Investigation and Comparative Analysis of Energy Potentials from Different Biomass Sources

Ushie P.O.[1], Odok E.O.[2], Ettah E.B[3], Ishaje M.E.[4]

[1,3,4]Department of Physics, Faculty of Science, Cross River University of Technology Calabar, Nigeria
[2]Department of Mathematics Faculty of Science Cross River University of Technology Calabar, Nigeria

Abstract— *Comparative analysis of energy potentials from different biomass sources were investigated to determine the energy potential stored in them: biomass materials used were cattle manure, wood and dry grass. Instruments used for this investigation includes: coffee can, thermometer, stop watch, heat source etc. simple heat equation was used to evaluate the heat potential in each material. Results shows that heat energy of cattle manure was 0.33264788J, wood was 0.1661868J and that of dry grass was 0.1001J. Showing that cattle manure has higher energy potential than wood and grass, meaning it will have more application for energy generation.*

Keywords— Biomass, Energy Potentials, Heat Sources.

I. INTRODUCTION

The term "biomass" refers to organic matter that has stored energy through the process of photosynthesis. It exists in one form as plants and may be transferred through the food chain to animal's bodies and their wastes, all of which can be converted for everyday human use through processes such as combustion, which releases the carbon dioxide in the plant materials. Many of the biomass fuels used today come in the form of wood products, dried vegetation, crop residues, and aquatic plants. Biomass has become one of the most commonly used renewable sources of energy in the last two decades, second only to hydropower in the generation of electricity. It is such a widely utilized source of energy, probably due to its low cost and indigenous nature, that it amounts for almost 15% of the world's total energy supply and as much as 35% in developing countries, mostly for cooking and heating (Adam & Howard, 2014). Biomass is one of the most plentiful and well-utilized sources of renewable energy in the world. Broadly speaking, it is organic material produced by the photosynthesis of light. The chemical material (organic compounds of carbons) is stored and can then be used to generate energy. The most common biomass used for energy is wood from trees. Wood has been used by humans for producing energy for heating and cooking for a very long time. Charcoal, in turn has been used for forging metals and for light industry for millennia. Both wood and charcoal form part of the backbone of the early industrial revolution (much Northern England, Scotland and Ireland were deforested to produce charcoal) prior to the discovery of coal for energy (Kueh *et. al.,* 1998).

Wood is still used extensively for energy in both household situations and in industry, particular in the timber, paper, pulp and other forestry related industries. Woody biomass accounts for over 70% of the primary energy consumed in Calabar, and it accounts for much more of the primary energy consumed in most of the developing country, primarily for cooking and space heating. It is used to raise steam, which in turn is used as a by-product to generate electricity (Williams, 2009). Manure containing undigested and partially digested dietary nutrients is a resource that benefits plants growth and adds organic matter to improve soil structure. Nutrients in animal feed that are sources of energy include carbohydrates – comprised of carbon (c), hydrogen (4) and oxygen (0) – from forage and cereal grains, for example, other nutrients are protein (in the forms of amino acids) and fats (or lipids), comprised primarily of C,H,O as well as phosphorus (P) and Nitrogen (N). The energy content of animal feed is expressed in specific heat. One specific heat is the quantity of heat required to raise the temperature of one grain of water by 1 degree Celsius (^{0}C) from a standard initial temperature and pressure at sea level. Not all of the energy in the feed is utilized by the animal (Koelsch *et. al.*, 1989).

Specific Heat: The rise in temperature of a body is proportional to the quantity of heat supplied to the body, the mass of the body and the nature of the substance of the body. We can in general write that:

$$H = MC_p\Delta\Theta \quad (1)$$

Where: H = Quantity of Heat (J), M = Mass of the Material (Kg), $\Delta\Theta$ = Change in temperature (^{0}C) and C = Constant (specific heat capacity of the material) (jkg^{-i}. ^{0}C^{-1})

(Nayyeri, e*t. al.*, 2009) found that; the thermal properties of dairy cattle manure were measured at the different temperature and moisture content. They specific heat and thermal conductivity of dairy cattle manure increased linearly from 1.9925 to 3.606kj.kg^{-1} ^{0}C^{-1} and from 0.091 to 6814wm^{-1} respectively. Using the ultimate analysis of biomass, a low heating value (LHV) is the correction to high heating value (HHV) due to moisture in the fuel (biomass) or water vapor formed during combustion of hydrogen in the fuel.

