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Prediction of livestock manure and mixture higher heating value based on fundamental analysis

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HIGHLIGHTS

- HHV and characteristics of various livestock manure and mixture were determined.
- HHV correlations with livestock manures and mixtures characteristics were examined.
- Lower AAE value was obtained when pig manure excluded from equations database.
- Proposed equations give better accuracy than previous published equations.

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ABSTRACT

The ongoing availability of livestock waste presents an opportunity for its utilization as renewable energy resource through biological or thermochemical conversion. However, the conversion efficiency and the potential energy content of livestock waste needs to be estimated in order to design such a renewable energy production system. To address this, eight types of livestock waste were collected from each of 12 commercial farms from April to May 2009. The higher heating value (HHV), which represents the actual energy content, along with characteristics of livestock waste was determined. Moreover, equations for estimating HHV from proximate, ultimate, and chemical analysis were established by regression analysis. The developed equations were then validated using additional livestock waste data. The HHV of livestock waste was found to be in the range from 11.92 to 19.44 MJ/kg dry matter. The equation, HHV = 0.1970VM + 0.3955 represents the best-fit equations derived from proximate analysis with an Average absolute error (AAE) value of 9.17%. The equation, HHV = 0.1865CH + 0.2671PR + 0.2141F − 0.2151 is best-fit equation derived from chemical analysis with an AAE value of 5.31%. The equation derived in this study, HHV = 0.3198C + 0.0803O + 0.4704N − 1.4502S + 0.9364, was compared with ten recently published correlations based on ultimate analysis and showed better accuracy by having the lowest AAE values of 8.57%. All developed equations can be used to estimate HHV of various livestock waste with the exception of swine manure. The main reason for this limitation arises from the unique characteristics of pig manure in comparison to other livestock waste found in this study.

1. Introduction

The rapid decrease of fossil fuels has become one of the most important worldwide concerns in recent years [1]. It is predicted that even several fossil fuel producing and exporting countries will not be able to meet their own energy demands in the future. Oil resources in most Middle-East countries, account for about 50% of the total proven oil reservoirs in the world and are estimated will be depleted within 30 years [2–5]. As an example, Saudi Arabia (the largest oil reservoir country) will not be able to meet its domestic and international oil resource demands within 20 to 30 years [5]. Even worse, global energy demand is estimated to increase rapidly by an average annual rate of 1.4%, which will equal 49% in 2035 [6].

For that reason, the present day use of renewable energy is an urgent matter. In fact, considerable research has been conducted regarding the possibility of obtaining energy from renewable resources. In addition, the potential of biomass as feedstock to provide a sustainable supply of energy has become a major research topic all over the world [1,6–11]. The trend to produce energy from biomass utilization is rising and is considered to be very important [7,12].

At the same time, intensive farming has become the trend in many countries and produces a large amount of livestock waste

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Nomenclature

AAE	Average absolute error	H	Hydrogen
ABE	Average bias error	HHV	Higher heating value
B	Beef manure	L	Layer manure
BM	Beef manure mixture	M	Moisture
BR	Broiler manure mixture	N	Nitrogen
C	Carbon	O	Oxygen
CH	Total carbohydrate	P	Pig manure
D	Dairy manure	PR	Protein
DM	Dairy manure mixture	S	Sulfur
DU	Duck manure mixture	VM	Volatile matter
F	Fat		
FM	Feedlot manure		
FS	Fixed solid		

[13,14]. For example, more than 1500 million fresh tons of livestock waste is produced annually in the EU-27 [15] and about 35 million dry tons of livestock waste is produced annually in the United States [16]. Livestock waste is one example of a valuable and sustainable energy resource since it will always be produced as long as human populations exist. Conversion of livestock waste to bioenergy can be achieved through biological or thermochemical processes.

