

Calorific Value of Manure from some Nigerian Livestock and Poultry as Affected by Age

E.A. Echiegu, O.A. Nwoke, B.O. Ugwuishiwu, I.N. Opara

Abstract— The increasing demand for energy and the high cost of fossil fuels have led to increased interest in such renewable energy sources as animal manure. Manure can be subjected to different thermochemical conversion processes such as direct combustion, gasification, pyrolysis, etc. Many researchers have determined the calorific value (CV) of animal manure but these were obtained with animals from mostly developed countries where animals are better fed with possibly improved manure characteristic. In this study, the CV of manure from Nigerian beef cattle, poultry chickens and pigs were determined including the effect of time of storage on the CV. Results showed that pig manure had the least average CV of 2.870 MJ/kg. This was followed by poultry with a value of 3.423 MJ/kg and beef cattle with a value of 4.158 MJ/kg. These values are lower than those reported by other researchers and may be attributed to the nature of manure, breed of animal and type of feed on which the animals were raised. Results also showed that the older the manure the higher the CV. Also the higher the ash content of the residue after the combustion process, the lower the CV.

Index Terms— Caloric value, Heating value, Animal manure, Bomb calorimeter, Nigerian livestock, Renewable energy

1 INTRODUCTION

The increasing world demand for energy and the high cost of fossil fuels have elevated interest in alternative and renewable energy sources such as biofuels, forests, wind, solar energy and animal manure. The energy content of animal feed is expressed in calories. Not all of the energy in the feed is utilized by the animal. Some of the energy is lost during the digestion process in form of gases produced by fermentation in the gastrointestinal tract of animals; some are lost through heat of respiration while others are lost in manure (feces and urine). Several processes have the potential to transform the energy in manure to useable bio-energy.

Dry animal manure can be subjected to direct combustion to produce heat. Cow dungs have been used to run brick furnaces in the rural areas of India [1]. Apart from direct combustion, other thermo-chemical processes employed in the utilization of animal manure for energy generation include *co-firing*, *gasification* and *pyrolysis*. Steam produced from heat of combustion is used to power turbines that turn generators to produce electricity. Opportunities exist for on-site or on-farm manure to energy conversion system using small and modular conversion units to eliminate issues associated with transport of manure off site.

The conversion of biomass into renewable energy products (e.g. biofuels and electricity) has been extensively studied in recent years because it not only enhances fuel diversification but also mitigates the emissions of greenhouse gases

(GHG) and air pollutants (especially in sulfur oxides) as compared to fossil fuels like coal [2], [3], and [4]. Prior to 2007, only bench- and pilot-scale demonstration projects used animal waste as feed stock in combustion systems [5]. The world's first poultry litter-fueled plant was established in Eye, UK and Europe's largest biomass-fueled electricity generator is at Thetford, UK [5]. Recently, it has been reported that the State of Delaware in the United States of America will burn poultry manure and bedding to produce electricity for back-up to public supply [6]. Indeed, more researchers are beginning to focus on animal manure as alternative and renewable energy source [5], [7], [8], [9], [10], [11], [12] and [13].

Although animal manure has traditionally been subjected to composting as a waste management option or recycled directly into farmland as fertilizer supplement to promote plant growth [10], livestock facilities have greatly expanded in size making this option non feasible because of its attendant waste handling and environmental pollution problems. Besides, transporting a low value product such as manure over long distances is expensive; thus using excess manure as fixed fuel source instead of as fertilizer could save not only money but the environment [12].

As fuel for thermo-chemical conversion process, manure must contain sufficient heating value for the process to be cost effective. A number of researchers have determined the calorific value of animal waste [5], [12], [14] and [15]. These values were obtained with animals from mostly developed countries where animals are better fed with possibly improved manure characteristics. The aim of this paper is to determine the calorific values of animal manure from some Nigeria farm animals. The specific objectives are: (1) to determine the calorific value of Nigerian beef cattle, swine and poultry manure; and (2) to determine the effects of time of storage on the calorific values of the animal manure. The scope of this work is only limited to determination of the calorific values of beef cattle, swine and poultry manure. The effect of time of storage is

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based on freshly defecated manure, the one that has been stored for 30 days (1 month), and that of 60 days (2 months).

2 MATERIALS AND METHOD

2.1 Experimental Apparatus

An OGAMASEIKO-Type (JAPAN) Model 9904 adiabatic calorimeter shown schematically in Fig. 1 was used in the determination of calorific value.