Thermal Conductivity: Different materials conduct heat differently and so it is essential to know about the conducting power of a material (Vasudeva, 2010). Let us consider a cubic section of a material whose face A is at a higher temperature θ_1 (say) and let the opposite parallel face B be at a temperature θ_2, now heat will flow from face A to phase B depending on the following factors.

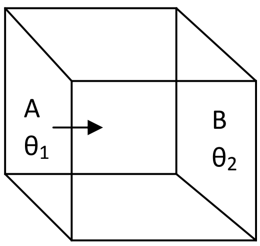


Fig.1: Cubic Section of the Wood

It will be directly proportional to the area of cross-section, since more is the area of the face of a cube, more is the flow of heat i.e.,

$$Q \propto A \qquad (2)$$

It will be directly proportional to the time of flow of heat i.e.

$$Q \propto t \qquad (3)$$

It will be directly proportional to the difference of temperature of the two faces of the cube. The more is the difference of temperature, the more rapid is the flow of heat i.e.

$$Q \propto (\theta_1 - \theta_2) \qquad (4)$$

It will be inversely proportional to the thicker of the cube, i.e. more is the difference between the two faces of the cube, and less is the flow of heat i.e.

$$Q \propto \frac{1}{d} \qquad (5)$$

Combining the above equations, we have $Q \propto A \frac{(\theta_1 - \theta_2)}{d} t$

Introducing the proportionality constant k, we have

$$Q = KA \frac{(\theta_1 - \theta_2)}{d} t \qquad (6)$$

Where K depends on the material in which the heat is flowing. From equation (4)

$$K = \frac{Q\, d}{A(\theta_1 - \theta_2)t} \qquad (7)$$

This constant K is known as co-efficient of thermal conductivity.

If A = 1cm^2, $\theta_1 - \theta_2 = 1^0$c, t = 1 sec, d = 1 cm

Then θ= K. So K can be defined as the quantity of heat that flows for one second through a cm cube whose apposite face are maintained at a difference of temperature of 1^{0}c.

Proximate Analysis: The proximate analysis of a good initial indicator of biomass (manure) quality. Biomass samples are analyzed to determine the moisture content, ash and volatile matter (solid) material in biomass that, when heated at a specific temperature, converts directly into the gaseous phase without undergoing a liquid phase. Proximate analysis also determines fixed carbon, which is calculated by subtracting moisture, ash and volatile matter from the total biomass.

Ultimate Analysis: Ultimate analysis reports the percentage of C, H, O, S and N in the biomass. The values of these elements differ by types of animal manure or other biomass type. The ultimate analysis can determine the heating value of biomass, including manure; helps determine the design and operation parameters of a bio-energy producing system by the different thermo-chemical processes.

Evolution of Grass Energy: In the late 1800's, grasses were widely used as a heating fuel in the Prairie Region of Calabar – Nigeria, an area with little forested land. Farmers in these areas relied on harvested straw and prairie grasses, or "Prairie coal", which were often twisted into boundless and burned in simple stoves. Today, modern solid biomass heating systems are highly engineered, automated and dean-burning. Like the existing wood Pellet market in Europe and the developing market in the United States; grasses may soon be Pelleted and delivered in bulk by a special tanker truck, pneumatically blown into storage systems, and automatically fed into the combustion system with no manual labor required.

