DEVELOPMENT OF AN IMPROVED PEDAL POWERED WASHING MACHINE

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Abstract: This research work deals with the design and fabrication of an improved cloth washing machine capable of small-scale industrial application as well as household use. The project is aimed at developing a washing machine that is efficient, affordable, durable and compatible for rural areas with little or no supply of electricity; by working on the efficiencies of pre-developed machines and providing solutions to their deficiencies; a dynapod with gear-sprocket system combined with the belt-pulley system is use to transmit torque via leg cranking to the shaft of the washing drum (agitator in electric washing machine); the dynapod is also used to vary (increase or decrease) the speed of the machine to facilitate different speeds for the three main operations in laundry process washing, rinsing, and spinning which are the three main operations of the washing machine, speed is further increased with the aid of the belt-pulley system. With an overall efficiency of 84.98%, the cost of fabricating the machine is 45,000NGN (123.80USD) and this can be significantly reduced if produced in a large scale. The machine is easy to use and maintain as the system of operation is simple, it is eco-friendly and safe for the user. The machine is capable of community application therefore can be used by the entire populace of a rural area or settlement.

Keywords: Pedal, Washing Machine, Dynapod, Pulley

1. INTRODUCITON

Washing of cloths is deemed as a very important aspect of our lives in terms of hygiene and beauty, but it is also seen as undesirable and stressful this is largely due to the time, effort energy and cost washing clothes actually requires; this has made laundering a very important part of human daily life. Due to such great importance, really great effort has been invested in ensuring that washing of clothes become less and less stressful. In many ancient cultures, peoples cleaned their clothes by pounding them on rocks. Laundry was often a communal ritual, especially in places near rivers, springs, and other bodies of water, where the washing was done textiles (Mary Bellis, 2019). Laundering by hand involves soaking, beating, scrubbing, and rinsing. Due to such an important and continuous domestic chore, minds had to come together to find innovative ways which would be better more constructive, less time consuming and comfortable way of carrying out laundering processes, hence the adoption of the washing machine.

In rural areas washing laundry is one of the activities and responsibilities that is laborious and time consuming. Electric powered washing machines do not work because of electricity and also due to their very expensive cost. Hence the development of a machine that would be cost effective and less laborious without using electricity became necessary.

The washing machine is one of the most valuable and useful tools today regarding domestic laundering. A washing machine is basically a machine designed to wash clothes or clean laundry such as bed sheets, towels, underwear and generally clothing. This project intends to design and fabricate an improved pedal powered washing machine using mechanical energy from pedaling.

1.1. **Purpose of the study**

The aim of the project is to develop an improved pedal powered washing machine.

2. LITERATURE REVIEW

Innovative minds have always had entire humanity in there heart and this often into spreading out innovation to effectively meet the needs of all putting into consideration financial status and developmental access of different people. This has led to various designs of a manually operated washing machine especially pedal powered.

A designed and fabricated Pedal Powered Washing Machine (Gaurang Bhatawedekar *et al.,* 2015) used a double speed altering pulley system with a pedal attached to a base entirely disconnected from the seat of the operator, the design makes can produce just two speeds depending on the input speed of the operator. it was ergonomically discomforting and has ambiguity in speed variation.

Another innovative design which entails a top-load washing drum and a pulley system to increase the input speed, the design whose cost of fabrication is $59, considerably low lacks a seat for the operator and is restricted to just a single pulley system there putting the responsibility of speed variation solely on the operator. (Tawanda Mushiri *et al.*, 2017)

Human relationship with pedal powered system was researched and the following deductions were made as shown in Figure 1 and 2; (David G *et al.*, 1986)