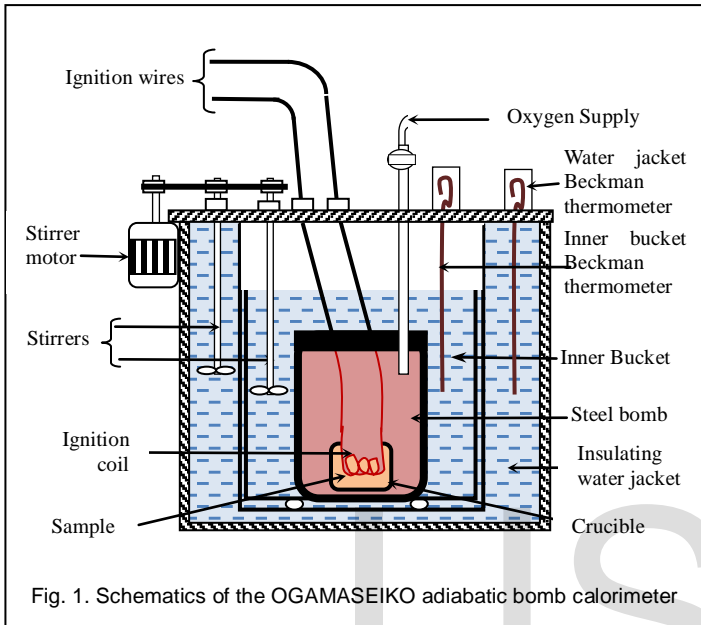


Fig. 1. Schematics of the OGAMASEIKO adiabatic bomb calorimeter

The equipment consists essentially of four parts: a bomb or vessel in which the combustible charges are burnt; a bucket or container for holding the bomb in a measured quantity of water together with the stirring mechanism; an insulating jacket to protect the bucket from transient thermal stresses during the combustion process; and a thermometer for measuring temperature changes within the bucket. The bomb is a strong, thick-walled chromium-nickel steel alloy vessel which is opened for inserting the sample, for removing the product of combustion and for cleaning. Valves are provided for filling the bomb with oxygen under pressure and for releasing residual gases at the conclusion of the test. Electrodes are also provided to carry an ignition current to a fuse wire inserted in the sample for the purpose of igniting the sample.

The bucket is carefully designed with sufficient capacity to hold the bomb completely submerged in water with a probe to read the temperature and a motor-driven stirrer included to promote rapid thermal equilibrium without introducing excessive heat in form of mechanical energy of the mixing process.

The jacketing system consists of water filled jacket equipped with a means of closely monitoring and controlling the water temperature. The temperature of the water in this outer jacket follows the temperature of the water in the inner vessel throughout the whole experiment to ensure that there is no radiation heat exchange between the outer jacket and the inner vessel thus eliminating the need for correction calcula-

tion. The water temperatures are monitored with a Beckman's thermometer which is known to provide excellent resolution and repeatability and with an accuracy of up to 0.001°C.

In the use of the calorimeter, the heat released during the combustion of the sample is taken by the water in the bucket resulting in its temperature rise. Thus:

$$m_s CV = \int_{T_o}^T [(mC_p)_b + (mC_p)_w] dT \quad (1)$$

where m is mass (g)
 CV is the caloric value of the sample (cal/g)
 C_p is specific heat (cal/g °C)
 T_o is the initial temperature (°C)
 T is the final temperature (°C)
 Subscript s = sample, b = bomb, and w = water
 Assuming a constant specific heat;

$$m_s CV = [(mC_p)_b + (mC_p)_w] (T - T_o) \quad (2)$$

Replacing the mass of calorimeter bomb, thermometer, stirrer, etc. by its water equivalent weight (m_e) then:

$$m_s CV = [(m_w + m_e)] C_{p_w} (T - T_o) \quad (3)$$

Taking into consideration, the temperature correction for radiation losses (T_c), and a correction factor (C_f) for the contribution of fuse wire to the heat generation by the sample, the heat evolved in the oxidation of N and S usually present in fuels [16], etc the calorific value of the sample is computed from.

$$CV = \frac{(m_w + m_e)[(T_c + T) - T_o] C_{p_w} - C_f}{m_s} \quad (4)$$

Since the calorimeter is adiabatic with insignificant radiation heat losses, $T_c = 0$. Also, with the specific heat capacity of water, $C_{p_w} = 1.0$ cal/g °C, equation (4) reduces to:

$$CV = \frac{(m_w + m_e)[T - T_o] - C_f}{m_s} \quad (5)$$

For this bomb calorimeter, m_e and C_f are standardized as 581 g and 154 calories, respectively.