The biological conversion of livestock waste uses anaerobic digestion in which organic matters are converted into methane or hydrogen by anaerobic microorganisms [16–19]. Thermochemical conversion of livestock waste can be done by pyrolysis, gasification, and direct liquefaction in which organic matter is converted into hydrogen, hydrocarbon gases, bio-oil, or char by applying high temperature and pressure [16,18]. These processes, however, are dependent on several factors such as temperature, pH, pressure, residence time, etc. [16,17], which makes the energy gain less than the actual energy content of the original livestock waste. In order to determine the conversion efficiency of livestock waste to energy through a biological or thermochemical process, the potential energy content of livestock waste, also referred to as the heating value, must first be measured.

The heating value can be defined as the quantity or the sum of heat that is produced when biomass goes through complete combustion. It is also the standard energy measurement of a fuel [19]. Two kinds of heating value can be differentiated, a Higher heating value (HHV) and a Lower heating value (LHV). The total heat given off when a substance goes through combustion and including the latent heat generated from the condensation of the water vapor is called HHV. When latent heat is not included, it is called LHV [7,11].

The heating value can be measured experimentally with an adiabatic bomb calorimeter [3–5]. Another approach is using mathematical modeling that calculates the heating value based on fundamental analysis data (proximate, ultimate, and chemical analysis) [1,6,7,9–11,20–23]. Based on previous studies, predicting the HHV of a material from fundamental analytical data provides an easier and practical way to measure its HHV. Many studies have been established related to the HHV estimation of plant biomass (peanut shell, rice straw, corn straw, olive cake, etc.). Several studies have calculated HHV from fundamental analysis data [1,6,7,10,11,19,21,23]. Other researchers have also established a formula for carbonaceous materials [21,24]. Thipkhunthod et al. [22] used a different approach by developing an equation for estimating HHV of sewage sludge from proximate and ultimate analysis. Annamalai et al. [23] estimated the higher heating value of cattle manure and plant biomass by applying the Boie equation.

There are, however, limitations in the studies measuring and correlating the HHV of various types of livestock manure and mixture with their characteristics. Therefore, the objectives of this study are to provide a HHV and to develop an equation for estimating HHV from proximate, chemical, and ultimate analysis of various types of livestock manure and their mixture.

2. Materials and methods

2.1. Sample collection

Each of livestock manure and their mixture, from now on referred to as livestock waste, were collected from 12 commercial farms in South Korea from April to May 2009. A total of eight different kinds of samples were collected, which included: dairy manure (D), dairy manure mixture (DM), beef cattle manure (B), beef cattle manure mixture (BM), pig manure (P), layer manure (L), broiler manure mixture (BR), and duck manure mixture (DU). Samples were collected from each farm and mixed together prior to analysis. Approximately 1 kg of waste was collected and stored at 4 °C until further use.

2.2. Analytical method

2.2.1. Ultimate, proximate, and chemical analysis

Ultimate analysis or elemental analysis was conducted following the drying of samples at 105 °C for 24 h and passing them through a 200 mesh screen. Pretreated samples were then analyzed by using a Flash Elemental Analyzer (Model EA1112, Finnigan). The elements analyzed included: carbon, hydrogen, nitrogen, oxygen, and sulfur. Proximate analysis, which is a measure of water content, fixed solid, and volatile matter was determined by following APHA standard methods for total, fixed, and volatile solids in solid and semisolid samples. Chemical analysis which analyzes the content of protein, fat, and total carbohydrate was conducted by following AOAC standard methods. Prior to the chemical analysis, all samples were air-dried.

2.2.2. Higher heating value

Dried samples were mixed using a steel blade and screened through an 80 mesh screen. Samples were then packed in vinyl bags and analyzed with an automated bomb calorimeter (IKA, C5000, Germany). The HHV was determined by subtracting the total HHV of the samples and vinyl bags with the HHV of vinyl bags alone.

2.3. Data analysis

Correlations of a HHV with proximate, ultimate, and chemical analysis were estimated by the Pearson correlation test. Moreover,