

Design of Water Hyacinth (*Eichhornia crassipes*) Harvester

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water hyacinth (*Eichhornia crassipes*) is a free floating aquatic plant that grows in still or slow moving fresh water bodies and has become one of the world's worst aquatic weeds due to its ability to form dense floating mats on the water's surface. These mats have significant impacts on rivers, wetlands, dams, lake, and irrigation systems. However, water hyacinth, which evades waterways and reduces recreation and aesthetics value of water bodies, needs to be controlled. This purpose of this study was to design a harvester for control of water hyacinth. The anatomy and physiology of the water hyacinth were used to design the machine using basic engineering procedures. The main feature of the water hyacinth harvester included an electric motor (2.0 h p), mower disc (100 x 70 x 7.36 mm), shaft (26 mm diameter) with 4 blades made of stainless steel. The machine operates with capacity of 10,646 tons /hr. at the speed of 3.04 m/s. The capacities of the loading and delivery conveyors are 846.60 tons /hr. and 538.75 tons /hr. respectively. Fabrication of the designed water hyacinth harvester, using local materials will promote and enhance indigenous technologies that will improve physical control of the plant.

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Keywords: Water hyacinth; harvester; design; cutting blade; physical control; capacity.

1. INTRODUCTION

Aquatic weeds can be defined as plants growing in or on water which in excessive amounts are undesirable [1]. They could be: free floating plants; aquatic grasses; emerged plants; phreatophytes, and floating island weed. The report noted that water hyacinth (*Eichhornia crassipes*) was a free floating perennial aquatic plant (or hydrophyte) native to tropical and subtropical South America, with broad, thick, glossy and ovate leaves [1-4]. Water hyacinth may rise above the surface of the water up to one metre (1 m) in height. The leaves are 10 – 20 cm across and float above the water surface, with long, spongy and bulbous stalks. An erect stalk supports a single spike of 8 – 15 conspicuously attractive flowers mostly lavender to pink in colour with six petals. Water hyacinth reproduces primarily by way of runners or stolon, which eventually form daughter plants. The report showed that heavy infestations can affect water bodies in a number of ways:

- (1) Safety and health risk; Children and livestock may be in danger of drowning if they become entangled in the roots and stolons of a heavy infestation.
- (2) Loss of water; High rates of transpiration through the leaves during dry season;
- (3) Degradation of water quality; as the weed dies and decomposes oxygen is removed from the water causing water pollution and stagnation. The stagnation affects water quality and may result in the death of aquatic animals.
- (4) Reduces recreation and aesthetics value of water bodies
- (5) Navigation impediment; Total cover of the water surface by the weed which hinders the water transportation system [5-8]. However, this aquatic plant may actually be used as a renewable natural resource. These include bedding materials for mushroom culture, feed for biogas and gasification plants, pulp and paper production, fertilizers, animal feeds, handbags, medicinal, and phytoremediation (wastewater treatment) [9-11]. Three commonly used control efforts to suppress this weed include physical, chemical and biological controls. However, no control is better than the other because each has its

advantages and disadvantages. The choice of control is dependent on the specific conditions of each affected location such as the extent of water hyacinth infestation, regional climate and proximity to human and wildlife [12,13]. Physical control is performed by land based machines such as bucket cranes, draglines or boom or water based machinery such as aquatic weed harvesters [5] including dredges or vegetation shredder. Mechanical removal is seen as the best short term solution to the proliferation of the plant.