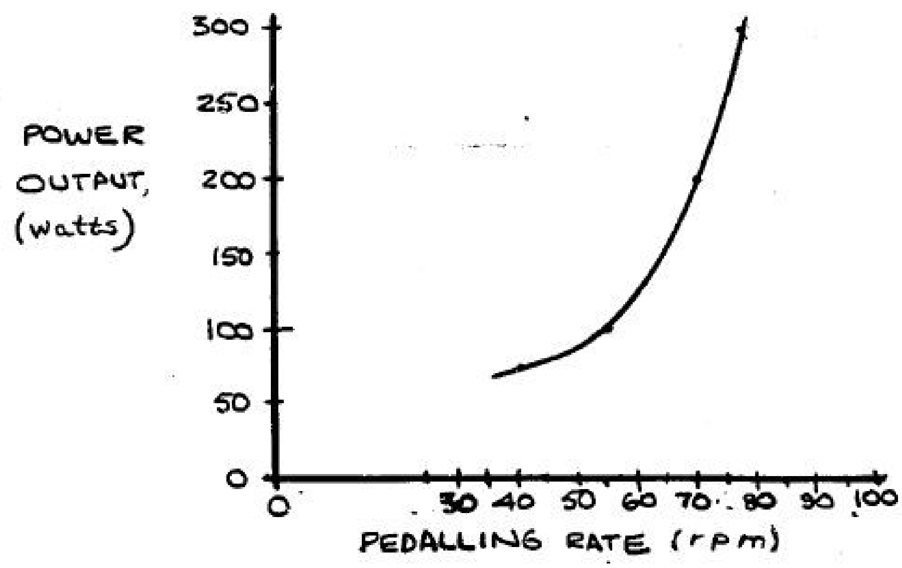


Figure 1: Graph of Power output against pedaling rate

A designed and fabricated pedal operated washing machine with the washing tub positioned behind the dynapod, with a maximum capacity of 2KG the machine speed is varied using a pulley system and a linear side motion accomplished using rack and pinion (Krishnamurthy M. *et al.*, 2017). The position of the washing tub made it impossible for the operator to monitor the progress of the machine and limited to a single pulley system, variation of speed for the operations of laundry which include washing, rinsing and spinning is becomes the sole responsibility of the operator.

Another design sort to transform a scrap electric washing machine to a manually operated washing using pedal power coupled with few gear system and rack-pinion system to turn the inner tub of the machine and also provide it with a back and forth movement (Adarsh Ranjan *et al.*, 2014) the design is a little bit ambiguous and would require a little technical know-how for maintenance which may not be available at the rural area or intended target user.