2.2 Sample Collection and Preparation

Samples of freshly defecated manure from beef cattle, pigs and poultry were collected from the University of Nigeria, Nsukka livestock farm. The beef cattle of various breeds (*Ndama, Muturu, White Fulani and Sokoto Gudali*) were raised on pasture; the pigs were raised under complete confinement while the poultry were raised in battery cages. The cattle fed on grass without any additional feed supplement; the pigs were fed on feed formulated at the farm using cassava, brewery offal, etc while the poultry chickens were fed with commercially available poultry feeds.

Each of the samples was divided into three portions. The first of the portions (referred to as *Fresh*) were used for calorific value (CV) determination within one day of their defecation. The second and third portions were stored indoors at room temperature of 27 – 29 °C and their CV determined after 30 days and 60 days, respectively.

2.3 Experimental Procedure

At the beginning of each CV determination, the moisture contents of the samples were first determined. The samples were subsequently bone dried, crushed, ground and sieved with a 0.2 mm sieve. One gram (1.0 g) each of the samples was then accurately weighed out using an electronic weighing balance. The measured sample was then wrapped with a thin paper with an ignition wire wound round the paper. The sample was put in the sample pan and was placed in the carrier ring of the calorimeter after which each of the ignition wire was connected to the electrodes on the bomb cover. The wire forms parts of an electric circuit which is completed by a firing button situated in a position remote from the bomb. The cover was then transferred from the cover support to the main body of the bomb. The packing having been inserted, the box nut was fitted and tightened manually.

Next, pure oxygen was admitted through a reducing valve fitted on an oxygen cylinder via a lead pipe connected to the oxygen inlet of the bomb until the pressure in the bomb ranged between 25– 30 atm.

Once this was completed, water was poured in the hot water vessel of the equipment, and heated by the heating coil provided in the vessel. After this, a rubber hose was connected to the water supply inlet and the drain outlet of the instrument provided on the side of the main body.

The bomb was lowered into a known quantity of warm water in the inner vessel formerly resting on a triangular support in the intermediate vessel with an air space between them. The ignition cap provided on the cover was connected to the ignition terminal of the bomb. The intermediate vessel was rightly placed on the bottom of the outer jacket.

Next, water was supplied into the outer jacket up to the designed level. The separated covers were set and tightened and the inner vessel stirrer was equally fixed. The external connection to the circuit was made. Both the inner vessel and the outer jacket stirrer were connected to an electric motor by a round belt and the water in the two vessels stirred in a regular manner by the motor-driven stirrers. The Beckmann's thermometers for inner and outer jacket were rightly placed. The temperatures of the water in the two vessels were adjusted to achieve stabilization. The essence of this stabilization was to ensure that there was no heat exchange between the outer jacket and the inner vessel. The stabilized temperature was taken as the temperature before ignition.

For ignition, the ignition button on the main body of the calorimeter was depressed to ignite the sample in the bomb. As soon as ignition started the heat generated inside the bomb

was conducted quickly thus increasing the temperature of the water in the inner vessel. The Beckmann's thermometer was read at interval of one minute until the temperature of the inner vessel was again steady for another three minutes. This steady temperature was taken as maximum temperature rise for the sample under test. The same procedure was repeated for the different samples.

3 RESULTS AND DISCUSSIONS

3.1 Moisture Content

The moisture content (wet basis) of the manure samples at the commencement of each CV determination is shown in Fig. 2. The moisture content (MC) for the beef cattle, poultry and pig at the time of collection were 69.54, 67.92 and 46.21 % respectively. At 30 days the MC were 37.1, 22.4 and 30.29 % respectively while at 60 days the values were 30.17, 19.5 and 26.28, respectively. Moisture content plays a role in the CV value of solid fuels as the moisture has to be evaporated in the process of burning the fuel. The relationship between energy content and MC is as follows:

$$CV = \left[\frac{100 - MC}{100} \right] \times ECD - \left[\frac{MC}{100} \right] L_w \quad (6)$$

where ECD is the adjusted gross energy content per unit of biomass component, dry basis (KJ/kg) and L_w is the heat of vaporization of water ($\text{KJ kg}^{-1} \text{ } ^\circ\text{C}^{-1}$). However since the samples were bone dried at the commencement of each CV determination, the effect of moisture content on the CV was not consid-

