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ENERGY ANALYSIS FOR PRODUCTION OF POWDERED AND PELLETISED ORGANIC FERTILIZER IN NIGERIA

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ABSTRACT

Energy study was conducted in an organic fertilizer plant in Ibadan, Nigeria, to determine the energy requirement for production of both powdered and pelletised organic fertilizer. The energy consumption patterns of the unit operations were evaluated for production of 9,000 kg of the finished products. The analysis revealed that eight and nine defined unit operations were required for the production of powder and pellets, respectively. The electrical and manual energy required for the production of powdered fertilizer were 94.45 and 5.55% of the total energy, respectively, with corresponding 93.9 and 5.07% for the production of pelletised fertilizer. The respective average energy intensities were estimated to be 0.28 and 0.35 MJ/kg for powder and pellets. The most energy intensive operation was identified as the pulverizing unit with energy intensity of 0.09 MJ/kg, accounting for respective proportions of 33.4 and 27.0% of the total energy for production of powder and pellets. Optimisation of the pulverizing process is suggested to make the system energy efficient.

Keywords: organic fertilizer, production, energy requirement, unit operations, Nigeria.

1. INTRODUCTION

Energy is one of the most critical input resources in the manufacturing industries. In most cases, energy cost out weighs the costs of other resources such as raw material, personnel, depreciation and maintenance [1]. Hence, energy utilization efficiency constitutes a major determinant in the overall unit cost of production. Therefore, energy audit is an important management tool required for economic utilization of energy resources in any manufacturing outfit. Inefficient energy utilization could lead to huge economic losses. Excessive energy consumption adds to the costs of goods produced especially in the energy intensive industries.

In view of this, attempts should be made for higher efficiency of utilization of fuel, electricity, thermal energy and labour, these being the major components of manufacturing cost. In Nigeria, the major sources of industrial energy are fossil fuel, natural gas, coal and electricity generated by thermal and hydro power station. The supply of electricity in the country is in acute shortage due in part to the dearth of underlying power generation technology and old facilities of the power stations, and also due to the problems in the transmission and the distribution of the energy. Consequently, most companies in the country now rely mainly on the use of heavy-duty generating plant for the supply of their electrical energy which is used for operations such as air conditioning, lighting and some machining processes [2].

The increasing energy demands coupled with the finite energy resources, the rising cost of fossil fuels and the considerable environmental impacts connected with their exploitation necessitate the needs to understand the mechanisms, which degrade the quality of energy and energy systems. The processes that degrade the quality of energy resources can only be identified through a detailed analysis of the whole system [2]. This account for the extensive work that has been done on energy auditing system of many manufacturing operations with the aim of improving the design and performance of energy transfer systems. Although extensive literature exists concerning the energy audit of many manufacturing processes such as rice processing [3], sunflower oil expression [4], palm-kernel oil processing [5,6], cashew nut processing [7], poultry processing [8], cassava-based foods [9], milk processing [10], and sugar production [11], limited work has been reported on energy audit of fertilizer processing operations.

The energy requirements for the production, packaging, transportation, and application of inorganic fertilizers have been reported by Helsel [12]. The study revealed that the energy intensities required for production of Nitrogen, Phosphate and Potash fertilizers were 69.5, 7.7 and 6.4 MJ/kg, respectively. This thus indicates inorganic fertilizer production as an energy intensity operation. The adoption of modern manufacturing techniques has led to significant improvement in the energy efficiency for Nitrogen fertilizer production from a threshold value of about 400 MJ/kg (1910) to theoretical minimum of 40 MJ/kg (2000) [13]. Gellings and Parmenter [14] reported the energy requirements for transportation and application of inorganic and organic fertilizers. The study revealed that higher energy values were required for the transportation and application of organic fertilizer compared to inorganic fertilizers. However, the study did not quantify the energy requirement for the production of organic fertilizer. To the best of the authors' knowledge no work has been conducted on the energy requirement and energy cost analysis of organic fertilizer manufacturing operations.

