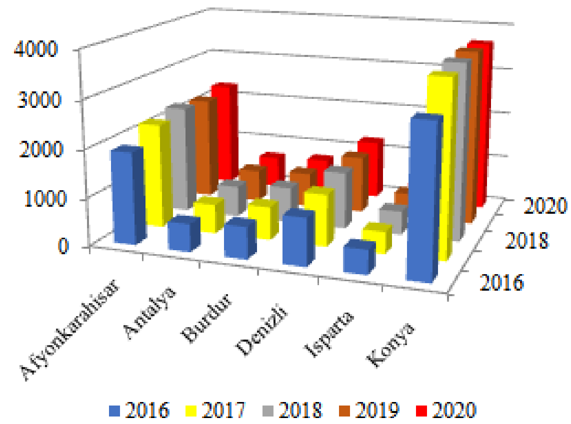

Figure 4. Energy value of methane ($10^6 MJ.(m^3)^{-1}.year^{-1}$)

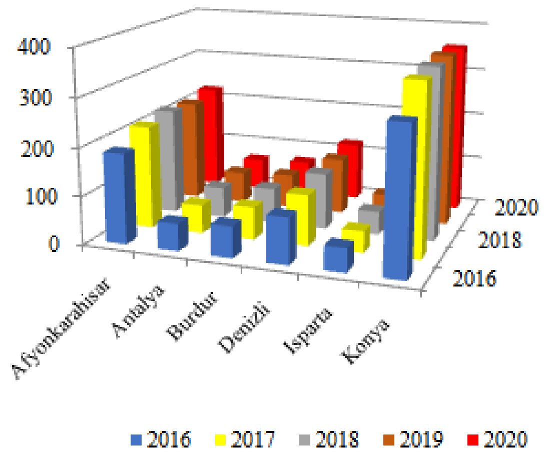

Figure 5. Electrical energy equivalent ($10^6.kWh.(m^3)^{-1}.year^{-1}$

The electrical energy potential per capita that can be obtained by the conversion of methane to electrical energy in the provinces used in the study is given in Figures 6 and 7. The total electricity consumption per capita is given in Figure 8 and the ratio of the total electricity produced per capita to the total consumption is given in Figure 9. The total population between 2016 and 2020 is 38.45 million people. In the case of obtaining electrical energy from animal manure, the electrical energy potential per capita was determined as approximately 159 $kWh.person^{-1}.year^{-1}$. The capacity to meet the per capita electrical energy need from biomethane is Afyonkarahisar, Burdur, Konya, Isparta, Denizli, and Antalya, respectively. While Antalya has the highest population among the provinces, this province is followed by Konya, Denizli, Afyonkarahisar, Isparta, and Burdur, respectively. The electrical energy potential of Afyonkarahisar that can be obtained from biomethane for 2020 is calculated as 223 million $kWh.year^{-1}$ and the amount of energy that can be produced per capita is calculated as 302 $kWh.person^{-1}.year^{-1}$. It has been determined that approximately 11.49% of the per capita electrical energy need of Afyonkarahisar province in 2020 can be obtained from animal manure. While the highest consumption coverage rate by years was seen in Afyonkarahisar in 2018, the least consumption coverage was in Antalya in 2019.

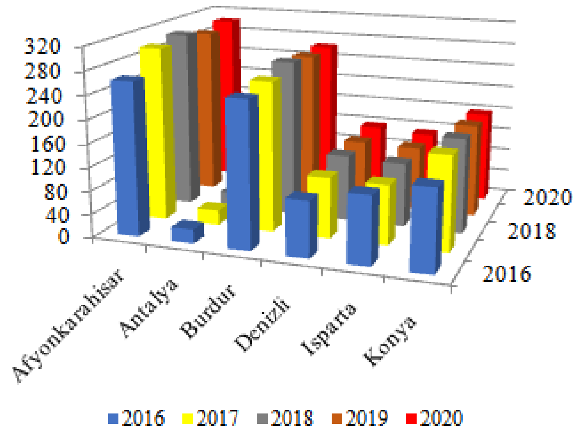

Figure 6. Electric potential per capita (kWh.person^{-1}.year^{-1})

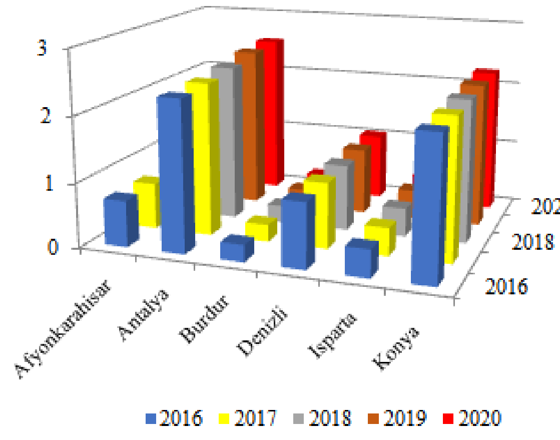

Figure 7. Population distribution by years (10^6 people)