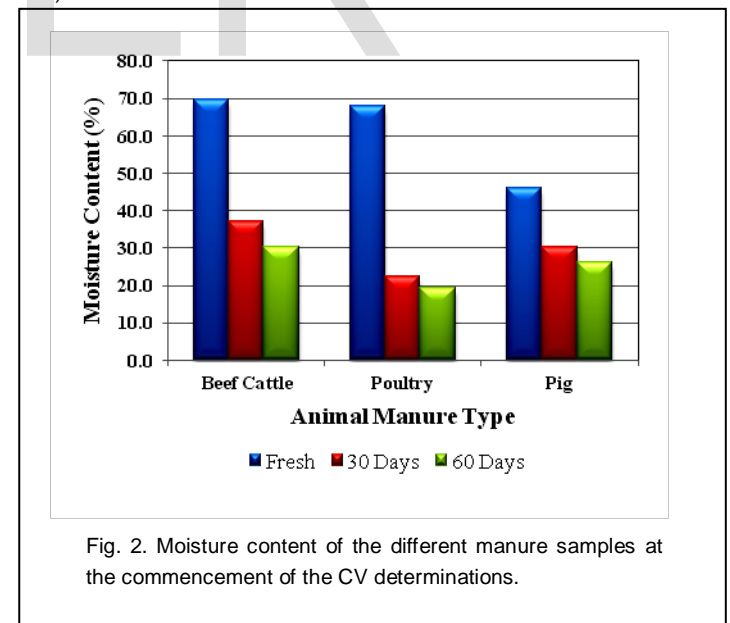


Fig. 2. Moisture content of the different manure samples at the commencement of the CV determinations.

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3.2 Temperature

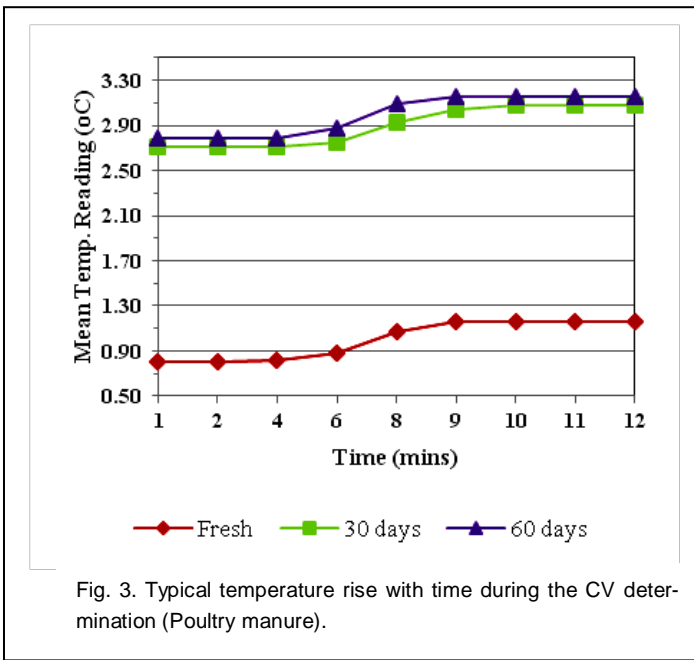


Fig. 3. Typical temperature rise with time during the CV determination (Poultry manure).

Figure 3, which was obtained with poultry manure, shows a typical rise in temperature with time. From the graphs, it can be deduced that the rate of temperature rise was constant within the first four minutes of pre-firing, then rises up to the time of about 8 – 9 minutes of heating and remained constant again till the end of the experiment. Another point to note from the graph is that there is a higher temperature rise during the combustion of various ages of the manure – the older the manure, the higher the temperature rise.

3.3 Calorific Values of the Samples

Table 1 shows the calorific values of the beef cattle, poultry and pig at different ages of manure. Figure 4 shows a comparison of the calorific values of the manure sample.

From the table, it is seen that the mean calorific value for cattle manure, which was 4.004, 4.200 and 4.271 MJ/kg for fresh, 30 days and 60 days old, respectively was higher than when compared to the value for similar age of manure of the other animals. The next highest was that of poultry manure while the least was that of pig manure.