The average annual fertilizer usage of 12.8 kg/hectare in Nigeria is very low compared with Zimbabwe and Western Europe with respective values of 57.1 and 231.4 kg/hectare [15]. The acute shortage in fertilizers required to maintain about 21 million hectares of farmland in Nigeria has been reported by Obigbesan [16]. The fertilizer requirement of Nigeria was 1.2 million

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metric tonnes per annum for the period of 1985-1987. The demand has continued to increase since then, while the country's total fertilizer supply increased from 750,000 tonnes in 1988 to 1.65 million tonnes in 1994, the supply drastically reduced to 835,000 tonnes in 1995. Of this total, only about 313,190 metric tonnes (37.5%) was produced locally and the trend has continued to increase [16]. The removal of 30% fertilizer subsidies by the government of Nigeria, the subsequent ban on importation of chemical fertilizers and constant breakdown of the existing five inorganic fertilizer manufacturing plants in the country have created scarcity leading to unaffordable prices of chemical fertilizer. Thus, making inorganic fertilizers to be beyond the reach of peasant farmers. The high cost of chemical fertilizer and the current global shift toward organic farming have led to increase in the demand for organic-based fertilizers. Therefore, many composting plants are springing up in different parts of the country [1]. The high organic content of the solid waste generated and the acute stortage in fertilizer requirement in the country favours the composting option as a sustainable and cost effective management strategy for solid waste and soil fertility. The use of organic based fertilizers has been found to increase crop yield, improve the quality of product, control soil-borne diseases, improve soil properties and conserve soil moisture [17]. The advantages of organic fertilizers over the inorganic fertilizers are: ability to supply the required plant nutrients, enhancement of the soil organic matter content, good water holding capacity, improved physical quality of the soil and cost effectiveness [15].

Development of various indigenous processing plants for organic fertilizer production has made business very important and on the forefront of various researches works [1]. Organic fertilizer production involves the conversion of organic wastes by aerobic or anaerobic microbial degradation. The basic operations involved in the production process include operations such as collection of the organic waste stocks, transportation, sorting, shredding, composting and curing, drying, screening, pulverising, mixing, pelleting and bagging. These operations require high and steady energy supply to function. Hence, there is need for efficient energy management strategy for production of organic-based fertilizer. The aim of this study was therefore to analyse the energy consumption pattern of the various unit operations required for the production of organic based fertilizer in Nigeria. The essence of the study is to identify the energy inefficiencies in the unit operations as a step towards the optimisation of the system.

2. MATERIALS AND METHODS

2.1 Process description

An organic fertilizer processing plant located in Ibadan, Southwestern Nigeria was selected for this study. The plant was developed locally and installed in 1996 [1]. The plant, sited in a typical municipal market, produces both powdered and pelletised organo fertilizer using market refuse and animal intestinal waste. The types of energy sources utilized in the production system were electrical and manual energy. Electrical energy was the major source of energy used during production. Due to inconsistency in power from the National grid, a standby generating set with a capacity of 135 kV A was used as an alternative source for electrical power supply.

There were nine defined unit operations in the production process for pelletised fertilizer, while eight unit operations were involved for production of powdered fertilizer. The process flow chart of the production system is shown in Figure-1. Refuse and animal intestinal waste were collected by the State Waste Management Authority and transported to the plant with a truck. The wastes were received, weighed and stored in different storage chambers for about 3 days before processing commenced. The storage chambers were made of rectangular concrete walls with a capacity of about fifteen thousand tonnes. The processing began by sorting manually the non bio-degradable components of the market refuse such as iron, nylon, metal, glass, etc consisting of about 13.5% by weight of the total and 29.0% by volume.