Mechanical control methods involve the complete or partial removal of plants by harvesting, shredding, mowing, rototilling, rotovating and chaining. Mechanical control methods can also be used to expedite manual harvesting activities, which include hand harvesting, raking, and cut stump control, with the use of motor-driven machinery [14,15]. The water hyacinth harvester simply called machine, it is also known as aquatic scavenger. The harvester is a boat which is capable of cutting and carrying the harvested weeds to the shore. Designed, fabricated and tested water hyacinth harvester on laboratory and average harvesting capacity was 6.5 t/hr./m width of the conveyor when the traveling speed was 0.56 km/hr [16]. Designed and fabricated a water hyacinth harvester with capacity of 106.5 tons/hr [10]. The aquatic weed harvester performed similar functions as under water lawn mower by cutting the vegetation, collecting and storing the weeds on board. Aquatic weed harvesters are fitted with a pick up conveyor at the forward end of the machine, which can be lowered up to 2.5 m deep to cut weeds. One horizontal and two vertical cutter bars sever the vegetation as the machine moves through the water, when the storage hold becomes full, the weed harvester returns to shore to unload [5]. The usage of mechanical harvester for water hyacinth control has not been encouraged by Nigeria government. The majorities of harvesting is done by hand individually or communities that affected by the weed. The study was performed to design and modify an existing water hyacinth harvester that is suitable for local conditions and uses local materials.

2. MATERIALS AND METHODS

2.1 Theoretical Considerations of Water Hyacinth Harvester Components Parts Design

The design of this prototype machine was based on the machinery design requirements, material selection and design assumptions as stated in the following sections.

2.2 Water Hyacinth Harvester and Material Selection

The materials selected are presented in Table 1. Isometric and orthographic projection are presented Figs. 1 and 2 respectively.

The choice of components used for this project is based on the following factors:

- Efficiency of equipment
- Simplicity of design, and cost
- The major material used for the fabrication of essential components of the water hyacinth harvester machine were stainless steel and aluminum
- The stainless steel and aluminum were selected because it can easily be welded, machined light, resists oxidation and corrosive attack as it being used inside water and availably.
- Aluminum material reduces weight
- All fasteners are made from stainless steel.

2.3 Description and Operation Principle of Water Hyacinth Harvester

Water hyacinth harvester consists of vertical mower; pick up reel, loading conveyor, delivery conveyor and transmission units.

2.3.1 The vertical mowers

The mowers are the cutting unit of the machine. They are two in number, each carrying four blades which are bolted to the disc of the mower. It is operated at speed 182 rpm (3.04 m/s) and shaft sprocket driven by the driving sprocket on the pick-up reel.

2.3.2 Pick-up reel

The pick-up reel picks up the cutting weeds onto the loading conveyor. It is operated at the same speed as the mower and shaft gear driven by the

sprocket on the tail end of the loading conveyor shaft.

Table 1. Material selection

S/ N	Machine part	Material
1	Pulley	Aluminium
2	Shaft	stainless steel
3	Blade	Stainless steel
4	Shaft	Brass
5	Spur gear	Brass
6	Mower and reel disc	Stainless steel
7	Pick-up-reel	Brass
8	Bearing	Brass
9	V-Belt	Leather
10	Conveyor belt	Leather
11	Sprocket	Stainless steel
12	Chain for sprocket	Stainless steel
13	Bolts and nuts	Stainless steel
14	Flight	Aluminium

2.3.3 Loading conveyor

The loading conveyor is inclined at 14⁰ to the horizontal, picking the weeds with angular metal called flights riveted to it. The presence of the flight also prevents the weed from falling back. The weed dropped onto the delivery conveyor by gravity. The conveyors head driven by V-belt attached to the pulley of the electric motor head shaft.

2.3.4 Delivery conveyor

The delivery conveyor, placed at a horizontal direction, picks the weed with the flights riveted to it. The tail chain is driven by the driving chain on the head of the loading conveyor. The weeds from the delivery conveyor drop into drum.

2.3.5 Transmission units

The transmission unit consists of two pulleys, three belts (one V-belt and two flat belts), six shafts, four sprockets and twelve bearings. For the first line of transmission, one pulley is mounted on the motor and the second pulley at the end of the loading conveyor. The power from motor is supplied from the V-belt and is transmitted to the loading conveyor shaft. The shaft that carries the head end bearing drives the conveyor belt, which eventually drives the tail bearing and its shaft into which the driving spur gear is mounted. This driving spur gear transmits power to the pick-up reel by meshing with the driven spur gear on the reel shaft. The sprocket mounted on the tail end of the pick-up reel shaft driving the sprocket of the mower shaft of the

harvester. On the second line of transmission, there was a chain drive from the sprocket on the shaft on the head end of loading conveyor. This chain drive transmits power to another driven sprocket below the driving sprocket at the head bearing of the delivery conveyor.