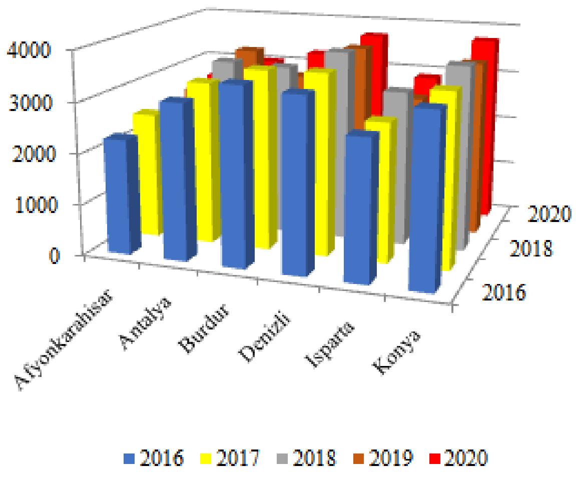

Figure 8. Total electricity amount per capita (kWh.year^{-1})

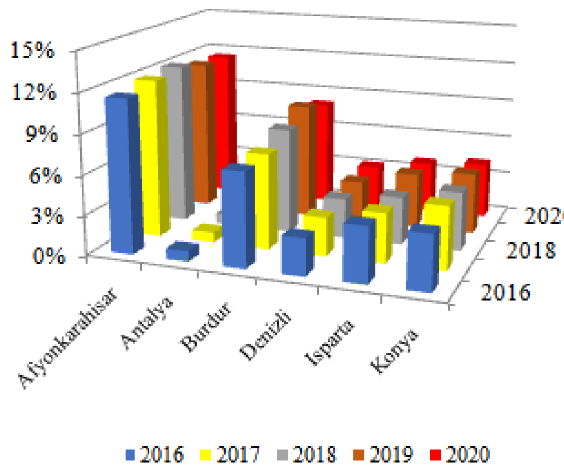

Figure 9. The ratio of electricity generation per capita to meet the total consumption (kWh.year^{-1})

Conclusion

Here is a more detailed and expanded version of the study, which was presented in the TFD 38 congress (İnan et al., 2022). In this study, the biogas energy potential was calculated by taking into account the different manure collectability rates for different animal breeds/species of Antalya, Afyonkarahisar, Burdur, Denizli, Isparta, and Konya provinces in Turkey's lakes region. In addition, the amount of methane from the biogas production available was determined. Depending on the amount of methane, the ratio of the amount of thermal and electrical energy and the amount of electrical energy per capita to meet the total consumption were determined . According to this;

- The provinces with the highest biogas potential originating from animal manure were determined as Konya, Afyonkarahisar, Denizli, Burdur, Antalya, and Isparta, respectively.
- Biogas potential was calculated as 3.39 billion m^3/year in total between 2016 and 2020, and biomethane potential as 2.03 billion m^3/year. While the total biomethane potential was 0.36 billion m^3/year in 2016, this value is 0.43 billion m^3/year for 2020.
- For the years 2016-2020, the total amount of thermal energy has been calculated as 43.64 GJ, and the total electric potential has been calculated as approximately 4.3 billion kWh.
- The total population between 2016 and 2020 was 38.45 million people. The provinces with the highest population were respectively Antalya, Konya, Denizli, Afyonkarahisar, Isparta, and

Burdur. The average per capita electricity consumption for the five years of relevant years is approximately 3173 kWh.

- In the case of obtaining electrical energy from animal manure, the per capita electrical energy potential has been determined as approximately 159 kWh.person^{-1}.year^{-1} for the years 2016-2020. It has been understood that the average per capita electrical energy supply will have the biomethane potential to meet the parts of Isparta (3.9%), Antalya (0.7%), Burdur (7.8%), Afyonkarahisar (11.7%), Konya (4.4%) for the provinces in the Lakes Region.

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Research Paper

Energy Management of Disaster Shelter Centres Established in the Recent Earthquakes in Turkey

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Abstract: Natural disasters create disasters stop human activities, destroy homes, businesses and the environment. Such disasters occur without warning and deprive hundreds or even thousands of people of drinking water, heating, lighting, communications, and electricity services. Turkey has experienced the last three important disasters. 6702 buildings in the Erzincan earthquake, 48,666 in the Van earthquake, 3,200 in the Elazığ and Malatya earthquake, 90,813 buildings in the İzmir earthquake were destroyed or heavily damaged, and a long-term power outage was experienced in the city center, towns and villages. Post-disaster housing needs are the most important element of the improvement of the modern disaster management system. The importance of alternative energy to be used in lodging centers after a major disaster is enormous. Lodging centers following disasters are built in safe areas-far from the city centers. Shelter centers are insufficient to meet the needs of lighting, heating, and hot water due to reasons such as distance from city and transformer capacity, as well as infrastructure for electrical energy. In this study, a decision-making road map was drawn for the shelters planned to be built in the future by evaluating the data on the integration of the solar panels into the containers to be used in the shelter centers.