In order to facilitate the rate of decomposition during the composting process, the sorted bio-degradable component of market refuse was shredded with a shredding machine to reduce the particle size. The shredded market refuse and abattoir waste were then co-composted aerobically with ratio of 3 to 1 by wet weight, respectively, inside open windrows for about 60 days. The organic wastes were piled up in layers and turned manually and sprinkled with water once a week. The compost was then cured for another 60 days and dried in a rotary dryer at low temperature to reduce the moisture content before the processing was continued. After composting and curing, the compost was screened with a mechanically operated separator fitted with a sieve of 15 mm in order to remove large, undegraded part of the compost, which was returned to the windrow and mixed with fresh compost, while the degraded part was conveyed via screw conveyor to the pulveriser. Other extraneous component like iron was removed by magnetic separator. The screened compost was then milled to fine powder using a hammer mill with a sieve size of 3 mm. Mineral additives such as Urea and rock phosphate were added and mixed with the milled compost. For the production of pellets, kaolin was added as artificial binding agent. Water was also added to increase the moisture content to about 15% on wet basis before bagging of the powdered fertilizer. The moisture content was increased to about 20% for the production of pellets. The milled and fortified compost was compacted mechanically with an extrusion pelletiser into 10 mm diameter pellets. The finished products (powder or pellet) were then bagged in 50 kg nylon laminated bags. The bagging process included the following operations such as, loading, weighing and sewing. The units operations were carried out on batch process. The energy input into each of these unit operations was accounted for by noting and quantifying the type of energy used, which were either one or a

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combination of electrical and manual energy. All electric motors in the plant were identified, and the amperage and horsepower rating, number of phases and voltage were noted to enable the estimation of electrical energy.

2.2 Data collection

The primary energy resources utilized in the plant were electrical and/or manual energy. An inventory of the electrical motors, power rating of the machines, heaters, number of personnel involved, time required for production, and material flow

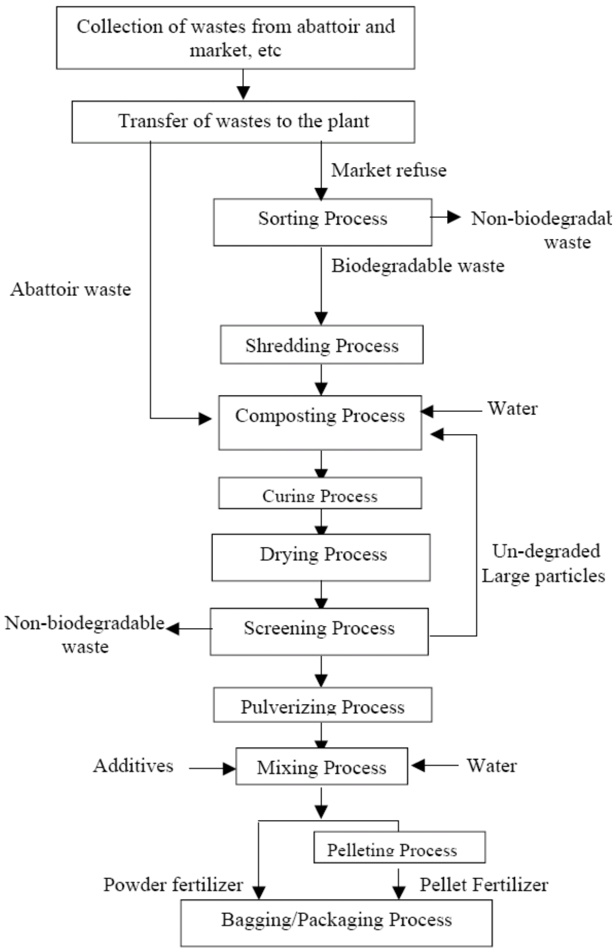

Figure-1. Flow chart of the organic fertilizer processing operations.

In each of the unit operation was made. The power rating of the electrical devices and capacity of each unit were collected from the plant's manager. The production processes were monitored and data collected over a period of 2 months. The measuring quantities used in the course of the data acquisition include: (i) a stopwatch for measuring the time spent in each unit, (ii) a measuring cylinder for measuring the amount of water and (iii) a weighing balance for measuring the quantity of materials used. The data for the time and energy input into each of the unit operations are presented in Table-1.

