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Design of Hand Tractor-trailed Biogas Sludge Applicator and Its Performance on Indonesian Dry Land

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Abstract

A hand tractor trailed biogas sludge applicator that has small-medium capacity, light ground pressures, and low-cost investment for small size Indonesian farm was developed. It consist of major component, i.e. 8.5 HP hand tractor as traction source, 1000 l sludge container, 4 HP single cylinder internal combustion engine for pumping system, and two adjustable furrow opener-closer. The test was performed under static and actual field state on Indonesian dry land to evaluate its performance. The result obtained during the trial test concluded that the applicator functioned properly as there is no faulty function for each component. The prototype has 1000 liter capacity of sludge mixture container and good pumping performance. The actual field performance of prototype revealed that it has 0.227 ha/h of effective field capacity observed, good traction performance at prepared (tilled) dry land, and considerably low operational cost in terms of the fuel consumption.

Keyword: biogas sludge; dry land; fertilizer applicator; hand tractor;

INTRODUCTION

Biogas plant in rural area is the most potential and promising renewable energy source in Indonesia. The abundance source of animal waste from small size cattle farm owned by single farmer family or community farmers was enough to supply their energy demand for daily cooking and electricity. Several studies were conducted on Indonesian biogas plants, i.e. technical aspects analysis [1]; and socio-economical aspects analysis [2]. Beside its potential as energy source, the end product of its digestion process i.e. sludge as post-digestion matter from biogas plant, can be used either in a liquid or solid form as potential organic fertilizer. It contains considerable amounts of mineral elements, i.e. nitrogen, phosphorus, and potassium. It also has a rapidity of action since N, P and K elements are easily available for plants [3]. Post-digestion pulp also contains a part of organic matter, which has a positive effect on physicochemical properties of fertilized soils. It also observed that soil porosity, organic substances and pH value have increased respectively [4].

Common practices of Indonesian application of biogas sludge fertilizer were manually spreaded into agricultural fields without or with semi-mechanized tools. Several studies were conducted to investigate its effect of application on Indonesian main crop, such as corn [5]. Current design and development of mechanized biogas sludge applicator in Indonesia was studied by [6]. The applicator was designed with a large capacity for industrial scale of sugarcane field and trailed by four wheel tractor with PTO-driven pumping system. Due to its large capacity and four wheel tractor-trailed systems, it seems not affordable and not feasible from economic stand point for Indonesian small scale farm. The use of four wheel tractor also has a potential source of excessive soil compaction do to its huge ground pressure and higher capacity of traction. The heavy vehicle traffic can have a negative impact on crop production which is caused by soil compaction and it can last for years and may not be eliminated by tillage [7].

For these reasons, it seems important to develop a brand new design of biogas sludge applicator that has a small-medium capacity, light ground pressure, and low-cost investment for small size farm. With the same trailing system, hand tractor or also known as walking-type tractor, is particularly suitable for small and medium size field where conventional four wheel tractor is either difficult or uneconomical to use. A study conducted by [8] revealed that the hand tractor offered substantial economic advantages over the four wheel tractor in Indonesia.

The aim of present study was to design and develop a hand tractor-trailed biogas sludge applicator and conducted its performance test on Indonesian dry land, i.e. sludge pumping performance, tractive performance, furrow opener characteristic, overall energy consumption, and field capacity performance.

MATERIALS AND METHODS

Design Consideration

The prototype of biogas sludge applicator was designed for several basic functions, i.e. (a) has ability to transport liquid biogas sludge; (b) has ability to placed biogas sludge into a soil furrow; (c) has ability to move and good maneuverability on uneven field; and (d) easy to operate for mid-trained operator. Due these desired functions, some factors influencing the design are considered in details as follows.

- Biogas sludge container

Biogas sludge container has a function to stored liquid biogas sludge to be spreaded. It was placed on top of wheel axle due to heavy normal load and center of gravity reason. The container has 1000 liter of volume made from low-density polyethylene (LDPE) plastic container and placed on steel cage.

- Pumping and piping system

A four stroke 4 HP single cylinder internal combustion engine was used as source of power for centrifugal pump to flow liquid biogas sludge from the container to output nozzle that placed behind furrow opener. Liquid biogas sludge was flow through a 1.25 inch in diameter .

- Furrow opener-closer

Two chisel plow was used as furrow opener that mounted in the back of trailer. It was made from steel to open soil furrow through hand tractor path. It was designed to make 10 cm depth of furrow. The furrow closer was made from steel plate that placed on the back of output nozzle. Operator could control it by operator through mechanical connecting rod.

