British Journal of Applied Science & Technology
10(6): 1-6, 2015, Article no.BJAST.17858
ISSN: 2231-0843

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Design and Evaluation of Livestock Dewatering Machine

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Authors' contributions

This work was carried out in collaboration between both authors. Authors AOI and UDB contributed to the conception and design of the machine. Author UDB wrote the first draft and handled the machine drawings. Author AOI critically revised the intellectual content. Both authors were involved in the research procedure, analyses of the study and literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/17858
Editor(s):
(1) Manoj Gupta, Department of Mechanical Engineering, NUS, 9 Engineering Drive 1, Singapore 117576, Singapore.
(2) Elena Lanchares Sancho, Department of Mechanical Engineering, University of Zaragoza, Zaragoza, Spain.
Reviewers:
(1) Ify L. Nwaogazie, University of Port Harcourt, Nigeria.
(2) O. P. Kolawole, Agricultural Engineering Department, Federal University of Technology Akure, Nigeria.
(3) Anonymous, Katholieke Universiteit Leuven, Belgium.
Complete Peer review History: http://sciencedomain.org/review-history/10211

Original Research Article

Received 27th March 2015
Accepted 2nd July 2015
Published 16th July 2015

ABSTRACT

A livestock dewatering machine was designed, fabricated and evaluated to improve on-farm management of animal waste. This is in response to the need to reduce and eliminate the many challenges of improper waste handling in livestock production farms in Nigeria. The machine consists of a hopper, gear rack, shaft, speed reducer, ball bearings, screen, and discharge chute. The machine is manually operated by cranking of the handle which transmits torque to the shaft and thus set the rack in motion. The rack compresses the slurry against the wall of hard casing, and the liquid is separated from the waste and let out through the screen at the bottom of the casing, leaving the dewatered waste to escape through the discharge chute. Particle size distribution analysis guided the choice of screen size of 2 mm diameter. The machine was tested with pig dung, and it gave a throughput capacity of 472.75 kh/hr and a separating efficiency of 9%.

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Keywords: Livestock waste; dewatering; machine design; pig dung; separation.

1. INTRODUCTION

Livestock production increased towards the end of the 20th century. The increase is attributed to continuous rise in demand for livestock products in developing countries. Production is expected to increase further in Asia, South America and Africa [1]. High concentrations of livestock generate large quantity of organic waste that poses great danger to the environment if handled improperly. Waste mismanagement results in higher local emissions of odour and ammonia gas from livestock farms. Transporting the slurry elsewhere for management can lead to increased risk of disease spreading among other livestock. Besides, the waste is harmful to the hydrosphere when discharged directly into receiving waters [2]. Negative effects from heavy applications of livestock waste may include salinization in semi-arid regions, toxic concentrations of heavy metals, and decreased soil aeration [3]. If applied at a rate higher than plant uptake, there is a great risk of nutrient leaching and runoff that will pollute surface and groundwater [4]. This will lead to an increased need for water purification to provide safe drinking water supplies.

Slurry management systems were developed to reduce labour arising from manure handling [5], to add value to the waste and to safeguard the biosphere. Livestock waste management technique consists in separating solids and liquid fractions [6]. Different systems for slurry separation include mechanical screen separators, sedimentation, centrifugation, chemical precipitation, reverse osmosis, evaporation and ammonia stripping [7]. Solid-liquid separation could enable more cost-effective transfer of nutrients from areas of high livestock density where they may be in surplus to areas with a lower livestock density [8]. Much of the trouble associated with livestock waste lies on its handling, storage and disposal or reuse. Manual livestock waste handling, storage and disposal involve much drudgery in most of our livestock farms, and this tends to constitute environmental hazards both to the hydrosphere and also to the ecosystem. With the view of solving the livestock waste problem, a dewatering machine for separating the solid and liquid content of the livestock waste for easier handling, storage and transport was developed for rural farmers in Nigeria.