Grasses for Fuel: No grass species can be grown effectively in all regions and climates, however, the most broadly considered grass for energy production is switch grass (and other native prairie grasses such as Big Blue stem and prairie cord grass). Miscantus, a super high-yielding crop, has garnered much interest and is now being studied. Reed canary grass is often naturally present and high yielding in wet, marginal areas, however, it is also recognized as invasive – chocking out other native wetland species – so it use as an energy benefits and disadvantages as a biomass fuel source. When considering which the best choice is, the first consideration is generally the yield per acre in any given microclimate or soil type, as this greatly influences the economics of conversion of the crop to a useful form for energy extraction. Another consideration is the mineral or ash content of a given grass on a given plot which may affect the value of the crop (Alayna, 2015). Grasses have 95% of the value of wood and several pioneering companies are beginning to produce high quality grass pellets for beating. Historically, since biomass combustion systems were designed around wood, simply substituting grass for wood in the same combustion system will generally not produce satisfactory results.

Grasses have higher ash content and a different chemical composition, therefore distinct combustion systems are needed to handle these differences. During combustion, higher chlorine and potassium levels in grasses vaporize and form salts or boiler walls. These salts can cause "clinkers" (incombustible residues) in systems not specifically designed to handle grasses, reducing performance markedly (Roos & Moser, 1997).

Biomass Energy from Wood: Biomass power is the largest source of renewable energy as well as a vital part of the waste management in structure. An increasing global awareness about environment, issues is acting as the driving force behind the use of alternative and renewable sources of energy. A greater emphasis is being laid on the promotion of bioenergy in the industrialized as well as developing world to counter environmental issues. Biomass may be used for energy production at different scales; including large scale power generation, CHP, or small scale thermal heating projects at governmental, educational or other institutions. Biomass comes from both human and natural activities and incorporates by products from the timber industry, agricultural crops forestry residues, household wastes, and wood. The resources range from corn kernels to corn stacks, from saybean and caudo oils to animal fats, from prairie grasses to hardwoods, and even include algae. They largest source of energy from wood is pulping liquor or black liquor, a waste product from the pulp and paper industry (Alex, 2006).

Rectilinear Flow of Heat along a Wood: Let us consider a long wood heated at one end and the flow of heat along $\mathcal{X}$-axis. Let us consider two parallel planers perpendicular to the $\mathcal{X}$-axis and at a distance $\mathcal{X}$ and $\mathcal{X}$+d$\mathcal{X}$ from the hot end. Let θ be the excess of temperature at the plane $\mathcal{X}$ and $\frac{d\theta}{dx}$ be the temperature gradient (Rate of change of temperature with distance). Then the excess of temperature at the plane $\mathcal{X} + \mathcal{S}\mathcal{X}$ will be $(\theta + \frac{d\theta}{dx}\mathcal{S}\mathcal{X})$ and the temperature gradient will be $\frac{d}{dx}[\theta + \frac{d\theta}{dx}.\mathcal{S}\mathcal{X}]$

If Q_1 and Q_2 be the quantities of heat that enter the plane at $\mathcal{X}$ and leave the plane at $(\mathcal{X} + \mathcal{S}\mathcal{X})$/sec. respectively.

We have $Q_1 = -KA\frac{d\theta}{dx}$ (8)

Where K is coefficient of thermal conductivity and A the area of cross-section of the wood;

$:. Q_2 = -KA\frac{d}{dx}(\theta + \frac{d\theta}{dx}.\mathcal{S}\mathcal{X})$

$Q_2 = -KA[\frac{d\theta}{dx} + \frac{d^2\theta}{dx^2}.\mathcal{S}\mathcal{X}]$ (9)

So the net amount of heat gained per second by the element of thickness $\mathcal{S}\mathcal{X}$, sandwiched between the two planes will be

$Q_1 - Q_2 = -KA\frac{d\theta}{dx} - [-KA(\frac{d\theta}{dx} + \frac{d^2\theta}{dx^2}.\mathcal{S}\mathcal{X})]$

$= -KA\frac{d\theta}{dx} - [-KA(\frac{d\theta}{dx} + KA\frac{d^2\theta}{dx^2}.\mathcal{S}\mathcal{X})]$

$= -KA\frac{d\theta}{dx} + KA\frac{d\theta}{dx} + KA\frac{d^2\theta}{dx^2}.\mathcal{S}\mathcal{X}$

$= KA\frac{d^2\theta}{dx^2}.\mathcal{S}\mathcal{X}$ (10)

Before we get the steady state, this heat will be partly used in raising the temperature of the element of the wood and partly it will be radiated.