- Hand tractor-trailed system

A Yanmar YST-DX type hand tractor powered by 8.5 HP single cylinder diesel engines was used as source of traction. The hand tractor use standard staggered echelons of half-width tread rubber tire as traction tools. The biogas sludge applicator trailer was towed to three point hitch of hand tractor during operation.

- Ergonomic consideration

Due to safety and occupational health during operation, the biogas sludge applicator equipped with proper seat for operator. The seat was placed on proper position near hand tractor's handle grip.

The schematic of biogas sludge applicator prototype was depicted on Fig. 1.

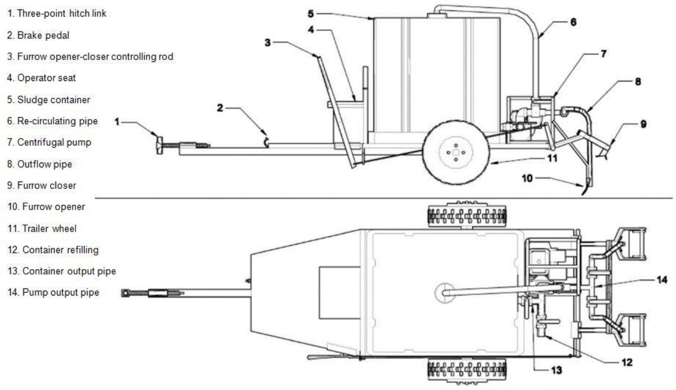

Figure 1: Schematic (side and top view) of biogas sludge applicator prototype

Performance Test

The performance test was performed both on laboratory and field test. The test included sludge pumping performance, tractive performance, furrows opener characteristic, overall energy consumption, and field capacity performance. The detailed process for every test was described as follow.

Sludge pumping performance

Sludge pumping performance was performed under static state to evaluate its sludge pumping performance at different engine speed, i.e. ranging in between 1000-3250 rpm. The test was conducted with a method used by [6], with measuring volume of liquid out from nozzle output. It performed three times for each engine speed as replication and obtained value were averaged.

Tractive Performance

The tractive performance of biogas sludge applicator and its trailer system, i.e. hand tractor was conducted on actual field test in order to characterize and evaluate its tractive performance and maneuverability on uneven dry field. The test was conducted on actual dry land (about 14% of moisture content) at STPP laboratory field, Lawang, Malang; and one important tractive performance related with biogas sludge applicator performance was determined, i.e. wheel slip. Wheel slip has key influence on biogas sludge applicator performance since sludge pumping system and trailing system were unsynchronized and independent from each other. The operator must adjust sludge pumping debit in accordance to applicator forward speed, which was influenced by wheel slip. The adjustment was made in order to make sludge spread evenly.

The wheel slip measurement on dry field was measured with proposed method by [9]. Wheel slip measurement conducted on ±20 m of straight dry field with two data obtained, i.e.

distance traveled when the hand tractor was driven without towed biogas sludge applicator for five full wheel revolutions (m_o); and distance traveled when the hand tractor was driven with towed biogas sludge applicator for five full wheel revolutions (m). Wheel slip (*i*) was calculated as follow and its measurement depicted schematically by Fig. 2. The test replicated five times at different spot of location and the data obtained were averaged.

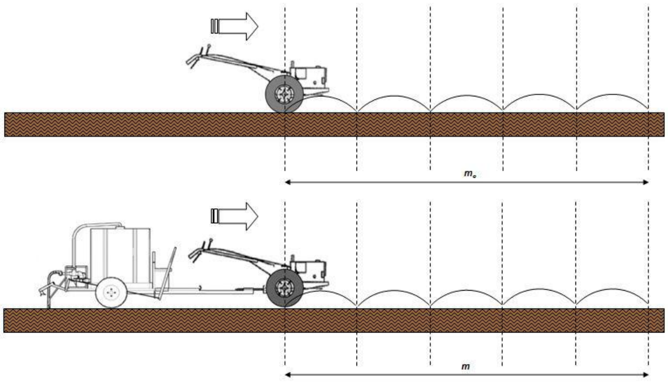

Figure 2: Schematic of wheel slip measurement

$$i = \frac{m_o - m}{m_o} \times 100\% \quad \text{.................................(1)}$$

Furrow Opener Characteristic

Furrow opener was characterized by its depth and cross-section profile. The depth and cross-section profile of furrows were measured manually using standard method as previously used by [6]. The measurements were conducted at five different location and the data obtained were averaged.

Energy Consumption

The biogas sludge applicator has two engines as source of power for its work, namely 8.5 HP single cylinder diesel engines and 4 HP four stroke single cylinder internal combustion engines. Energy consumption for respective engine was measured by fuel meter embedded into engine fuel system. Energy consumption measurement was conducted during operation, replicated five times and data obtained were averaged.