Keywords: *Disaster, lodging centers, alternative resource, renewable, solar energy*

Introduction

Turkey is a country that is often faced with natural disasters like floods, rock falls etc. landslides, especially earthquakes, due to its geological, tectonic, meteorological, seismic, topographic and climatic structure. Turkey is third in the world in terms of human loss in earthquakes and eighth in terms of number of people affected by the earthquake. On average, every year there is at least one earthquake with a magnitude of 5 to 6 (AFAD, 2018).

The disaster is defined as natural and anthropogenic events that incite economic, social and physical losses for human life, hindering human activity, or interrupting normal life (Ergunay, 1996). Most of the disaster types that affect people's lives, and their life quality are caused by nature. Cases that cause destruction, damage and damage are called disasters and multiple forms of calamity are called affaults. Disasters are the loss of many people and other living things. Although disaster species are generally known for risk management, it is not possible to prevent or cease to occur (Özcelik, 2020)

Disasters are divided into two groups: man-made and natural disasters. Natural disasters are natural phenomena, especially earthquakes, such as floods, fires, rock falls, hurricanes, typhoons, landslides. Human-borne disasters are human-caused disasters such as explosions, pollution, traffic accidents, and war-related immigration (Acerer, 1999).

Disaster types often follow each other as chains, not alone. For example, earthquakes are not the only damage caused by the destruction of ground movements and the damage it causes. Other natural disasters after the destruction follow fire, landslide, and flooding. In Turkey, natural disasters account for earthquakes, landslides, flooding, rock falls, fires, avalanches, storms, and the rise of groundwater (Ergunay, 1996).

Disasters affect public life, leading to loss of life and property. The first stage after a disaster is during disaster-affected victims, health care, food and shelters. Disasters directly affect society, business revenues, based on duration and status. This chain reaction is followed by a decline in family income and production of businesses. In the period after the disaster, it can lead to inequality in income

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distribution, inflation and increased epidemic diseases (Bazoglu, 1980). The effects of disasters are most directly seen in the housing sector (Sey & Tapan, 1987).

Urgent accommodation is the healthy provision of basic accommodation and hospitality for victims who have been exposed to disasters. To this end, tents or containers for areas such as hangars, gyms, dormitories are being provided to accommodate victims (AFAD, 2018). Temporary accommodation sites are accommodation sites (Maral, 2016) that have been pre-planned and provide the best living conditions for survivors of possible disasters to be temporarily housed and protected from natural conditions. In 25 different provinces after the earthquake disaster, Turkey has been given lodging for storage of tents and containers (AFAD, 2018). Given the statistics from natural disasters over the past seventy years, it is estimated that 60% of damage occurs because of earthquakes, 16% landslides, 13% flooding, 5% rock falls, 4% fires, and 2% avalanches, storms, etc. (Songur, 2000).

Earthquakes will continue from the past to the present and to the future through the movement of the Earth. Earthquakes are dangerous and measures should be known. To avoid the effects of the earthquake, people can go on living normal lives without being harmed by proper planning and risk management. In our history, the situation does not look very bright. Earthquakes are always a disaster for us. The absence of a catastrophe will only be the conscious individual and the society by providing earthquake-centric education, law, and coordination (Bayraktar v. 2019). Between 1966 and 2021, there were 34 earthquakes in Turkey, more than 6.0 magnitude (Table 1).

Table 1. 1966-2021 earthquakes in Turkey larger than Mag=6*(Source: http://www.koeri.boun.edu.tr,2022)*

Date	Occurrence Time	Location	Violence	Mag	Loss of Life	Damaged Building
19.08.1966	14.22	Varto (Muş)	IX	6.9	2396	20007
28.03.1970	23.02	Gediz (Kütahya)	IX	7.2	1086	19291
22.05.1971	18.43	Bingöl	VIII	6.8	878	9111
06.09.1975	12.20	Lice (Diyarbakır)	VIII	6.6	2385	8149
24.11.1976	14.22	Muradiye (Van)	IX	7.5	3840	9232
30.10.1983	07.12	Erzurum-Kars	VIII	6.9	1155	3241
13.03.1992	19.08	Erzincan	VIII	6.8	653	8057
01.101995	17.57	Dinar (Afyon)	VIII	6.1	90	14156
27.06.1998	16.55	Ceyhan (Adana)	VIII	6.2	146	31463
17.08.1999	03.01	Gölcük (Kocaeli)	X	7.8	17480	73342
12.11.1999	18.57	Düzce	IX	7.5	763	35519
19.08.1966	14.22	Varto (Muş)	IX	6.9	2396	20007
22.07.1967	18.56	Mudurnu (Adapazarı)	IX	6.8	89	7116
03.09.1968	10.19	Bartın (Zonguldak)	VIII	6.5	29	2478
28.03.1970	23.02	Gediz (Kütahya)	IX	7.2	1086	19291
22.05.1971	18.43	Bingöl	VIII	6.8	878	9111
06.09.1975	12.20	Lice (Diyarbakır)	VIII	6.6	2385	8149
24.11.1976	14.22	Muradiye (Van)	IX	7.5	3840	9232
28.03.1978	03.48	Alaşehir (Manisa)	VIII	6.5	53	3072
30.10.1983	07.12	Erzurum-Kars	VIII	6.9	1155	3241
13.03.1992	19.08	Erzincan	VIII	6.8	653	8057
01.101995	17.57	Dinar (Afyon)	VIII	6.1	90	14156
27.06.1998	16.55	Ceyhan (Adana)	VIII	6.2	146	31463
17.08.1999	03.01	Gölcük (Kocaeli)	X	7.8	17480	73342
12.11.1999	18.57	Düzce	IX	7.5	763	35519
3.2.2002	09:11	Çay - Sultandağı (AFYON)	VII	6.4	44	622
1.5.2003	03:27	BİNGÖL	VIII	6.4	176	6000
2.7.2004	01:30	Doğubayazıt (AĞRI)	VII	5.1	17	1000
23.10.2011	13:41	Van	VIII	7.2	644	17005
24.01.2020		Elazığ	VIII	6.8	41	18760
30.11.2020		İzmir	VII	6.6		2500