The reasons for the variations in the values are the fact that ruminant animals have a peculiar digestive system. They are more capable of utilizing roughages as feed and this contains high fibre content which does not digest easily. Invariably, this fibre enhances combustion. Cattle belongs to the ruminant class and undergo the above stipulated condition, hence its high calorific values. Both poultry and pigs feed on concentrates but the gizzard in the poultry digestive system churns the feed well with the help of stones and this creates a suitable surface finish for combustion to take place; and because of this poultry emerged next to cattle manure in the heat content followed by pig manure.

TABLE 1
CALORIFIC VALUE OF THE MANURE SAMPLES AND OTHER FUELS

Sample	Age	Mean Calorific Value (MJ/kg)
Cattle manure	Fresh	4.004
	30 days	4.200
	60 days	4.271
	Mean	4.158
Poultry manure	Fresh	3.164
	30 days	3.457
	60 days	3.648
	Mean	3.423
Pig manure	Fresh	2.785
	30 days	2.881
	60 days	2.944
	Mean	2.869
Bituminous coal		31.015 [5]
Sub-bituminous coal		27.830 [5]
Lignite coal		22.885 [5]
Wood chips		19.000 – 21.000 [15]
Saw dust		20.100 [15]
Straw		18.86 [16]

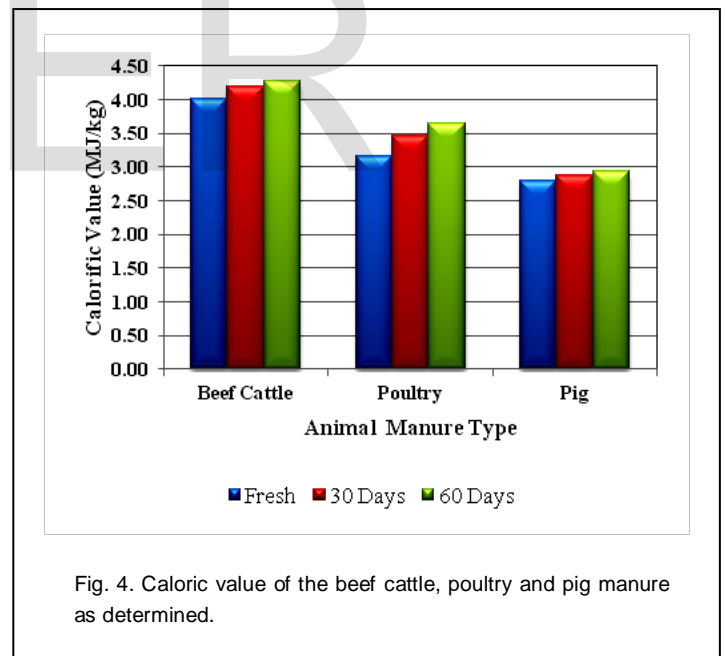


Fig. 4. Caloric value of the beef cattle, poultry and pig manure as determined.

Also, as shown in Table 1, the average CV for the cattle, poultry and pig manure were 4.158, 3.423 and 2.869 MJ/kg respectively. Compared to values given by other researchers this appears relatively low [5],[12],[14] and [17]. For example, Santoianni, *et. al.* gave the higher heating values for chicken litter, cattle feedlot manure and belt harvested hog manure as 10.620, 7.865 and 19,700 MJ/kg, respectively [5]. Mukhtar gave the heating value of dairy manure as 19.771 MJ/kg (8500

BTU/lb) [12].

Keener and Wicks gave the heating value of swine and cattle manure as 18.8 and 17.01 MJ/kg, respectively [14] while Stromberg gave a value of 17.5 MJ/kg for poultry manure [17].

These values are all higher than the value determined and can be attributed to the type of feed on which the animals were raised, the breed and the nature of the manure i.e. the amount of other matters such as beddings, stones, etc contained in the manure. The manure used for this study was pure manure without other additional wastes. Also while the values given by the above researchers tends to indicate that pig manure had higher heating value than cattle, the result of this study showed a contrary value which again can be attributed to breed of animal, type of feed used and nature of manure.

Again, from the table, is is seen that that compared to conventional solid fuels such as coal, the calorific value determined was quite low. Finally, it has been indicated that biomass with a heating value less than 8.100 MJ/kg would be of little value to a suspension or grate-fed thermo-chemical conversion plant because it would require a net energy input to sustain the combustion [18] implying that manure from the Nigerian animal may not be suitable for such conversion process.