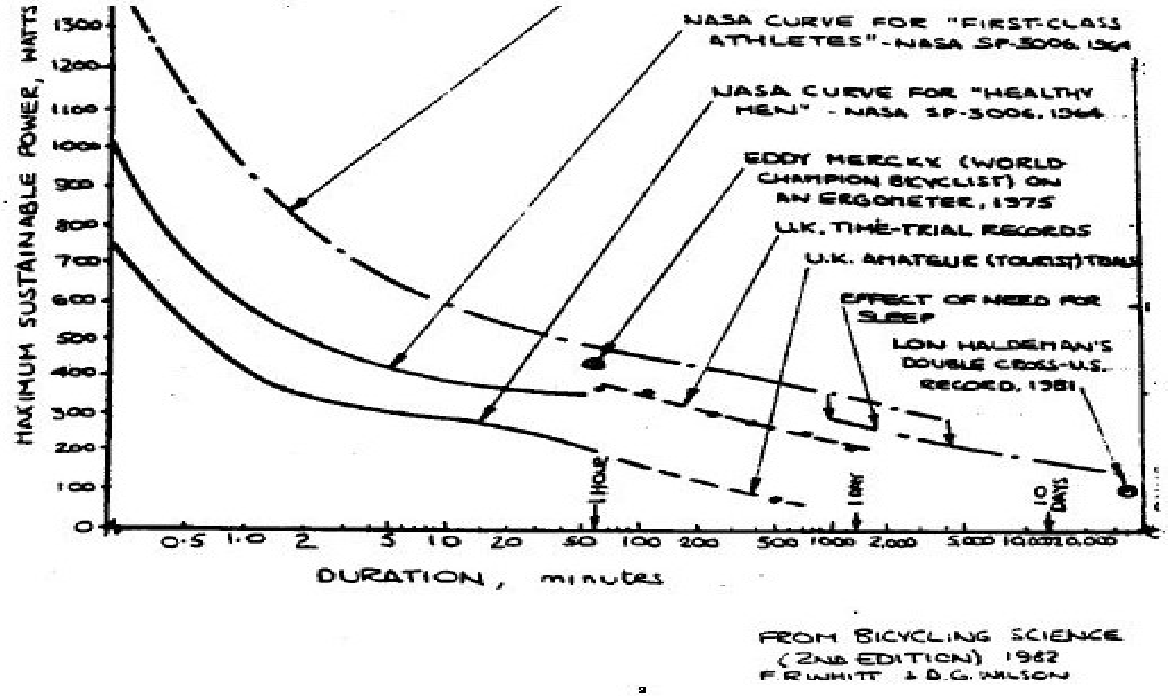


Figure 2: Graph of maximum sustainable power versus pedaling duration

3. METHODOLOGY

3.1 Design Concept

This design is an improvement on several earlier designs, it sorts out the cost of procuring a scrap electric washing machine of (Adash *et al*, 2014), and back sited washing rub of (Junaid *et al*, 2015) and ambiguity of design using rack and pinion of (Krishnamurthy *et al*, 2017) and also the single speed machine of (Tawanda *et al*, 2017). The design offers an adjustable gear system on the dynapod which makes it possible to vary the speed for different laundry operation and also further increasing the speed using a belt and pulley system. The position of the washing drum makes it easier for the operator to monitor the progress of laundry for example during spinning; the operator can keep the tub opened to notice the dryness of the cloth at a glance. The component of the design includes:

1. **Outer and inner drum/tub**: the inner drum houses the load (the clothes), inside the inner drum is the washing shaft also known as the agitator. The inner drum is perforated

to allow the easy access of the water and detergent mixture while the washing action is taking place. The outer drum serves as the water tub as well as the external body to the inner drum. It has the entry gate for supplying water to the machine and the exhaust tap for disposing used water.

2. **Sprockets (Gears)**: the sprockets wheel with teeth that meshes with the chain; one of the wheels in the cog-set it replaces the electric motor and speed control of the automatic electric washer.
3. **Cog-set**: the set of rear sprockets that attaches to the hub on the rear wheel
4. **Chain and belt:** the chain a system of interlinking pins, plates and rollers that transmits power from the front sprocket to the rear sprocket(s) while the belt transmits the rotatory motion from the intermediate pulley to the shaft of the agitator.
5. **Shifting lever**: this controls the shifting of the chain from one sprocket to the other for speed change to suit the operation and material.
6. **Shaft:** this transmits torque from one component to another; the intermediate shaft transmit torque for the driven sprockets to the intermediate wheel.
7. **Pulley**: this receives torque from the shaft and transmits speed to the washer shaft via a belt.
8. Ball bearing and hub
9. **Frame**: this is the support system of the machine.

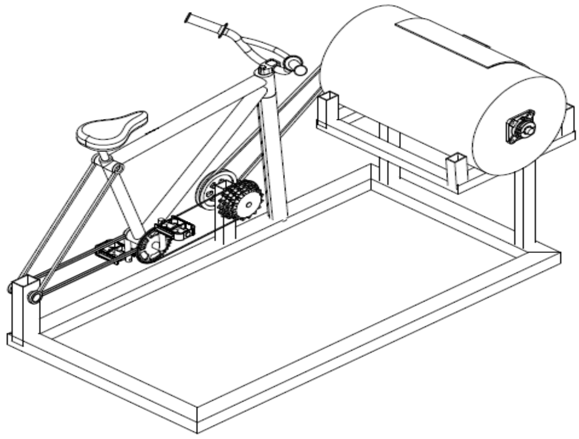
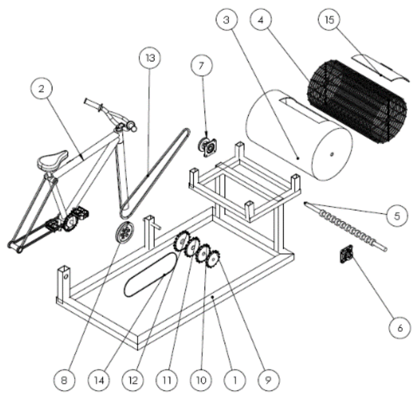


Figure 3: Isometric View



ITEM NO.	PART NUMBER	QT
1	Frame	1
2	Bicycle	1
3	Outer Drum	1
4	Inner Drum	1
5	Drum Shaft	1
6	1inch - 4 Bolt Flange Bearing	2
7	Pulley	1
8	Pulley	1
9	15T No.80	1
10	16T No.80	1
11	17T No.80	1
12	18T No.80	1
13	Belt	1
14	Chain	1
15	Cover	1