The Kandilli Observatory and Earthquake Research Institute of the University of Bogazici hold information on the history, times of earthquakes, places, violence, loss of life, and damaged buildings. The problems at lodging centers after natural and human-caused disasters require lighting, heating and hot water. In the event of a possible disaster, meeting humanitarian needs due to these problems may vary according to the nature and severity of the disaster. Disaster life containers (such as Ankara, Konya, Afyon, Antalya, Bursa) located in the Metropolitan area by the Ministry of Interior Disaster and Emergency Situations are shipped from these provinces to the disaster area and assembled in safe zones. Because the event, time, and location of the disaster are not known, the need for energy can be revealed. Economic analysis of solar system integration has been undertaken using an alternative solar source to the disaster life containers to avoid the need for energy in temporary accommodation centers to be built.

Material and Method

The study explored solar energy potential, total solar radiation, sunbathing times and average annual solar radiation in Turkey. The daily energy needs of the disaster-life containers in lodging centers have been calculated in case of a disaster. This research led to the design of the solar panel system for containers and the cost analysis of the solar panel system.

Solar Energy Potential in Turkey

The sun is a very important source of energy for the earth and its energy resources. Therefore, both heat production and electricity production share is large. As a result of its location, Turkey is located between 36-42° north parallel and 26-45° east meridian, so geographically sunbathing is more favorable to Germany, Italy, Spain and Belgium than other European countries. There is a constant reaction from the sun, and the energy is released. Electricity and heat production have been realized using this energy in different fields. In electricity generation, "solar cells" can be transformed into systems, transforming solar energy directly into electricity (Figure 1).

Figure 1. Solar cells *(Source: www.dunyaenerji.org.tr, 2022)*

Figure 2. Condensed solar energy *(Source: www.tespam.org, 2022)*

Turkey's annual solar power potential has been given an average annual sunbathing time (Figure 3). Our country has an average annual solar radiation of 1,304 kWh/m2 and an average sunbathing time of 2,640 hours. This is a total of 108 days of sunbathing, approximately 7.2 hours per day, to 3.57 kWh/m2 daily. The energy potential has 26.2 million TEPs (equivalent to 20 tons of oil). For 10 months in a year, technically 64% of the surface area and 16% of the entire year could benefit from solar energy. The location of the required investments should be considered with the solar potential (Figure 8). The Earth receives an energy of 170 million MW per second from the Sun. This energy is approximately 1,700 times Turkey's annual energy output.

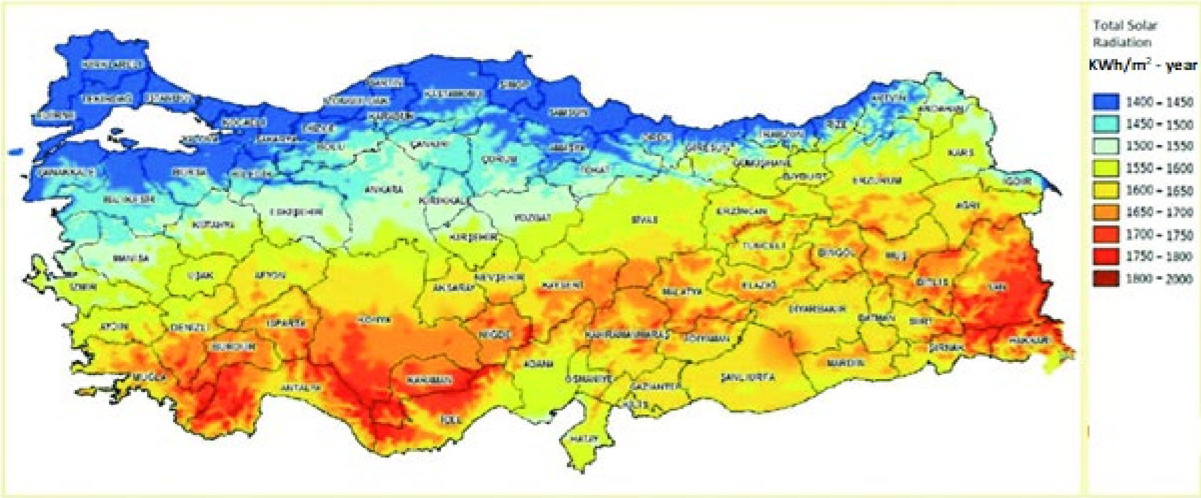

Figure 3.Total solar radiation *(Source: www.mgm.gov.tr,2022)*

Turkey's average sunbathing times from 1991 to 2020 were shown in Figure 1. The months with the highest sunbathing times are July, August and June. The lowest months were December, January, and February.