If $\frac{d\theta}{dt}$ is the change of temperature per unit time; ɛ the density of the material; $\mathcal{S}$ the specific heat of the material, then the quantity of heat required to raise the temperature of the element for unit time will be.

$Q_1 - Q_2 = A.\mathcal{S}\mathcal{X}\ ɛ.\frac{d\theta}{dt}$ (11)

If P is the perimeter of the element, the surface area of the element = P. $\mathcal{S}\mathcal{X}$.

Let E be the emissivity or the radioactive power of the surface and θ the average excess temperature of the element, then the amount of heat radiated by the element/sec.

$Q_1 - Q_2 = E.P.\mathcal{S}\mathcal{X}.\theta$ (12)

Hence from equations (10), (11) and (12) we have

$$KA\frac{d^2\theta}{d\mathcal{X}^2}.\mathcal{S}\mathcal{X} = A.\mathcal{S}\mathcal{X}\ P.S.\frac{d\theta}{dt} + E.P.\mathcal{S}\mathcal{X}.\theta$$

Transpose the equation and make $\frac{d^2\theta}{d\mathcal{X}^2}$ subject formula we have;

$$\frac{KA}{KA}\frac{d^2\theta}{d\mathcal{X}^2}.\frac{\mathcal{S}\mathcal{X}}{\mathcal{S}\mathcal{X}} = \frac{A.\mathcal{S}\mathcal{X}.ɛ.S}{KA.\mathcal{S}\mathcal{X}}\frac{d\theta}{dt} + \frac{E.P.\mathcal{S}\mathcal{X}}{KA.\mathcal{S}\mathcal{X}}\theta$$

$$\frac{d^2\theta}{d\mathcal{X}^2} = \frac{ɛS}{K}.\frac{d\theta}{dt} + \frac{EP}{KA}\theta \quad (13)$$

Equation (13) is the standard equation for the flow of heat in one direction and this equation can be solved by taking into consideration the actual conditions of the problem.

(i) Let the amount of the heat lost by radiation be negligibly small i.e. E = 0;

Equation (13) will now be written as:

$\frac{d^2\theta}{dX^2} = \frac{eS}{K} \cdot \frac{d\theta}{dt} + 0$

$\therefore \frac{d^2\theta}{dX^2} = \frac{eS}{K} \cdot \frac{d\theta}{dt}$

Or cross multiply we have:

$\frac{d\theta}{dt} = \frac{k}{eS} \cdot \frac{d^2\theta}{dX^2}$

Where $\frac{k}{eS}$ = h; $\frac{d\theta}{dt} = h\frac{d^2\theta}{dX^2}$ (14)

h is diffusivity and it determines the rate at which temperature changes.

(ii) At the steady state, the amount of heat is taken up by any part of the rod i.e.

$\frac{d\theta}{dt}$ = 0, equation will be reduced to $\frac{d^2\theta}{dX^2} = \frac{EP}{KA}\theta$

Where $\mu^2 = \frac{EP}{KA}$

$\therefore \frac{d^2\theta}{dX^2} = \mu^2 \theta$ (15)

$\frac{d^2\theta}{dX^2} - \mu^2.\theta = 0$

Equation (15) is a differential equation of second order. So it is general solution may be written as: $\theta = Ae^{uX} + Be^{-uX}$ (16)

Where A and B are constants and their values can be found from the initial and final conditions.

Since above relation have exponential form, so in order to have a viable solution we may take a very long wood so that the other and of the wood may approximately be taken at the room temperature.