The effect of age on CV is shown in Figure 5. As can be seen from the figure, the storage period of the manure plays a significant role in the calorific values. As stated above, the CV of the 60 day old manure samples appeared the highest compared to the other ones. This in effect tells us the need for an increased storage period and drying temperature which reduces the nitrogen quantity retained in dehydrated manure. This is effective as nitrogen in the dried solid fuel inhibit the combustible rate of the fuel.

Another point to note is the ash content of the residue left after the combustion process (Figure 6). From the figure, cattle

have the least ash content after combustion, followed by poultry

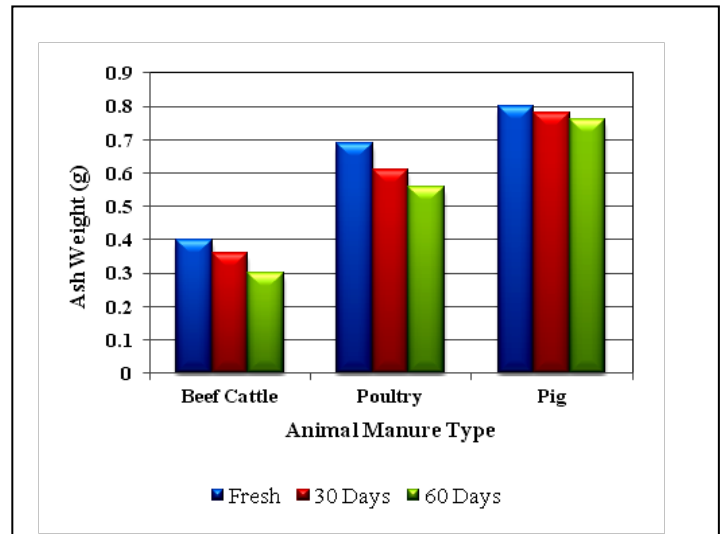


Figure 6. Ash content of the residue after the combustion of the manure.

and then pig. This is to say that the higher the ash content, the lower the calorific value (i.e. ash content is inversely proportional to the calorific value).

4. CONCLUSIONS

The Calorific values of the solid fuels tested varied with pig manure having the least average value of 2.870 MJ/kg and cattle having the highest value of 4.158 MJ/kg. The value for poultry was 3.423 MJ/kg. These values were lower than those reported by other researchers and is attributed to the breed, nature of manure and the type of feed on which the animals were raised. Storage period also plays a significant role on the calorific value. As shown by the study, the older the manure the higher the calorific value. The study also showed that the higher the ash content of the residue after the combustion process, the lower the calorific value. The ash contents of the cattle, poultry and pig manure ranged from 0.3 – 0.4 g, that of poultry ranged from 0.55 to 0.70 g while that of swine ranged from 0.75 to 0,80 g depending on the age of the manure.

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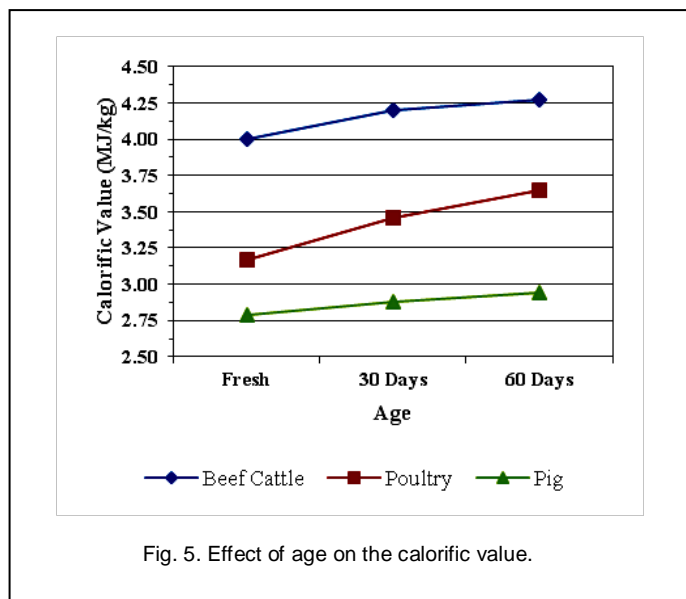


Fig. 5. Effect of age on the calorific value.

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