2. MATERIALS AND METHODS

2.1. Conception of the Machine

The machine is conceptualized to consists of a solid frame made of angle iron of adequate thickness for stability, a hopper that will hold reasonable quantity of slurry before refilling, a sluice gate, shaft, a gear, rack, speed reducer , a ball bearings for power transmission, discharge chute and a cover perforated with holes for evacuation of solid waste and wastewater.

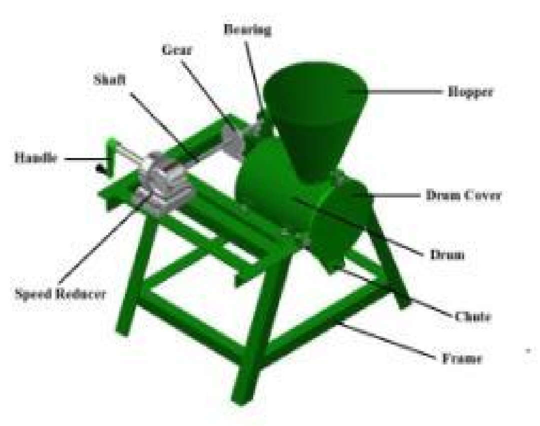

Fig. 1a. The dewatering machine detailed view

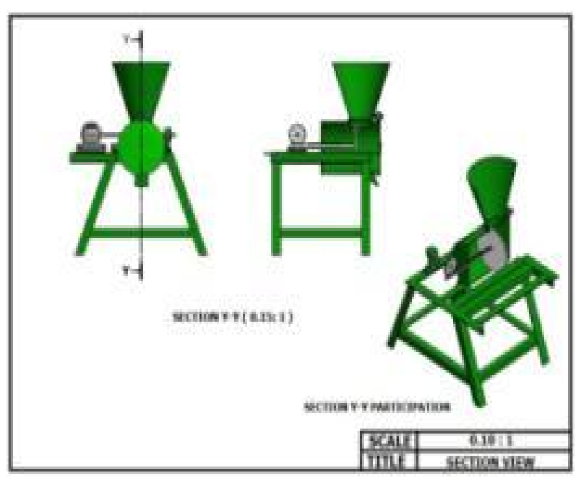

Fig. 1b. The section view of the dewatering machine

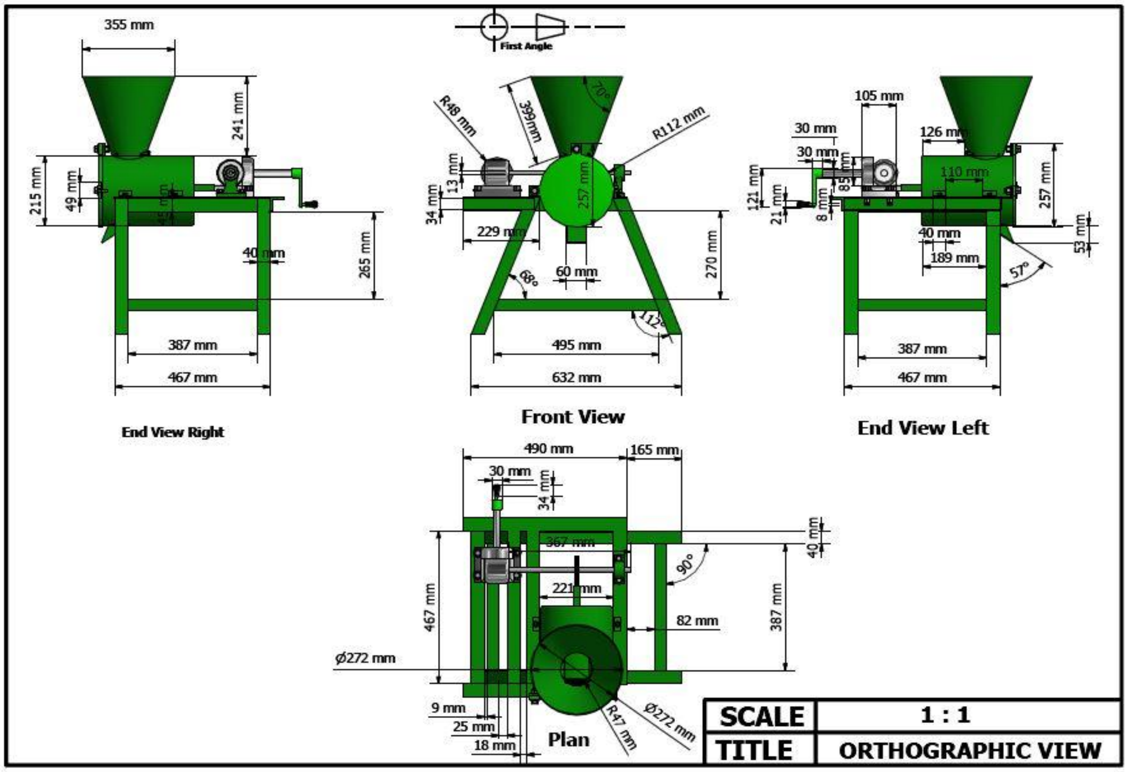

Fig. 1c. Orthographic view of the dewatering machine

2.2 Design Considerations

The following were taken into consideration in the design of the dewatering machine: the ability to separate solid effectively from the slurry, the properties of the waste to be dewatered, efficient power utilization to reduce energy loss, the wastewater discharge tube, ergonomic of the machine and affordability to local farmers. Besides, to achieve high efficiency, preliminary investigation on pig dung properties was carried out. The moisture content of the livestock waste was obtained using oven at (105± 3)°C for 24 hrs [9].

2.3 Design of Machine Components

The relevant properties of ping dung were used as the basic empirical data for the design.

2.3.1 Hopper design