2.3 Estimation of energy input into each unit operation

The energy components (electrical and manual) for each of the unit operation were calculated for the production of 9,000 kg of finished fertilizer for both powdered and pelletised fertilizer. The following procedures were used:

2.3.1. Electrical energy

The electrical energy usage by the equipment was obtained as the product of the rated power of each motor and the number of hours of operation. A motor efficiency of 80% was assumed to compute the electrical inputs [4]. This was calculated mathematically as:

$$Ep = \eta Pt \tag{1}$$

Where *Ep* is the electrical energy consumed in kW h, *P* is the rated power of motor in kW, *t* the hours of operation in hours and η the power factor (assumed to be 0.8).

2.3.2. Manual energy

This was estimated based on the values recommended by Odigboh [18]. According to him, at the maximum continuous energy consumption rate of 0.30kW and conversion efficiency of 25%, the physical power output of a normal human labourer in tropical climates is approximately 0.075kW sustained for an 8–10 h workday. This was calculated mathematically as:

$$Em = 0.075\,Nt \tag{2}$$

where E_m is the manual energy in kW h, 0.075 is the average power of a normal human labour in kW, *N* is the number of persons involved in an operation and *t* the useful time spent to accomplish a given task in hours.

Table-1. Required parameters for evaluating energy in organic fertilizer plant.

Operation	Required Parameters	Value
Sorting	Time taken for sorting (h)	8.0
	Number of persons involved in sorting	5
Shredding	Electrical power (kW)	11.25
	Time taken for shredding (h)	9.0
	Number of persons involved in shredding	2
Composting	Time taken for sorting (h)	7.0
	Number of persons involved in sorting	5
Drying	Electrical power (kW)	5.25
	Time taken for drying (h)	9.0
	Number of persons involved in drying	2
Screening	Electrical power (kW)	15.00
	Time taken for screening (h)	9.0
Pulverising	Electrical power (kW)	26.25
	Time taken for pulverising (h)	9.0
Mixing	Electrical power (kW)	7.13
	Time taken for mixing (h)	9.0
Pelleting	Electrical power (kW)	18.75
	Time taken for pelleting (h)	9.0
	Number of persons involved in pelleting	2
Bagging	Electrical power (kW)	5.63
	Time taken for bagging (h)	9.0
	Number of persons involved in bagging	4

3. RESULTS AND DISCUSSIONS

The time and energy used for the production of 9,000 kg of both powdered and pelletised products are given in Tables-2 and 3. The energy consumption data obtained provides useful information on the sources of energy requirement of each processing unit. The data revealed that the total energy requirement for the production of powder and pellets were found to be 2,523.68 and 3,151.18 MJ, respectively. The total energy intensities were estimated to be 0.20 and 0.35 MJ/kg for the production of powdered and pelletised fertilizer, respectively. The estimated energy intensities for production of both powdered (0.20 MJ/kg) and pelletised (0.35MJ/kg) organic fertilizer were considerably lower compared to the energy intensities required for production of Nitrogen (69.5 MJ/kg), Phosphate (7.7 MJ/kg), and Potash (6.4 MJ/kg) fertilizers [12]. The electrical energy intensities were 0.27 and 0.33 MJ/kg for the production of powdered and pelletised products, respectively. The corresponding manual energy intensities were 0.016 and 0.018 MJ/kg. These clearly indicated that the pelletised product consumed more energy than the powdered product. The manual energy consumption for both powdered and pelletised fertilizer represented proportions lower than 6% of the total energy consumption.

It was observed that all the unit operations required electrical energy except for composting and sorting that was done manually. However, screening, pulverizing and mixing utilised only electrical energy and do not involve manual energy. The most energy intensive operating unit in the production system was identified as the pulverising unit with 850.50 MJ of energy, accounting for 33.4 and 26.99% of total energy required for the production of powder and pellets, respectively. To optimize the energy consumption of the pulverising unit, process and/or machine design modifications will be required. The process modification option will involve a change of process, the wet grinding method is suggested because of the low energy input requirement and drying can then be effected after the wet grinding process. The design modification option will involve increasing the capacity of the pulverising unit in order to increase the rate of production of the unit. Additional cost of investment will be required for the process modification option, while minimal additional cost may be required for the machine design modification option. Therefore, in terms of cost effectiveness, the machine design modification is considered to be the most feasible option.