Figure 4: Exploded View and Machine part list

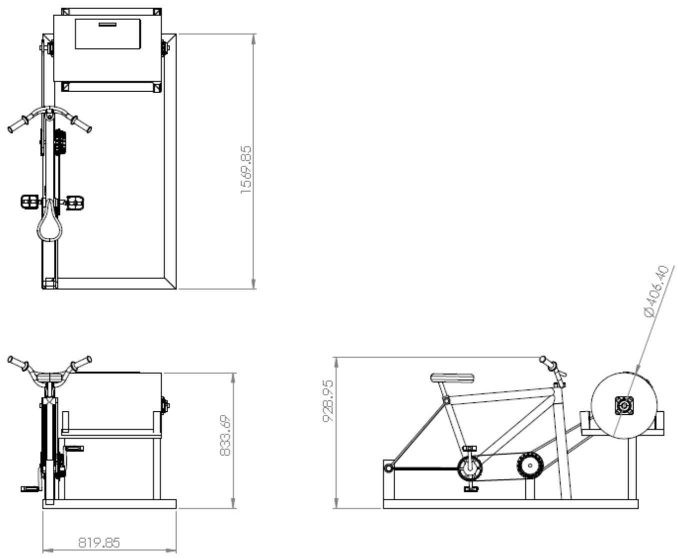


Figure 5: Orthographic View

3.2 Design Analysis

SYSTEM OF FORCE AT THE PEDAL

For effective calculation of forces and torque in the system; the following assumptions were made:

Mass of the laundry man (m) – 50kg
Duration of pedaling (t) = 60mins = 3600s
Starting speed (N_s) – 60rpm
Pitch diameter (Rp) = 0.2427m
Crank lever length (Rc) = 170mm = 0.170m
Power generated by man during leg cranking = 125W

Angular velocity of the Driver sprocket (ω_s) - $\frac{2\pi N}{60}$ (1)

$$\omega = 6.28rad/s$$

Torque delivered to the pedal during cranking $T = \frac{P}{\omega}$ (2)

$$T = 19.9Nm$$

Force delivered to the sprocket $Fd = \frac{T}{Rc}$ (3)

$$\boldsymbol{F = 117.1N}$$

Force generated by pedal (Fg) = Force delivered during cranking (Fd)

Torque generated (T) = $Fg \times R$ (4)

$$\boldsymbol{T = 28.42Nm}$$

Power generated by the driver sprocket (P) = ωT (5)

$$\boldsymbol{Pin = 178.48\ W}$$

SPEED SYSTEM OF THE MACHINE

$\omega A = speed\ of\ pedal\ gear\ (driver\ gear)$
$NA = Number\ of\ tooth\ of\ the\ driver\ gear$
$\omega B = speed\ of\ driven\ gear$
$NA = Number\ of\ tooth\ of\ the\ driven\ gear$

Washing Speed:

$\omega A = 60rpm\ \omega B = ?\ NA = \boldsymbol{48\ teeth}\ NB = \boldsymbol{27\ teeth}$

$$\frac{\omega A}{\omega B} = \frac{NB}{NA} \quad (6)$$

$\boldsymbol{\omega B = 106.67 rpm}$

Gear Ratio $GR = \frac{NB}{NA} = \frac{27}{48} = 0.56$

The speed of the driven gear is equal to the speed of the driver pulley

$\omega B = \omega c$; $\omega c = speed\ of\ driver\ pulley$;

$Dc = diameter\ of\ the\ driver\ pulley$

$\omega d = speed\ of\ driven\ pulley$; $Dd = diameter\ of\ the\ driven\ pulley$

$\omega c = 106.67 rpm$; $\omega d = ?$; $Dc = 160mm$; $Dd = 80mm$

$$\frac{\omega c}{\omega d} = \frac{Dd}{Dc}$$

$\boldsymbol{\omega d = 213.34 rpm}$

Pulley Ratio $GRp = \frac{Dc}{Dc} = \frac{160}{80} = 2$

Total Gear/Pulley Ratio (TR) = GR $\times$ GRp = 0.56 $\times$ 2 = 1.12

Speed Ratio $(SR) = \frac{NA}{Nd} = \frac{60}{213.34} = 0.281$

Rinsing Speed

Number of tooth for gear = **21 teeth**

Speed of drum shaft and inner drum = **274.28rpm**

Gear Ratio = **0.43**

Total Gear/Pulley ratio (TR) = **0.86**

Speed ratio (SR) = **0.219**

Spinning Speed

Number of tooth for gear = **16 teeth**

Speed of shaft and inner drum = **360rpm**

Gear Ratio = 0.33

Total Gear/Pulley ratio (TR) = 0.667

Speed ratio (SR) = 0.167

Belt Selection

Diameter of driver pulley =160mm

Diameter of driven pulley = 80mm

Center distance $C = 2 \times \left(\sqrt{(D + d) \times d}\right)$ (7)