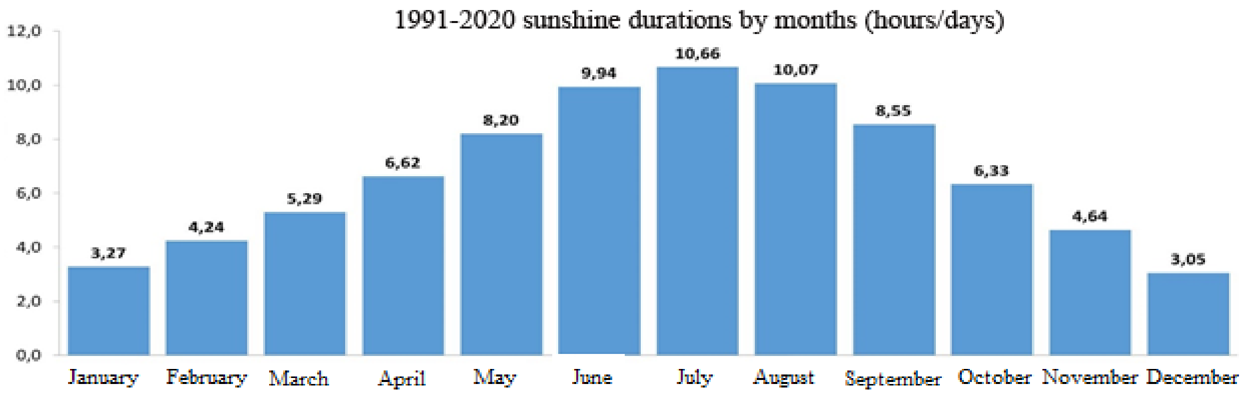

Figure 4. Turkey's sunbathing times by month (hours/days) *(Source: www.mgm.gov.tr,2022)*

According to the installed power report of TEIAS data from October 2021, the solar power plant is the primary source of energy with the number of plants. There are 8,212 solar power stations. The power produced by these plants has an estimated 7,658.6 MW. It is based in Turkey at 99,050.4 MW. The power generated by primary energy sources in Turkey is 99,050.4 MW.

Design of the Solar Panel System

The Solar Panel System (SPS) has several steps to be taken care of. The solar battery system consists of a solar panel, inverter (right current alternating current), charge regulator, and various electronic evenings. One of the things to look out for when selecting these electronic evenings is the efficiency of the electronic equipment that drives the system. The average solar panel yield (η_{pe}) is 80%, the battery yield ($\eta_{battery}$) is 80%, and the inverter yield (η_{inv}) is 90% (Alkan, 2014).

The first stage is the choice of solar panels; it is necessary to consider efficiency when doing panel calculations based on the amount of energy needed in the SPS.

The second stage battery selection is possible to be designed in two different ways as a grid-independent and network-dependent system. At times of daylight, batteries are needed when there is no need for batteries, while at times when there is no daylight. In battery selection, the battery is selected according to its economics and characteristics.

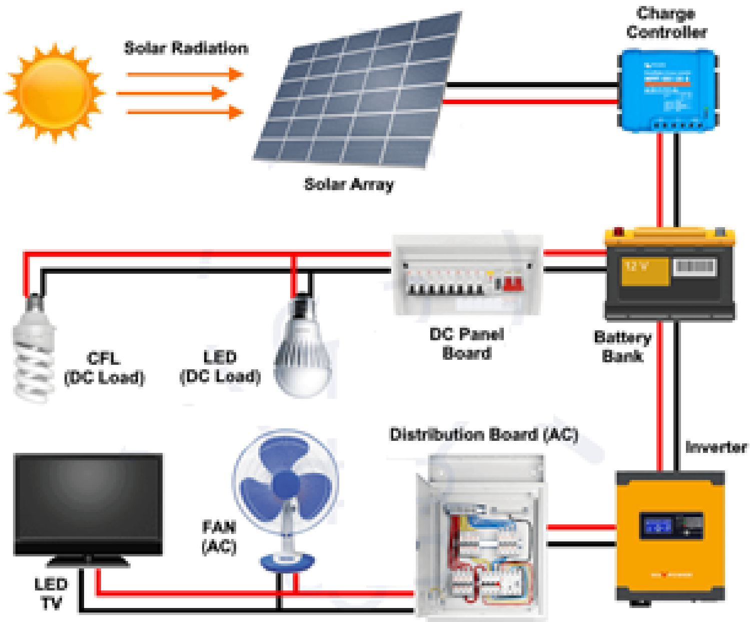

Figure 5. Exterior representation of the Solar Panel System (SPS) *(Source: www.electricaltechnology.org)*

The third stage charge regulator; once battery selections are made, charge regulators are needed to protect it from overcharging and electrical surges in the battery.