2.4a Design Considerations and Assumptions

The design calculations for water hyacinth harvester are based on first principle of mechanics of machines and design consideration and assumptions stated below. Equations were adopted from [17-19]. At the beginning of this machinery design work, the following assumed data were used and both the design and construction parameters were based on them, most of which were obtained from the machine size, blade arrangement on the mower disc which is the angle of rake resistance of blade rotation related to the depth of the blade and material for construction. The some assumptions and forces due to water per unit areas are as follows:

- (1) The angle of shearing resistance of rotate blade related to the depth of the blade, $\phi = 30^\circ$
- (2) The angle of water/interface friction exist between cutting edge $\beta = 10^\circ$

- (3) The angle of water/interface friction exist between cutting edge and water $\beta = 10^\circ$
- (4) Adhesion of water/interface $C_\alpha = 3446.99 \text{ N/m}^2$
- (5) The cohesion of water $C = 10340.98 \text{ N/m}^2$
- (6) The rake angle with horizontal $\alpha = 45^\circ$
- (7) Water unit weight $\gamma = 6.3288 \text{ N/m}^2$
- (8) The depth of paddle $Z = 0.3 \text{ m}$

2.4b Determination of the Forces Acting on Mower Disc and Blade

Determination coefficient of friction existing between paddle wheel and water surface, k

$$k = \tan^{-1} \left(\frac{\sin \alpha \cot \phi}{90 - \phi} \right) \tag{1} [17]$$

Where

Θ = angle of splashing resistance of rotate cutting blade ----- 45°

$$\phi = \alpha + \frac{\Theta}{2} = 45 + \frac{45}{2} = 67.5$$

$$k = \tan^{-1} \left(\frac{\sin 45^\circ \cot 67.5^\circ}{90 - 67.5} \right) = \frac{\tan^{-1}(0.2706)}{22.5} = \frac{15.14}{22.5} = 0.6730$$

2.4.1 The calculation for the Vertical water force per unit depth (PV)

$$PV = \gamma Z^2 N_\gamma + CZ N_c + C_\alpha Z N_\alpha + g Z N_g \tag{2a} [17]$$

Where Z is the depth of blade = 0.30m = 11.8

$$N_\gamma = 0.355, N_c = 0.578, N_\alpha = 0.120, N_g = 0 \quad C = 1.510 \text{ bf/m}^2 \text{ and } C_\alpha = 0.51 \text{ bf/in}^2$$

$$PV = (0.036 \times 11.81^2 \times 0.355) + (1.5 \times 11.81 \times 0.578) + (0.51 \times 11.81 \times 0.120) + 0 = 1.789 + 10.239 + 0.722 = 12.751 \text{ bf} = 56.72 \text{ N}$$

2.4.2 The sideways water force per unit Width Ps

$$P_s = \left(\frac{C_\alpha Z N_{sc}}{2} + \gamma \left(\frac{Z}{2} \right)^2 N_{s\alpha} + \left(\frac{N_g}{\gamma} \right)^2 N_{s\alpha} \right) k \tag{2b} [17]$$

$$= \left(\frac{1.51 \times 11.81 \times 41.6}{2} + 0.0361 \left(\frac{11.81}{2} \right)^2 \times 4.133 + 0 \right) 0.67$$

$$= 256.618 \text{ bf} = 1141.44 \text{ N}$$

2.4.3 The value for the resistance force P

$$P = P_s + P_v \cos \beta \tag{2c} [17]$$

$$P = 256.618 + 12.751 \cos 10^\circ = 269.175 \text{ bf} = 1197.30 \text{ N}$$

2.4.4 The draught per unit width D_F

$$D_F = PV\sin(\alpha + \beta) + PS\sin\alpha + C_\alpha\gamma\cos\alpha \tag{2d} [17]$$