An angle of repose of 18.12° obtained from preliminary investigation on livestock waste properties was considered in the hopper design. The following formulas [10] were used to compute relevant parameters:

$$V = \frac{\pi h}{3}(R^2 + r^2 + R \times r) \quad (1)$$

$$S_T = \pi[r \times (r + L) + R(R + L)] \quad (2)$$

$$L = \sqrt{h^2 + (R - r)^2} \quad (3)$$

where: V = total volume of hopper (mm^3), R = upper radius (mm), r = lower radius (mm), L = slant height (mm), S = total area of a truncated cone (mm^2) and h = height or distance between the centers of the base and top circles.

2.3.2 Casing design

The casing drum forms the main housing where the whole dewatering operation takes place. The drum is designed to hold reasonable quantity of waste and to facilitate the compressing and discharging operations. Furthermore, possibility of adhesion between the waste and the drum was also considered during the fabrication of the drum.

$$V_c = 2\pi r^2 h \quad (4)$$

2.3.3 The Screen size

Particle size distribution test was done to determine the screen size to be used in the dewatering process. American series screen numbers 10, 16, 30, and 50 according to ASTM E- 11- 70 (sieve sizes 2 mm, 1.18 mm, 0.60 mm and 0.425 mm) were used and the screens were weighed on a sieve shaker (ANAND) at a time interval of 60 seconds in order to determine the amount of waste retained in the screen. From results obtained in Table 1, a 2 mm sieve diameter was used for the design.