In the fourth and final stage, inverter is made according to the capacity of the solar system while Inverter is selected. The electronics and electrical goods we use in our daily lives are usually powered by 220 volts and 50 Hz electric current. And all of these electronics and electrical appliances that we use are consistent with alternating current. So, the solar energy that we're producing in solar cell systems is a 12-volt direct current. It is necessary to use inverter to convert the solar energy produced by solar cell systems into an alternative energy current.

Containers set up in temporary accommodation centers consist of 21 m², with 2 rooms, 1 toilet and bath (Figure 6). The main characteristic of the standard disaster life containers is easy to manufacture, fast shipping, and ready for use as soon as possible. Due to full fabrication production, it is readily available for use when downloading from the crane with a discrete installation capability in case of disaster and emergency. Containers are ready to use in minutes, with two people, as well as no other materials, due to its discrete capability and the availability of a next-generation system with bolts and phases. Table 2 provides the electricity requirement for a planned disaster life container set up in a post-disaster temporary shelter.

Table 2. Energy of daily devices used in containers

Electronic Device Name	t_k	P_h	P_t
Refrigerator A+	4 (hours/week)	1200W/day	4800
Washing Machine, A+	6 (hours/weeks)	1000Wh	6000
32-Screen TV	10 (hours/weeks)	50Wh	500
Lighting	15 (hours/weeks)	55 kilowatt-hours	825
Electric Thermophone	20 (hours/weeks)	6 kilowatt-hours	120
Air conditioning	5 (hours/week)	1600Wh	8000
Weekly Energy Total			**20250Wh**
Daily Energy Total			**2890Wh**