Effective Field Capacity

Effective field capacity (EFC) of biogas sludge applicator measurement was conducted during trials by measured the area that accomplished by the applicator on one hour duration of work. The measurement was replicated five times and the data obtained were averaged. The EFC data was calculated as follow, where A is accomplished area in m^2, and T_p is time used during the operation in h [10].

$$EFC = \frac{A}{T_p} \quad \text{..(2)}$$

RESULTS AND DISCUSSION

The biogas sludge applicator has 5 m and 1.4 m of respective overall (with towed hand tractor) length and width. The applicator has two furrow opener-closer in the back of applicator with 60 cm space in between. It easy to operate by single mid-trained operator and receives good subjective feed-back and response from the operator. Fig. 3 depicted the actual photos from different perspective of the applicator in hand tractor towed position.

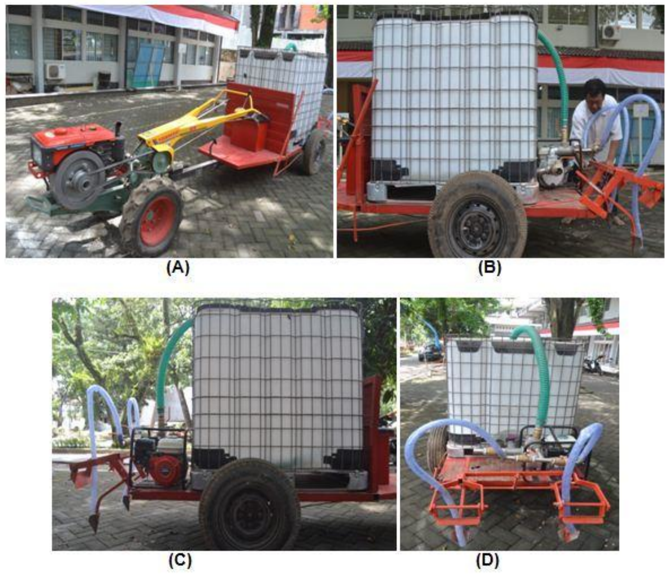

Figure 3: Biogas sludge applicator: (A) hand tractor as traction source, (B) sludge applicator and its sludge container, (C) sludge pump and piping system, (D) two furrow opener-closer at the back of applicator

The sludge pumping performance which evaluated by its debit (l/sec) under static stated at different engine speed ranged in between 1000-3250 rpm was showed by Fig. 4. The data revealed that the increase of engine speed caused the increase of sludge debit in exponential form. The exponential interaction in between the two was beneficial due to more accurate predetermined sludge debit adjustment before operation. It also could be used as the basis of engine rotational speed adjustment regarding to work plan and dose of sludge application. The sludge pumping system performance has slightly higher maximum debit compared to the same test conducted by [6] on their designed liquid fertilizer applicator, with 6.22 l/sec at about 540 rpm of PTO of four wheel tractor.

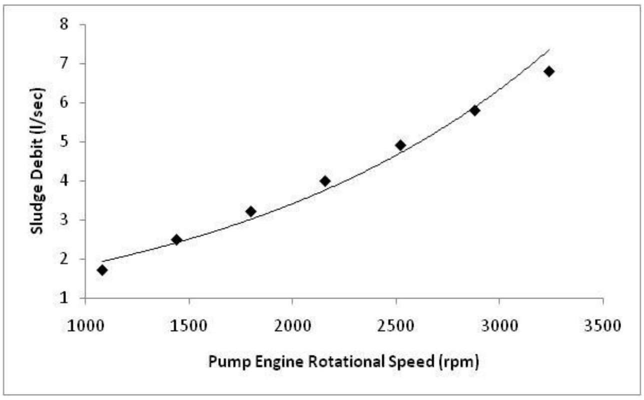

Figure 4. Biogas sludge debit at different pump engine rotational speed

Tractive performance test result showed that biogas sludge applicator trailer, i.e. hand tractor has wheel slip ranged 2-5% at 89-210 W of tractive power during operation. The small value of wheel slip and tractive power required was due the small depth (10 cm) of furrow opener and more porous dry soil caused by previous soil tilling preparation. The porous dry soil might result more penetration for hand tractor wheel with staggered echelons of half-width tread and give more traction with minimum wheel slip. The minimum wheel slip of applicator during operation was beneficial for more precise and evenly spread sludge. However, wheel slip of hand tractor during operation may be higher regarding more compacted or previously unprepared soil condition.