Table-2. Time and energy requirement for the production of powdered fertilizer.

#	Process	Produc-tion time (h)	Electrical energy Ep_i (MJ)	Manual energy Em_i (MJ)	Total energy Et_i (MJ)	Percentge energy (Et_i / Et_{tt})*100 (%)
1	Sorting	8	-	38.88	38.80	1.53
2	Shredding	9	365.50	17.50	383.00	15.06
3	Composting/Curing	7	-	34.02	29.16	1.15
4	Drying	9	325.62	17.50	343.12	13.5
5	Screening	9	486.00	-	486.00	19.11
6	Pulverizing	9	850.50	-	850.50	33.4
7	Mixing	9	230.85	-	230.85	9.08
8	Bagging	9	162.00	34.40	182.25	7.17
Total			Ep_{tt} = 2420.47	Em_{tt} = 142.30	Et_{tt} = 2523.68	100.00
Percentage of total (%)			94.45	5.55	100.00	

$$Ep_{tt} = \sum_{i=1}^{8} Ep_i\ , \quad Em_{tt} = \sum_{i=1}^{8} Em_i\ ,\ Et_{tt} = \sum_{i=1}^{8} Et_i$$

Table-3. Time and energy requirement for the production of pelletised organic fertilizer.

#	Process	Production time (h)	Electrical energy Ep_i (MJ)	Manual energy Em_i (MJ)	Total energy Et_i (MJ)	Percentage energy (Et_i / Et_{tt}) *100 (%)
1	Sorting	8	-	38.88	38.80	1.23
2	Shredding	9	365.50	17.50	383.00	12.15
3	Composting/ Curing	7	-	34.02	29.16	0.93
4	Drying	9	325.62	17.50	343.12	10.89
5	Screening	9	486.00	-	486.00	15.42
6	Pulverizing	9	850.50	-	850.50	26.99
7	Mixing	9	230.85	-	230.85	7.33
8	Pelleting	9	540.00	17.50	607.50	19.28
9	Bagging	9	162.00	34.40	182.25	5.78
Total			Ep_{tt} = 2,960.47	Em_{tt} = 159.80	Et_{tt} = 3,151.18	100.00
Percentage of total (%)			93.95	5.07	100.00	

$$Ep_{tt} = \sum_{i=1}^{9} Ep_i\ , \quad Em_{tt} = \sum_{i=1}^{9} Em_i\ ,\ Et_{tt} = \sum_{i=1}^{9} Et_i$$

The energy and mass flow diagrams for the production of powdered and pelletised products are shown in Figures 2 and 3, respectively, using the modified form of energy accounting symbol presented by Singh [19]. The electrical and manual energy consumption together with the material mass flow was assigned to each unit operations. The pelletised product involves nine defined unit operation while the powdered production unit involves eight units.