$$D_F = 12.75\sin(45 + 10) + 256.618\sin45^\circ + (0.51 \times 0.0361\cos45^\circ)$$

$$D_F = 10.445 + 181.456 + 0.0 = 191.194\text{ lbf} = 850.43\text{ N}$$

2.4.5 The Vertical Force per Unit Width F_V

$$F_V = PV\cos(\alpha + \beta) + PS\cos\alpha + C_\alpha Z \tag{2e} [17]$$

$$F_V = 7.314 + 181.456 + 6.023 = 194.793\text{ lbf} = 866.44\text{ N}$$

2.4.6 The total vertical force per unit width V_T

$$V_T = F_V \cdot b \tag{2f} [17]$$

$$= 194.793b = 58.44\text{ N/m}$$

Where b = the width of the paddle

2.5 Design of the Pulley System

2.5.1 V-Belt drive

$$D_1/D_2 = N_2/N_1 \tag{19} (3a)$$

Where D_1 = diameter of motor pulley (mm)
 D_2 = diameter of blade shaft pulley (mm)
 N_1 = speed of motor (rpm)
 N_2 = speed conveyor shaft (rpm)

2.5.2 Length of drive belts

$$L = 2C + \pi (D + d) / 2 + (D - d)^2 / 4C \tag{19}(3b)$$

$$C = A (A^2 - B)^{0.5}$$

$$A = 0.25 - \pi/2 (D + d)/8$$

$$B = (D - d)^2/8$$

Where,

L = length of open belt (mm)
 C = Centre distance (mm)
 D = diameter of conveyor shaft (mm)
 d = diameter of motor shaft (mm)

2.5.3 Determination of the weight of pulley, F_p

Density of material (Aluminium) = 2700 kg/m³;

Diameter, d = 0.30 m; thickness, t = 0.02 m

$$F_p = \text{density} \times \text{volume} \times \text{gravity} = 2700 \times 2.83 \times 10^{-3} \times 9.81 = 74.90 \text{ N}$$

2.6 Design of Mower Shaft

2.6.1 Determination of the Vertical Force acting on mower

The weight of the mowers = weight of the blade + weight of the discs.

Material density = 8000 kg/m^3

Length of mower's blade (L) = 100 mm = 0.1 m

Thickness of the blade (t) = 2 mm = $2 \times 10^{-3} \text{ m}$

Width of the blade (w) = 7.36 mm = $7.36 \times 10^{-3} \text{ m}$

Number of blades = 4

Diameter of disc (d) = 70 mm = 0.07 m

Thickness of disc (t) = 10 mm = 0.01 m

Mass of the blade $M_b = \text{Density} \times \text{Volume}$

$M_b = 8000 \times 0.1 \times 2 \times 10^{-3} \times 7.36 \times 10^{-3} = 0.047 \text{ kg}$

Total mass of blade = $0.047 \times 4 = 0.188 \text{ kg}$.

Mass of the Disc $M_d = \text{Density} \times \text{Volume} = 8000 \times \pi \times (0.07)^2 / 4 \times (0.01) = 0.3079 \text{ kg}$

Mass of the Mower $M_m = M_b + M_d = 0.48 \text{ kg}$

Force acted by the Mower on the shaft = $0.48 \times 9.81 = 4.72 \text{ N}$.

2.6.2 Tangential force on the gear acting upward F_t

$F_t = M_t \times g / r_p = 110.58 \times 9.81 / 3.3 = 328.8 \text{ N}$

2.6.3 Force of the gear acting downward

Diameter of gear = 66mm = 0.066 m; Face width b = 40 mm = 0.04 m

Mass of gear = Density x Volume = $8000 \times \pi (0.066)^2 / 4 \times (0.04) = 0.905 \text{ kg}$

Force of the gear acting downward = $0.905 \times 9.81 = 8.88 \text{ N}$.