2.3.4 The shaft design

The shaft is an important component of the dewatering machine, and on it are mounted the gear, the speed reducer and the bearing. The shaft diameter was computed as 14mm using the Equations (5) and (6) for shaft design, while the speed of 15 rpm was used chosen for hand cranking [11].

$$T = \frac{P \times 60}{2\pi N} \quad (5)$$

$$d = \sqrt[3]{\frac{16T}{\pi\tau}} \quad (6)$$

Where P = power (kW), T = torque (Nmm), τ = shear stress (MPa), N = speed (rpm)

3. PERFORMANCE EVALUATION

Numerous researchers have measured such evaluation indices as physical and chemical concentrations of manure elements, separator screening capacity, required energy, rate of energy consumption (KWh/m^3), cost, odour test and distribution of manure particles. The first two indices have been commonly used as measurement criteria for evaluation of manure separators [12]. Manure separation efficiency with regard to the removed solid particle is generally a measured parameter for separator performance. There are multiple methods for expressing a separator's performance; including percent removal, TS% (Total solid) of the separated solids and the % solids removed into the fibre stream. The separation efficiency, given by [12] is;

$$S.E = \frac{influent\ solid\ concentration - effluent\ \ solid\ concentration}{influent\ solid\ concentration} \times 100 \quad (7)$$

Where, S.E = separation efficiency

$$Throuhput\ capacity = \frac{the\ quantity\ handled}{time\ taken} \quad (8)$$

Table 1. Particle size distribution of the livestock waste at moisture content of 89.03%wb

Sieve diameter (mm)	Weight of sieve (g)	Weight of sieve + sample (g)	Weight of sample retained (g)	Sample retained (%)
2.00	341.4	401.1	59.7	56.3
1.18	356.8	378.8	22.0	20.75
0.60	376.4	389.1	13.0	12.98
0.425	328.4	333.0	4.9	4.35
Pan	240.5	246.9	6.4	6.04

Samples of pig dung obtained from the Farm Unit of Michael Okpara University of Agriculture, Umudike, Nigeria were used to test-run the machine, and the following data were obtained; see Table 2.

Table 2. Evaluation of the dewatering machine using pig dung

S/N	Quantity of pig dung (kg)	Initial moisture content (%wb)	Final moisture content (%wb)	Time taken to dewater (s)
1	11.25	89.03	84.06	85
2	10.80	84.06	76.50	79
3	9.49	76.50	66.65	75
Total	31.54	249.59	227.21	239
Average	10.51	83.20	75.74	80

Using Equation (8), the throughput capacity was found to be = 472.95 kg/h.

Also, with the help of Equation (7), the separating efficiency was gotten as;

S.E = $\frac{83.20-75.74}{83.20} \times 100$, which give S.E = 8.97% ≅ 9%

Separating Efficiency (S.E) = 9% was gotten for the pig dung

4. RESULTS AND DISCUSSION

From the result, it was found that sieve with mesh sizes of 2.00 mm (56.3%) and 1.18 mm (20.75%) had the highest percentage of retained solids about (77%) between them (see Table 1). Therefore, for the choice of screen hole for the machine a sieve hole size of 2 mm was chosen, reason been that it retained the highest percentage of solids among others (56.3%). The separation efficiency of 9% is higher than 4.22% obtained using in-channel flighted conveyor screen evaluated by [13] and lower than 25.8% for dairy slurry. The efficiency compared well with the range of 14-19% obtained by [14] using centrifugal separator for livestock waste. Other separation efficiency of manure separators ranges from 20-68% [4,15]. However, the efficiency of solid-liquid separation treatment of livestock waste is found to be improved using flocculants [16-19]. The through-put capacity of the machine was found to be 472.95 kg/h which showed that the machine was designed to handle large amount of livestock waste.

5. CONCLUSIONS

A livestock dewatering machine was designed, fabricated and evaluated to reduce the adverse effect of livestock waste on the environment. The machine was found workable, made with local materials in order to make it affordable at the cost of ₦56050 (US $281.73) to the local farmers. The machine was also found to satisfy the objective, which was to reduce the amount of drudgery involved in waste handling. The salient implication of this result is that the separated material was found to have a handling characteristic close to a semi- solid form (10-20%) by having a separating efficiency (% of solid removal) of 9% as shown in the literature of this study. The use of coagulants to allow tiny particles to floc is encouraged to improve separation process.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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