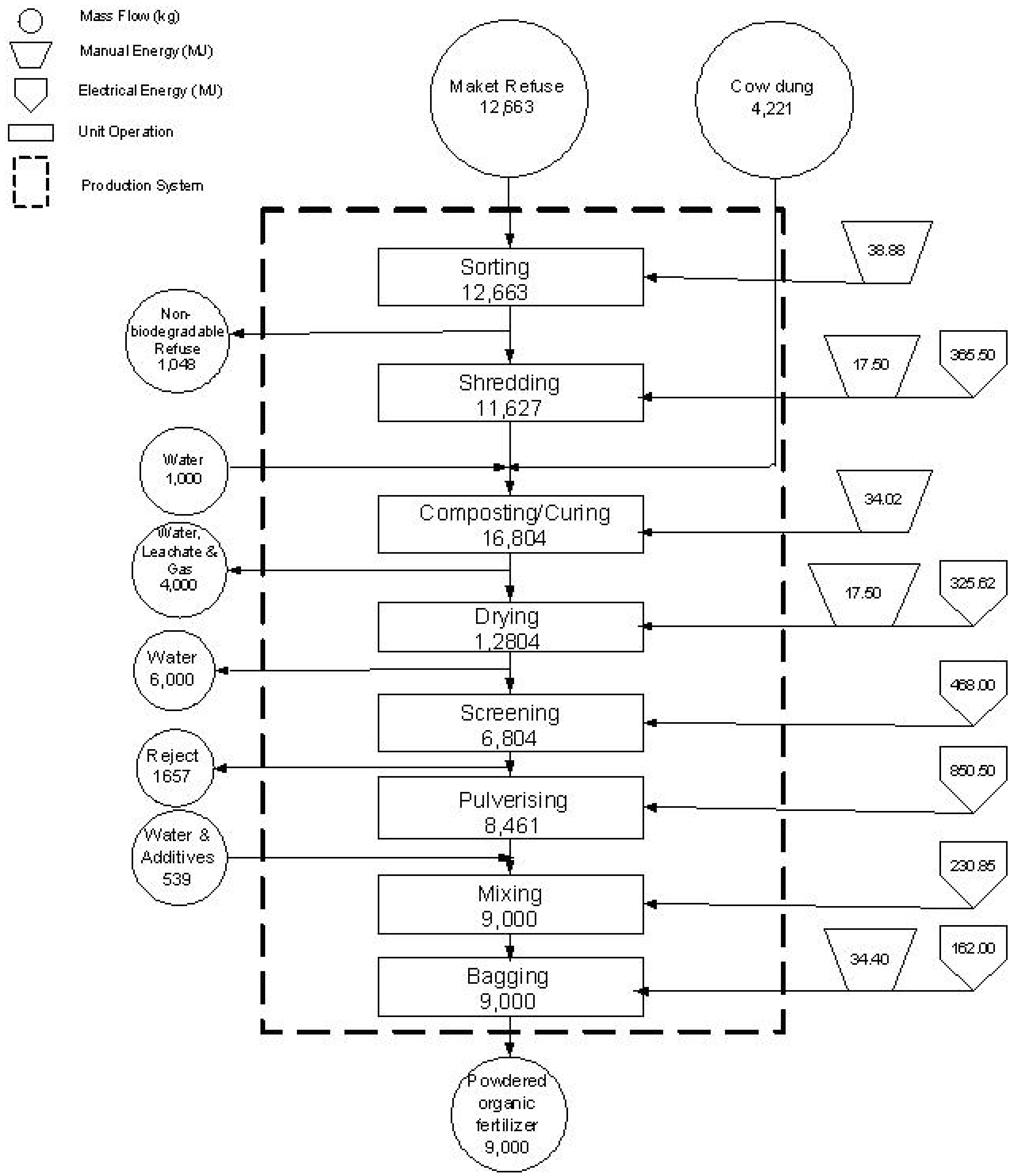

Figure-2. Energy and mass flow diagram for the production of powdered organic fertilizer.