Then

$X = 0, \theta = \theta_0$

and when $X = \infty, \theta = 0$ (17)

Putting these boundary conditions into equation (16)

$\theta_0 = A + B$ (18)

$0 = A\,\ell^{\infty}, 0 = A\,\ell^{\infty}, \ell^{\infty} \neq 0$

Putting (b) and (c) into (16)

$\theta = 0e^{uX} + \theta_o e^{-uX}$

$\theta = \theta_o e^{-uX}$ (19)

Equation (19) gives a general relation for the excess of temperature at any point at a distance X from the hot end after the steady state is reached.

(iii) If the wood is covered, so that amount of heat lost due to radiation is negligible,

E = 0 and hence $\mu^2 = 0$

Equation (13) becomes

$\frac{d^2\theta}{dX^2} = 0$

Integrating twice

$\int d\theta = \int A' \, dX$

$\theta = A^1 X + B^1$ (20)

Where A^1 and B^1 are constants and their values can be found from the initial and final condition

When $X = 0, \theta = \theta_0 = \theta_0 = B^1$

When $X = L, \theta = \theta_1, \theta_1 = A^1L + B^1, \theta_1 - B^1 = A^1L, A^1 = \frac{\theta_1 - B^1}{L} = \frac{\theta_1 - \theta_0}{L}$

$\therefore \theta = (\frac{\theta_1 - \theta_0}{L}) L + B^1$

$\theta_1 = \theta_1 - \theta_0 + B^1, \theta_1 - \theta_1 = -\theta_0 + B^1$

$\therefore B^1 = \theta_0$

Putting the value of A^1 and B^1 into (20)

$\theta = (\frac{\theta_1 - \theta_0}{L}) X + \theta_0$ (21)

Equation (21) gives the excess of temperature at any point x along the wood; the wood being covered so that amount of heat lost by radiation is zero.

Three Dimensions Flow of Heat: The above relation may be extended to three dimensions. The general case in which we consider that the heat flows on one direction may be treated in a similar way and then flow of heat may be found in there directions. The general equation of conduction may be written as:

$K [\frac{d^2\theta}{dX^2} + \frac{d^2\theta}{dy^2} + \frac{d^2\theta}{dz^2}] = e.S. \frac{d\theta}{dt}$

Therefore, $\frac{K}{eS} \nabla^2\theta = \frac{d\theta}{dt}$

$h = \frac{K}{eS}$

$h\,\nabla^2\theta = \frac{d\theta}{dt}$ (22)

Where h = diffusivity

∇^2 = Laplacian operator, after the steady state we have

$\frac{d^2\theta}{dX^2}$ = 0, equation (22) becomes

Therefore $\nabla^2 \theta = 0$

The simplest case of conduction in three dimensions is the flow of heat in a sphere where the heat is supplied from the centre.

Forest Residues: Forest harvesting is a major source of biomass for energy. Harvesting may occur as thinning in young stands, or cutting in older stands for timber or pulp that also yields tops and branches usable for bioenergy. Harvesting operations usually remove only 25 to 50% of the volume, leaving the residues available as biomass for energy. Stands damaged by insects, disease or fire are additional sources of biomass. Forest residues normally have low density and fuel values that keep transport costs high, and so it is economical to reduce the biomass density in the forest itself.

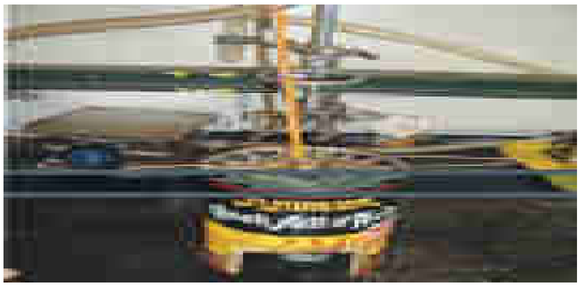
Agriculture or Crop Residues: Agriculture crop residues include corn Stover (stalks and leaves), wheat straw, rice straw, nut hulls etc. Corn Stover is a major source of bioenergy applications due to the huge areas dedicated to corn cultivation worldwide.