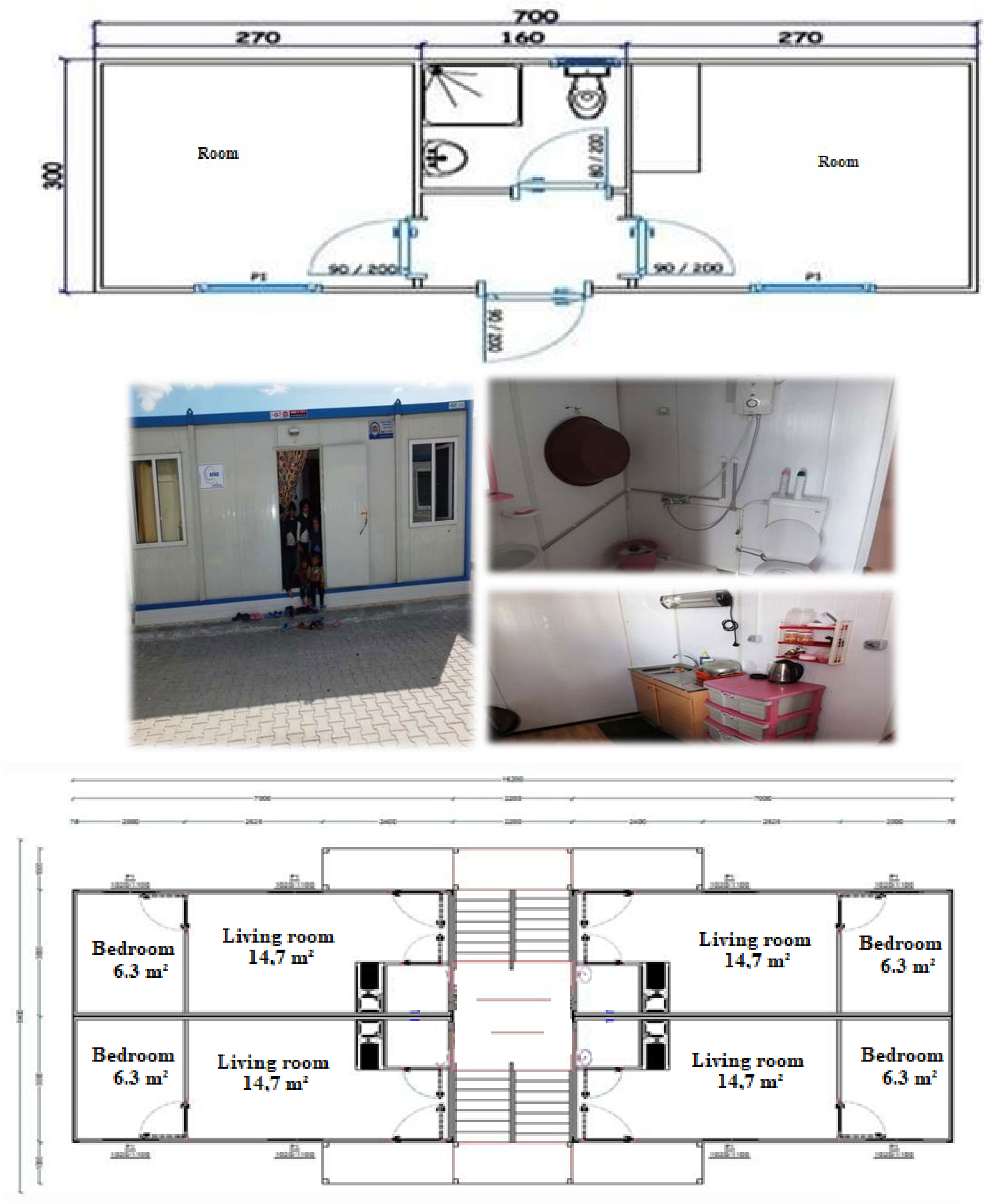

Figure 6. Disaster life container *(Source: www.afad.gov.tr,2022)*

The T320-72P solar panel is selected based on the energy needs of everyday devices for the solar panel system, which is designed for electrical generation in temporary accommodation centers, and the computed panel number, panel power, and panel efficiency. The maximum power of the T320 72P solar panel is 320Wp, the maximum voltage produced is 37.70V, and the maximum current is 8.49A (Table 3).

Table 3. Performance values of T320 solar panel

Panel Model	$P_{mak.}$	$V_{mak.}$	$I_{mak.}$	V_{oc}	I_{sc}
TT320 72P	320Wp	37,70 V	8,49 A	46,40 A	9,04 A

The solar panel has a 12-year manufacturer's guarantee. It guarantees 80% productivity over 10 years, 90% over 25 years. This GP is made from 72 156.75 mm x 156.75 mm silicon solar cells.

$$S.P.A : 1.959 \times 0.995 = 1{,}950\ m^2 \quad (1)$$

The equation for finding the solar panel field is calculated in 1.

$$P_{mak.} = I_{mak.} \times V_{mak.} \quad (2)$$

With equation 2, the maximum current ($I_{mak.}$) and voltage ($V_{mak.}$) of solar panels can be multiplied by the power of solar cells (Altas,1998).

$$\eta GP = \frac{Pmak.}{(SPA \times H)} \times 100 \quad (3)$$

The efficiency of the solar panel can be calculated in GP equation 3. In equation 3, the radiative value (H) is used because the region or state is not clear (H≅800 Wh/m^2). The maximum power ($P_{mak.}$) value of the panel (Kutlu,2002).

$$\eta sys = \eta SPx\eta batteryx\eta inv \quad (4)$$

In equation 4, the efficiency of the system is calculated by multiplying the solar panel, battery efficiency, and inverter yield values (Kutlu, 2002).

$$PS = \frac{D.E.Nx\eta sys}{(Pmax.xPPS)} \quad (5)$$

Calculating number of panels (PN) to be used in GPS in equation 5. The product of the inverter efficiency (η_{sis}) with the daily energy needs (D.E.N) is achieved by the product of the fog and maximum power of the panel (Pmax.) and by the product of the daily sunbathing time (PPS≅7.05) (Öztürk and Dursun, 2011).

$$AS = \frac{D.E.NxAk}{(VbxBc)} \quad (6)$$

In equation 6, the number of batteries (BN) is determined (Öztürk and Dursun, 2011). As is calculated by the battery voltage (V_b) and Battery capacity (Bc) values (Öztürk and Dursun, 2011).

$$\dot{I}C = \frac{D.E.Nx\dot{I}loss}{PPS} \quad (7)$$

After determining the number and of batteries we use for the solar panel system, the inverter capacity is calculated in equation 7. The translator capacity is estimated at 10% for losses incurred from the internet (Öztürk and Dursun, 2011).

$$CR = \frac{D.E.N}{PPS} \quad (8)$$

In equation 8, the charge regulator is derived from the daily sunbathing time portion of the daily energy need (Öztürk and Dursun, 2011).

Cost Analysis of the Solar Panel System

The cost of a solar battery system designed for integrating solar panel system of disaster life containers created or planned to occur in the aftermath of a disaster is an economically large part of the system being first investment cost, business and maintenance.

$$g = \frac{Ck + Cm + Cf}{E} = \frac{Ct}{E} \quad (9)$$

It is necessary to calculate the cost of energy generation achieved for the designed system. Therefore, system costs and Wh unit price are calculated in equation 9. Annual investment expenses or annual capital (C_k) refers to annual operating-maintenance costs (C_m), annual fuel costs (C_f), annual total expenditure (C_t), and annual electricity generation amounts (Keçeli, 2007).

$$C_k = I_{ac} \times a \quad (10)$$

In equation 10, to calculate annual investment expenses or annual capital costs; I_{ac} is achieved by the installation and assembly cost times the "a" depreciation factor (Köşker, 2007).

$$a = \frac{(1+i)^n i}{(1+i)^n - 1} \quad (11)$$

In equation 11, the depreciation "a" is calculated. Total life expectancy is "n", interest is "i (Kutlu, 2016).

$$E = I x A x \eta SP x \eta sys x 365 \quad (12)$$

In equation 12, the average annual radiative value is shown as "I," the panel surface area is "A," and the panel yield is "η_{SP}" and the system yield is "η_{sys}". Based on these values, it is possible to calculate the total amount of energy that can be produced for a year. Solar panels are divided by the total annual amount of energy spent on system installation, which calculates the cost per power by units of "g" in equation 9 (Korkmaz,2001).