$\boldsymbol{C = 277.13mm \sim 0.277m}$

Length of Belt

$$l = \frac{\pi(D+d)}{2} + 2C + \frac{(D-d)^2}{4C} \quad (8)$$

$\boldsymbol{l = 936.77 \sim 0.937m}$

Velocity of Belt

For washing; N = 106.67, D = 160mm

$$V = \frac{\pi DN}{60} \quad (9)$$

$\boldsymbol{V = 0.894 m/s}$

For rinsing; N = 137.14, D = 160mm

$\boldsymbol{V = 1.149 m/s}$
For Spinning; N = 180, D = 160mm
$\boldsymbol{V = 1.508 m/s}$

Power Output (at maximum speed)
The machine is a mechanical advantage device, it is designed to amplify force, thereby increasing the power output.
Power output of driver gear = 178.48W
Force generated by the driver gear = Force delivered to the driven gear = 117.1N
Pitch radius of the driven gear = 0.121m
Torque generated by the driven gear = $F \times R = 117.1 \times 0.121 = 14.21Nm$
Torque generated by the driven gear = Torque generated by the driver pulley
Radius of driver pulley = 0.08
Force on the driver pulley = $\frac{\text{Torque generated}}{radius\ of\ pulley} = \frac{14.21}{0.08} = 177.63N$
Force gen. by the driver pulley = force delivered to the driven pulley = 177.63N
Radius of the driven pulley = 0.04m
Torque generated by the driven pulley = $F \times R = 177.63 \times 0.04 = 7.11Nm$
Speed of the driven pulley = 360rpm
Angular velocity of the driven pulley = $\omega = \frac{2\pi N}{60} = \frac{2 \times \pi \times 360}{60} = 37.7 rad/s$
Power generated by the driven pulley = $= T \times \omega = 7.11 \times 37.7 = 268.05W$
$P_{out\text{-}put}$ = **268.05W**

Tension on Belt (At maximum speed)
T1 =? T2=? μ=? Θ=? α=?
c=0.374m r1=0.08m r2 = 0.04
ω=18.85rad/s v=1.508m/s P=268.05W

$$\sin\alpha = \frac{r1+r2}{c} \quad (10)$$

$\sin\alpha = 0.3209°$
$\boldsymbol{\alpha = 18.7°}$

$$\theta = 180 - 2\alpha \times \frac{\pi}{180} \quad (11)$$

$\boldsymbol{\theta = 2.49 rad}$

$$\mu = 0.54 - \frac{42.6}{152.6+v} \quad (12)$$

$\boldsymbol{\mu = 0.26}$

$$\frac{T1}{T2} = e^{\mu\theta} \quad (13)$$

$$P = (T1 - T2)v \quad (14)$$

$\boldsymbol{T1 = 248.28N}$
$\boldsymbol{T2 = 129.92N}$
Where:
T1 = tension on the tight side
T2 = tension on the slack side

***All formulas were used in reference to Khurmi, R. S. and Gupta, J. K. (2012)**

3.3 Materials
One of the objective of the project is to develop a cost effective machine by sourcing material from the local environment, several materials were considered based on some factors and

adequate trade off analysis helped prune doen the list of material available. Each component were made from a suitable material.