Urban Wood Waste: Such waste consists of lawn and tree trimmings, whole tree trunks, wood pallets and any other construction and demolition wastes made from lumber. Te rejected woody material can be collected after a construction or demolition project and turned into mulch, compost or used to fuel bioenergy plants.

Energy Crops: Dedicated energy crops are another source of woody biomass for energy. These crops are fast growing plants, trees or other herbaceous biomass which are harvested specifically for energy production. Rapidly growing, pest-tolerant, site and soil specific crops have been identified by making use of bioengineering. Herbaceous energy crops are harvested annually after taking two to three years to reach full productivity. These include grasses such as switch grass, elephants grass, bamboo, sweet sorghum, wheatgrass etc. short rotation woody crops are fast growing hardwood trees harvested within five to eight years after planting. These include poplar, willow, silver maple, cottonwood green ash, black walnut, sweet gum, and sycamore. Industrial crops are grown to produce specific industrial chemicals or materials, e.g. kenat and straws for fiber, and castor for ricinoleic acid. Agricultural crops include cornstarch and corn oil.

II. MATERIALS AND METHOD

Materials: The materials used in the research include: coffee can, large paper clip, thermometer (Celsius), stop



watch, 250ml Erlenmeyer flask, 100 ml water, matches, wire, small wire screen or foil with holes for air and ignition, 2 test tube clamps, gram scale, biomass sources like cattle manure, grass and wood.

Methods: The mass of the biomass samples (cattle manure, grass and wood) was weighed to be the same using gram scale as shown in table 1. The temperature of the water was measured using thermometer before the test as shown in table 1.

The sample was placed on the wire stand and fire is on from below. All of these were done under the coffee can as shown in fig. 2. The temperature reading was taken every 30 seconds using stop watch until the sample is completely done burned. The temperature is recorded in table 1. When the sample has finished burning, the char was removed and the next sample was set-up.

Fig.2: Full Front View of Experimental Set-up

III. DATA ANALYSIS

The data used for the analysis was gotten from the experimental work (practical).

Table.1: Data of Biomass Sample

Sample	Mass (kg)	Temperature of water before test T^oC	Temperature of water during test				
			$T_1{}^oC$	$T_2{}^oC$	$T_3{}^oC$	$T_4{}^oC$	$T_5{}^oC$
Grass	0.00477	32	34	38	40	42	46
Cattle manure	0.00477	34	36	38	48	56	60
Wood	0.00477	28	36	43	52	58	63

The total change in temperature and energy potentials for each biomass sample is calculated as shown in Table 2.

The heat energy (energy potential) was now evaluated using Eq. (1)

Grass: Where M = 0.00477kg, C_p = 1.50$Jkg^{-1o}C^{-1}$, $\Delta\theta$ = 14^oC and H = 0.10017J

Wood: where M = 0.00477kg, C_p = 1.34Jkg^{-1o}C^{-1}, Δθ = 26^{o}C and H = 0.1661868J

Cattle Manure: where M = 0.00477kg, C_p = 1.9925Jkg^{-1} ^{o}C^{-1}, Δθ = 35^{o}C and H = 0.33264788J

Table.2: Temperature Change and heat energy for different Biomass samples

Sample	T_I^{o}C	T_f^{o}C	ΔT^{o}C	Heat Energy (H)
Grass	32	46	14	0.10017J
Cattle manure	34	60	26	0.1661868J
Wood	28	63	35	0.33264788J