Results

A planned disaster life container for post-disaster temporary accommodation centers requires electrical energy for solar panel integration; the maximum power of the solar panel is 320Wp, panel efficiency is 18%, system efficiency is 90%. 2 batteries are required. The panel count is calculated from 4 T320 72P solar panels. Inverter capacity is 750VA inverter sufficient for 586.95 VA capacity. Charge regulator preferred charge regulator capacity of 750W for 450.8W power. Unit price amounts for equipment are shown in (Table 4).

Table 4. Economic analysis of GPS for containers

Equipment	Quantity	Unit Price	Amount ($)	Amount
Solar panel T320 72P	4	229$	916$	13576,4 TL
VRLA Battery	2	100$	200$	2964,28 TL
Solar Charge Regulator	1	190$	190$	2816,07 TL
Full Sine Inverter	1	230$	230$	3408,92 TL
Subtotal			1563$	23165,85 TL
Installation Cost (20%)	-	-	312,6$	4633,17 TL
Total			1875,6$	27799,02 TL

**The central bank has been calculated from 21.03.2022 (1$=14.82TL)*

Solar panels install cost 27799.02 TL; C_f has no fuel costs; C_f value is zero, C_m value (annual=100$) is 14812 TL, C_k is worth 2605 TL, and C_t valued at 3504.8 TL. Panel space is 1,950 m², with solar radiation not planned for any Turkish province, and an average efficiency of 90% panel yield 20%. If the system yield is 90%, then the equation 7 will produce an annual amount of energy of 13394.5 Wh. We can calculate that there are four solar panels in the solar panel system for the container, and that's 53578.2 Wh.

Because the life of the solar system is assumed to be 25 years old, the values of c_m, c_k, and c_t multiplied by 25. C_m= 370300 TL, C_k= 65125 TL, C_t= 87620 TL. The total annual energy output is 2227271.28 W. The unit electricity price is g=0.03835688 TL/Wh.

The EPDK (Enerji Piyasası Düzenleme Kurumu) approved 1 Kw of electricity for 2022 at 1.37 Tl/kWh for 150 kWh and 2.06 Tl/kWh for over 150 kWh for consumption. 2860WH per day energy consumption is 1043.9 kWh. This annual consumption energy quantity is 26097.5 kWh for 25 years. This 25-year consumption is 25 years of electricity costs by multiplying the power supply by the unit price of TEDAŞ grid electricity. The 25-year electricity bill that will be paid to the TEDAŞ institution is 26097.5 kWh × 1.37 TL/kWh=35753.58 TL (p). After 25 years, the interest rate account is $S=p(1+i)^{25}$ $S=35753.58(1+0.095)^{25}=345678.61$ TL. For the solar panel system designed for disaster containers, we will pay 27799.02 TL. The price difference is 317879.59 TL

Discussion

Turkey is dependent on foreign energy in terms of energy, such as Germany, the Netherlands, Portugal and Italy in Europe. The amount of energy consumed increases by 7% every year due to industrialization and population growth. However, fossil fuel reserves are decreasing. Since our country is a developing country, its energy needs are increasing day by day. While energy consumption was 220 billion kWh in 2012, it was 249 billion kWh in 2017. It is predicted that the consumption will be 460 billion kWh in 2023. Turkey is not a rich country in terms of natural gas and oil resources. In this context, alternative clean energy sources are important for depletion of fossil fuels and reducing dependence on foreign energy.

Solar energy, one of the renewable energy sources, has a high potential due to Turkey's geographical location. Although the sunshine duration of our country varies throughout the year, it is approximately 2,800 hours per year. In this study, feasibility studies of solar panels system for living containers to be established in temporary shelter centers created as a result of human and natural disasters in Turkey have been carried out and it is seen that profit is made. Since the technology of solar energy equipment is foreign-dependent, it is affected by the exchange rate. When a decrease is observed in the dollar exchange rate and the solar panel system has a life of 25 years, the difference is calculated as 317879.59 TL. According to the results of the economic analysis, it is thought that if electricity generation from the solar panels system is used in the accommodation centers, it will be profitable for the country's economy.

Containers used in disaster areas are preferred because of their low transportation and assembly costs. For this reason, with the solar panel system designed for containers, the basic needs of disaster victims such as shelter, heating/cooling, lighting and hot water will be met with the understanding of the social state in a 72-hour period. In addition, if the number of panels to be planned in the disaster area is increased and energy storage can be made because of R&D studies, the excess energy to be produced can be traded in case of demand.

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