2.6.4 Forces acting on the shaft both vertical and horizontal

2.6.4.1. The weight of the bearing

The area of the bearing = $\pi (d_o - d_i)^2 / 4$

$D_o = 80 \text{ mm}$; $d_i = 75 \text{ mm}$; $L = 152 \text{ mm}$

Volume of bearing = area x Length = $\pi (80 - 75)^2 / 4 \times (152) = 2984.5 \text{ mm}^3$

Volume of bearing = $2.985 \times 10^{-6} \text{ m}^3$

Weight of the bearing, $W_b = 8000 \times 2.985 \times 10^{-6} \times 9.81 = 0.234 \text{ N}$

2.6.4.2 Determination of tension in the loading conveyor belt that inclined at 14° to the horizontal.

The speed of the belt = 2.9 m/s; the density of the leather belt = 970 kg/m^3

Area of the belt = $w \times t = 0.152 \times 0.006 = 9.12 \times 10^{-4} \text{ m}^2$

Mass per one meter length of the loading conveyor belt = $0.00912 \times 1 \times 970 = 0.885 \text{ kg}$.

2.6.5 The vertical forces of gear on the shaft

Pitch diameter $d_p = 336 \text{ mm} = 0.336 \text{ m}$; Face width b = 40 mm = 0.04 m

Volume = $\pi (d_p)^2 / 4 \times (b)$

Mass of the gear = $8000 \times \pi (0.336)^2 / 4 \times (0.04) = 28.37 \text{ kg}$

Weight of gear = $28.37 \times 9.81 = 278.35 \text{ N}$.

2.6.6 Design of the shaft diameter

$$d^3 = \frac{16}{\pi S_s} \sqrt{\frac{(K_b M_b)^2 + (K_t M_t)^2}{1}} \quad (4) [18]$$

$$= 16 / 3.04 \times 55 \times 10^{-6} \sqrt{\frac{(2.0 \times 4.118)^2 + (1.5 \times 124.624)^2}{1}}$$

$$= 1.73269 \times 10^{-5}$$

$$d = (1.73269 \times 10^{-5})^{1/3} = 0.02597 \text{ m} = 25.97 \text{ mm} = 26 \text{ mm}$$

2.7 Design of the Chain on the Sprocket

2.7.1 Determination of the weight of chain F_{ch}

The weight per meter length of the chain is 1.099 kgf
 Length of the chain $L_{ch} = 1045.75 \text{ mm} = 1.04575 \text{ m}$
 $F_{ch} = 1.099 \times 1.04575 \times 9.81 = 11.182 \text{ N}$
 Half of the weight of the chain will act on each of sprocket = 5.59 N

2.7.2 Determination of the weight of sprocket F_{sp}

Density of sprocket material = 8000 kg / m³
 Depth of teeth $d_p = 0.07 \text{ m}$; Thickness $t = 0.015 \text{ m}$
 $F_{sp} = \text{Density} \times \text{Volume} \times \text{Gravity} = 8000 \times 5.773 \times 9.81 = 4.53 \text{ N}$

The sprocket tangential force F_t
 Given weight of sprocket as 141.29 kgf
 $F_t = 141.29 \times 9.81 = 1386.1 \text{ N}$

The tension in the chain driving sprocket is 1455.3 N included at angle 75.4° to the horizontal

$$F_{ych} = F \sin 75.4 = 1455.3 \times 0.9977 = 1408.4 \text{ N}$$

$$F_{xch} = F \cos 75.4 = 1455.3 \times 0.25207 = 366.86 \text{ N}$$

The total force acting at the point of sprocket F_2

$$F_2 = F_{sp} + \frac{1}{2} F_{ch} + F_{ych} - F_t = 4.53 + 5.59 + 1408.4 - 1386.1 = 32.45 \text{ N.}$$