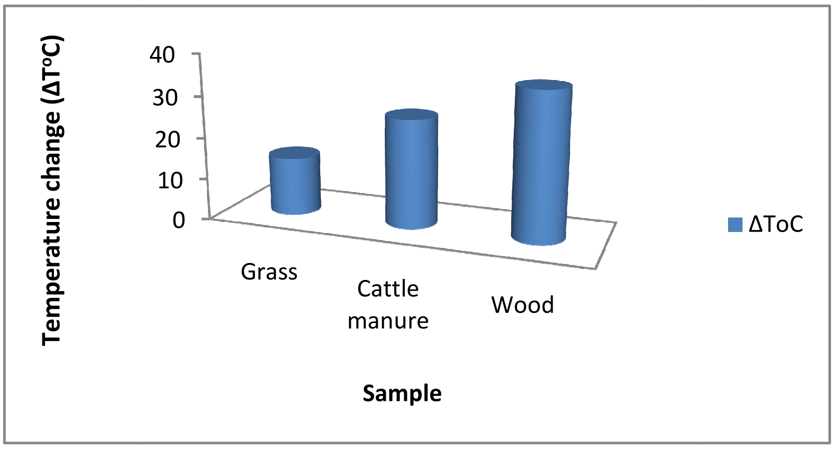


Fig.3: Plot of Temperature Change against Sample

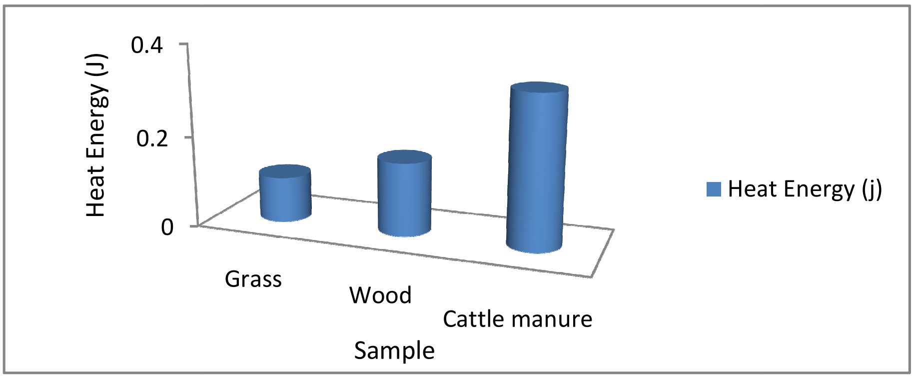


Fig.4: Plot of Energy Potential (heat Energy) against Biomass Sample

IV. RESULT(S) DISCUSSION

The result obtained from the study as shown in table 2, indicates that the sample: grass, cattle manure and wood has their change in temperature (ΔT) to be 14^{o}C, 26^{o}C and 35^{o}C respectively. That is the change in temperature increase as the moistening content of the sample decrease during the burning process. The heat energies (energy potentials) and specific heat capacities of the biomass sample vary as follows:

Grass: The specific heat capacity (C_p) of grass is 1.50Jkg^{-1} ^{o}C^{-1}. The energy potential (heat energy) is evaluated to be 0.10017J.

Wood: The specific heat capacity of dry wood is 1.34Jkg^{-1o}C^{-1}. From the evaluation the heat energy is 0.1661868J.

Cattle manure: The specific heat capacity (C_p) of dry cattle manure is 1.9925Jkg^{-1o}C^{-1}. And the heat energy evaluated is 0.33264788J.

Fig. 3 shows that grass has the lowest change in temperature 14^{o}C, followed by cattle manure 26^{o}C and wood has the highest 35^{o}C. Also fig. 4 shows that grass has the lowest heat energy (energy potential) 0.10017J, followed by wood 0.1661868J and cattle manure has the highest 0.33264788J.

V. CONCLUSION

Biomass is a renewable energy source not only because the energy in it comes from the sun, but also because biomass can re-grow over a relatively short period of time compared with the hundreds of millions of years that it took for fossil fuels to form. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates compounds composed of carbon, hydrogen, and oxygen. When those carbohydrates are burned, they turn back into carbon dioxide and water and release the energy they captured from the sun. The energy stored in the biomass samples is in form of chemical energy. The heat energy evaluated from grass, wood and manure are small in quantity i.e 0.10017J, 0.1661868J and 0.33264788J respectively. The heat energy of cattle manure 0.33264788J is higher than that of grass 0.10017J and wood 0.1661868J. The heat energy harnessed can be converted to electrical energy and to others forms of energy. This follows the law of conservation of energy which state thus "energy can neither be destroyed nor be created both can be transferred from one form to another".

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