The furrow opener characteristic was depicted schematically on Fig. 5. The average furrow depth during operation was 10.28±1 cm and 7.7±1.19 cm of furrow top width. After biogas sludge was out of nozzle, it was directly infiltrated due to porous soil condition. The furrow closer was properly close the furrow made by the opener and biogas sludge were considerably well-buried into soil.

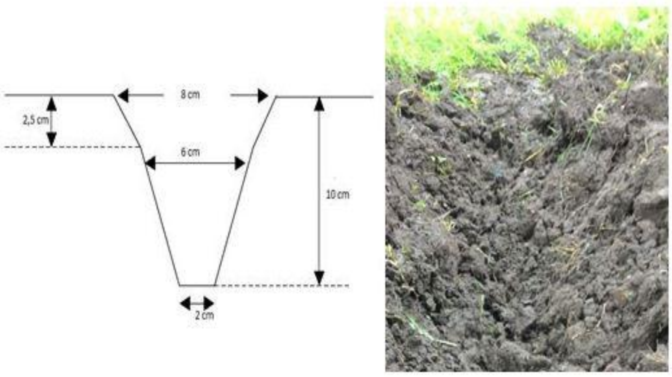

Figure 5: Cross-section profile of furrow made by furrow opener

Fuel consumption measurement by fuel meter embedded into engine fuel system shows that 8.5 HP single cylinder diesel engines of hand tractor consumed 12.62±0.21 ml/min of fuel on average and could generate about 89-210W of tractive power during operation. Fig. 6 depicted the result of the same measurement for 4 HP four stroke single cylinder internal combustion engines of pumping system. It shows that water-sludge (v/v) mixture affected the fuel consumption by the engine. The result indicates that at higher engine rotational speed, fuel consumption by the engine was slightly affected by the mixture viscosity. However, the relation between the two still needs further investigation.

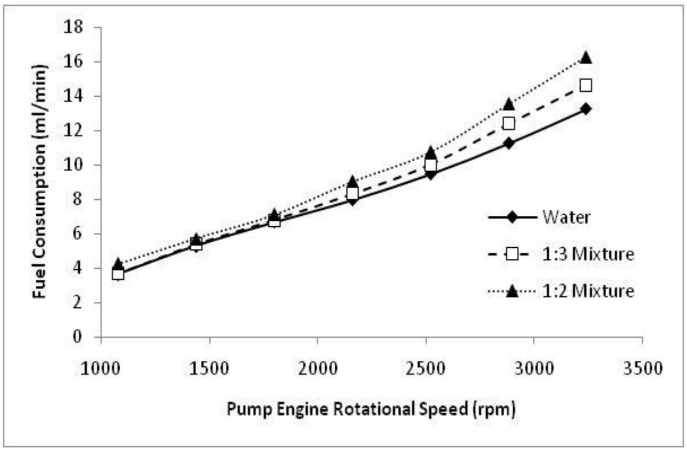

Figure 6. Fuel consumption (ml/min) at different pump engine rotational speed and different sludge mixture

From economic perspective, the operational cost of biogas sludge applicator was relatively low considering current Indonesian fuel price and its fuel consumption, i.e. 1 liter fuel for about 76 and 93 min of work duration for hand tractor and pump engine (for 1:2 water-sludge (v/v) mixture at 2520 rpm operation), respectively. It seems feasible and affordable for small size Indonesian farmer to adopt and use the applicator for their agricultural practices.

Effective field capacity (EFC) of biogas sludge applicator measurement indicated that EFC of biogas sludge was 0.227 ha/h. It was relatively higher if compared to average EFC of hand tractor for rice field land preparation, i.e. 0.1 ha/h [8]. However, one factor that could affect the EFC of the applicator was size of operation area, i.e. length and width dimension of operation area. This factor has implication for how often the applicator turn on operation area. During field test, about 7 sec was needed to pass the 90° turn (the typical turn on agricultural machinery operation). It was a bit difficulty for the operator due slightly longer overall (with towed hand tractor) length of applicator than commonly hand tractor based agricultural machinery. Hence, further investigation was needed in order to enhance its maneuverability, especially on turning performance characteristic.

CONCLUSIONS AND SUGGESTION

A hand tractor trailed biogas sludge applicator that has small-medium capacity, light ground pressures, and low-cost investment for small size Indonesian farm was developed. The performance test showed that the prototype has 1000 liter capacity and good pumping performance. The actual field performance of prototype revealed that it has 0.227 ha/h of effective field capacity, good traction performance at prepared (tilled) dry soil, and considerably low operational cost in terms of the fuel consumption.

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