2.8 Power Transmission

Density of weed = 167 kg / m³; volume of weed = 0.000513 m³ (calculated)
 Total mass of weed to be cut (harvested) = 0.0821 kg.
 Speed of reel = 3.04 m/s; total forces on chain = 32.445 N (calculated)
 Weight of weed $F_{weed} = 0.00051 \times 167 \times 9.81 = 0.84 \text{ N}$
 Power = 0.84 x 3.04 = 2.55 watts
 Weight of reel, $F_{reel} = 0.0001216 \times 8000 \times 9.81 = 9.543 \text{ N}$
 Power = 9.54 x 3.04 = 29 watts.
 Power to drive the chain = 32.445 x 3.04 = 98.63 N
 Power to drive pulley belt = 227.7 + 245 N x 2.55 N = 950.5 N
 Total power for the harvester = 1079.3 x 1.5 = 1618.95 (2.0 HP)

2.9 Performance Evaluation of the Harvester

2.9.1 Capacity of the harvester C_h .

$$C_h = M \times S$$

Where,

C_h = Capacity of the harvester

M = mass of the reel

S = speed

$$C_h = 0.9728 \times 3.04 = 2.9573 \text{ kg/s} = 10646 \text{ kg / hr.} = 10.646 \text{ tons /hr.}$$

2.9.2 Capacity of the conveyors

2.9.2.1 Loading conveyor

Density of leather belt = 970 kg/ m^3 ; width of belt = 0.152 m; length of belt = 0.55 m

Speed of the conveyor = 2.9 m/s = 10440 m/hr.

$$\text{Capacity of loading conveyor} = 0.0836 \times 970 \times 10440 = 846600.48 \text{ kg.hr} = 846.60 \text{ tons / hr.}$$

2.9.2.2 Delivery conveyor

Density of leather belt = 970 kg/ m^3 ; width of belt = 0.152 m; length of belt = 0.35 m

Speed of the conveyor = 2.9 m/s = 10440 m/hr.

$$\begin{aligned} \text{Capacity of delivery conveyor} &= 0.0532 \times 970 \times 10440 = 538745.76 \text{ kg /hr.} \\ &= 538.75 \text{ tons /hr.} \end{aligned}$$