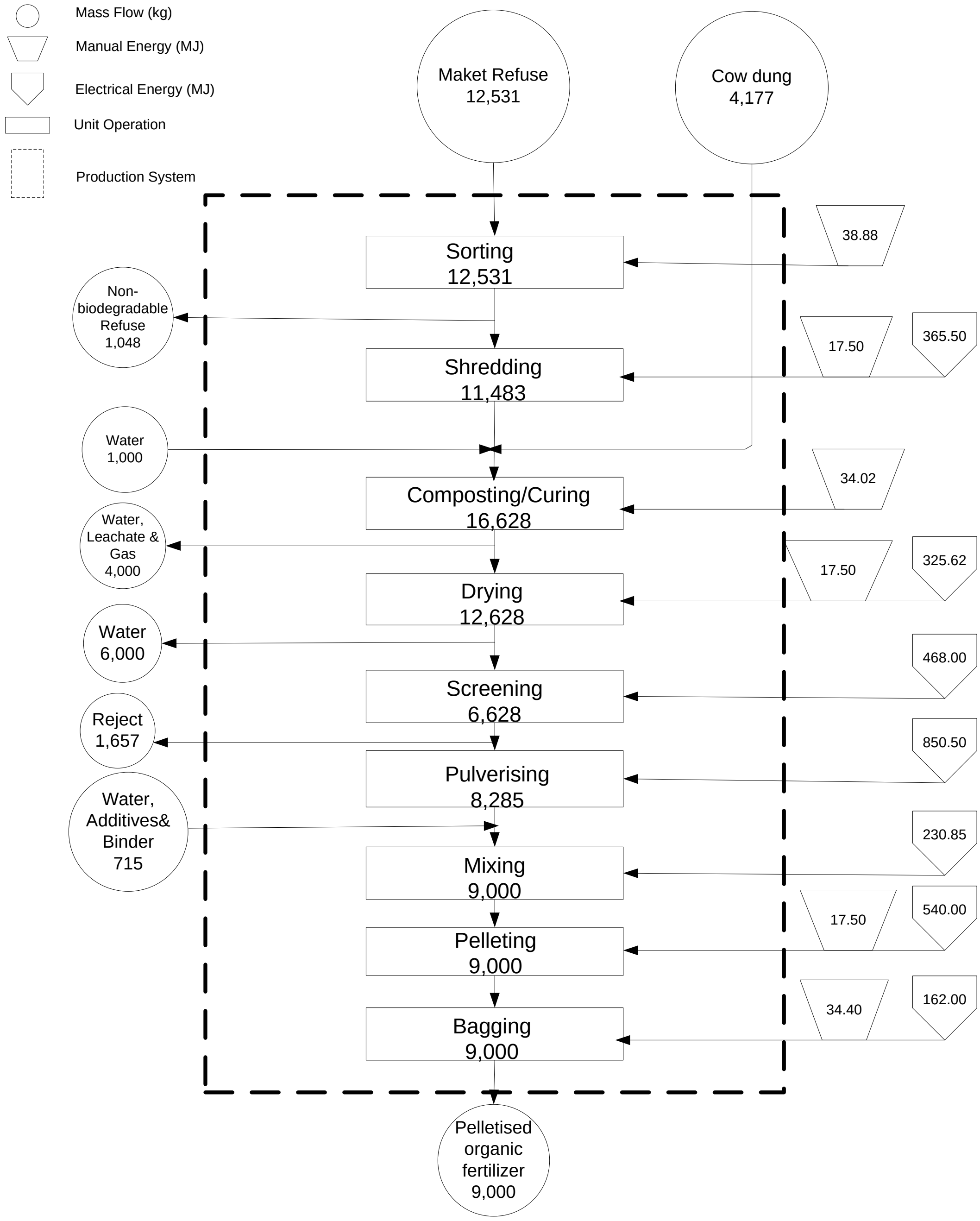

Figure-3. Energy and mass flow diagram for the production of pelletised organic fertilizer.

The two primary sources of electrical energy utility in the plant were the National grid and generating set. The acute energy crisis in the country often necessitated the use of power generator for most of the production time.

4. CONCLUSIONS

The energy analysis for production of powdered and pelletised organic fertilizer in Ibadan, Nigeria suggested that:

- Eight defined unit operations were required for the production of powdered organic fertilizer, while nine unit operations were required for production of pelletised organic fertilizer;
- Electrical and manual energy were the two major sources of energy input in the production of organic fertilizer;
- The estimated energy intensities for production of powdered and pelletised organic fertilizer were 0.28 and 0.35 MJ/kg, respectively; and
- The most energy intensive operation was the pulveriser, which accounts for 27.0% of the total energy for production of pellets and 33.4% for powdered fertilizer.

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