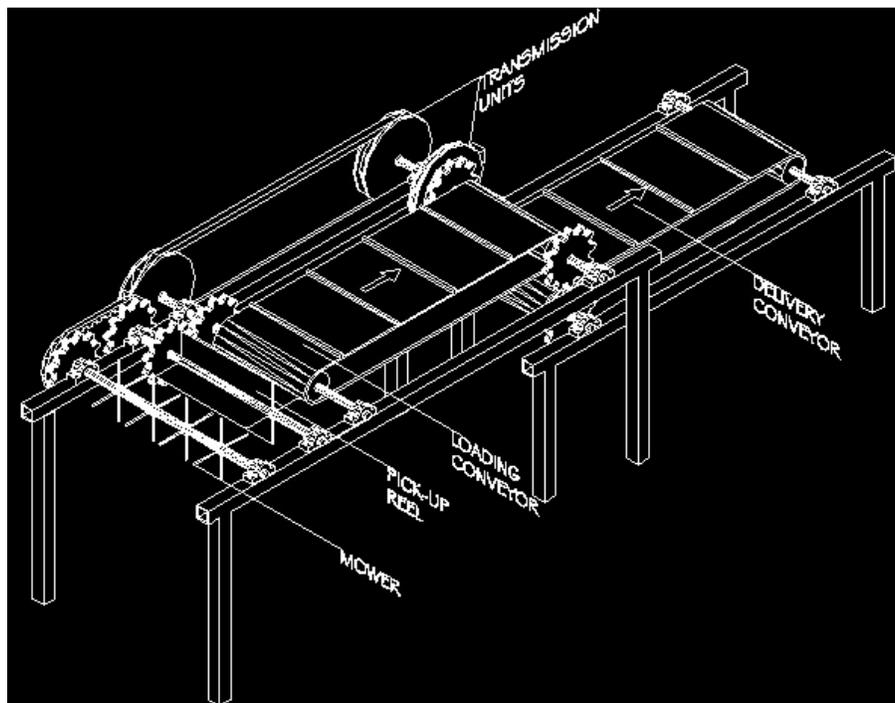


Fig. 1. Isometric diagram of water hyacinth harvester

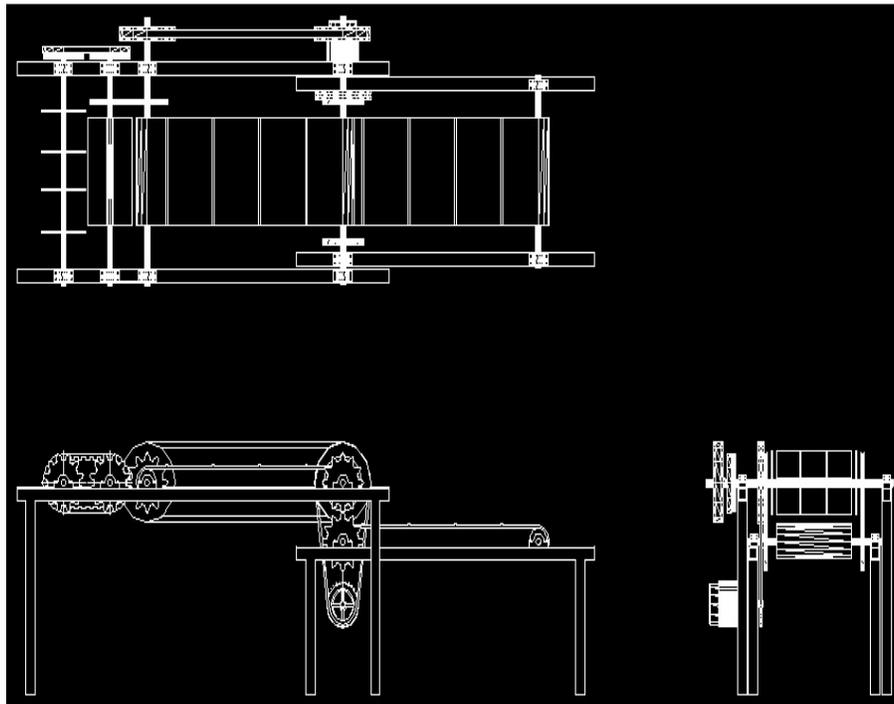


Fig. 2. Orthographic diagram of water hyacinth harvester

2.10 Performance Test

$$\begin{aligned}
 \text{Efficiency of the harvester } \eta_H &= \frac{\text{Area of the weed cut to the desired depth}}{\text{Area of the weed cut}} \times 100 & (5) \\
 &= \frac{0.000513 \text{ m}^2}{0.000936 \text{ m}^2} \times 100 = 54.8 \%
 \end{aligned}$$

3. RESULTS

Total vertical force acting on mower per unit width	= 58.4 N/m
Speed of motor	= 3.04 m/s
Speed of mower	= 3.04 m/s
Speed of conveyor	= 2.9 m/s
Shaft diameter	= 26 mm
Length of V- Belt	= 1.2 m
Length of chain	= 1.04 m
Total power	= 1.6 KWatts
Area of the weed cut to the desired height	= 0.000513 m ²
Area of the weed cut	= 0.000936 m ²

4. CONCLUSION

The water hyacinth harvester was designed and powered by 2.0 h p electric motor with speed of 3.04 m/s. The machine can be towed by a tractor or installed on barge and propelled to the desired

location. The theoretical efficiency of the machine was 54.8%. When the machine is developed, it will enhance physical control of the weed and improve waterway activities. The efficiency of the machine can be improved by increasing the width of the mower and its

speed. Finally, types of cutting edge, depth of cutting and speed variations should be assessed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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