Table 1: Shows the materials used

S/n	Component	Material selected
01	Drum support	Mild steel
02	Base frame	Mild steel
03	Bicycle frame	Mild steel
04	Sprocket	Mild steel
05	Pulley	Mild steel
06	Outer drum	Mild steel
07	Inner drum	Mild steel
08	Shaft	Mild steel

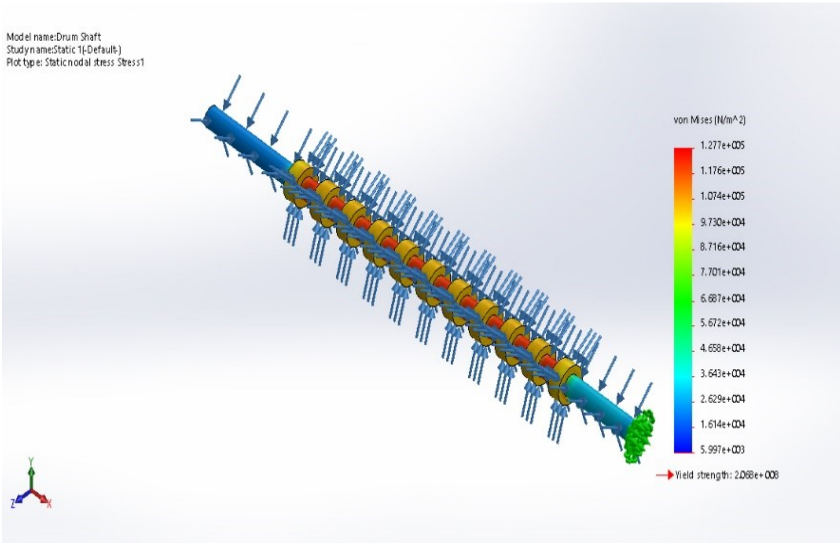


Figure 6: Stress analysis of the drum shaft

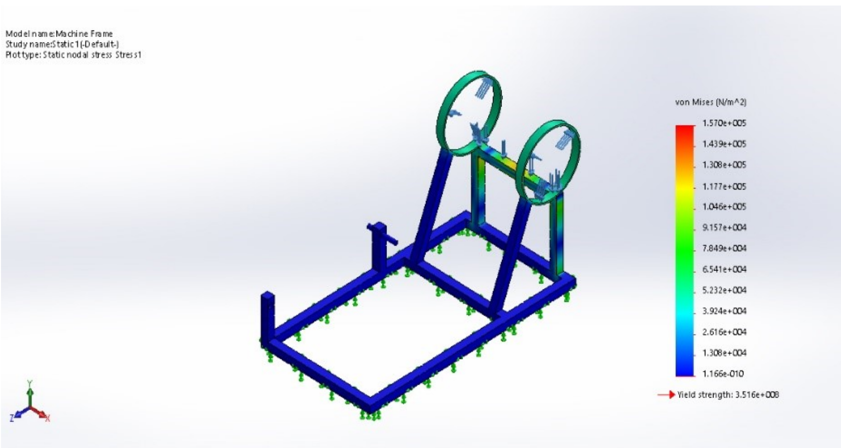


Figure 7: Stress analysis of the frame

4. RESULTS

4.1 Construction process

Fabrication of the machine included the cutting to size and shape of the materials and the welding together of the parts of the machine, Plate 1-4 shows the different view of the fabricated pedal powered washing machine. The frame (stand) of the drum was fabricated from square pipe iron as well as the base seat of the whole machine. Other parts of the machine were attached appropriately as specified in the design of the machine.

Plate 1: Dynapod and Drum stand

Plate 2: Side-view of assembled machine.

Table 2: Shows Input Parameters for design.

S/N	PARAMETER	SYMBOL	VALUE	UNIT
01	Human Input Rotational Speed	ωA	60	rpm
02	No of teeth on the largest sprocket	N_A	48	-
03	No of teeth of the smallest sprocket	N_B	16	-
04	Pitch Diameter of Largest Sprocket	D_C	9.556	in
05	Pitch Diameter of smallest sprocket	D_D	3.204	in
06	Operation time	T	60	mins
07	Diameter of small pulley	Ds	80	mm
08	Diameter of larger pulley	Dl	160	Mm
09	Diameter of washing shaft	D	100	mm

Table 3: Shows Output parameters from design calculations

S/N	PARAMETER	SYMBOL	VALUE	UNIT
01	Input Force	F	117.1	N
02	Input Torque	T	19.9	Nm
03	Pedal input Power	P	125	W
04	Pedal Power output	P	178.48	W
05	Pedal Mechanical efficiency	P M.E	88.76	
06	Speed Ratio (washing)	S Rw	1.78	
07	Speed Ratio (rinsing)	S Rr	2.29	
08	Speed Ratio (spinning)	S Rs	3	
09	Speed of Small Sprocket	N	106.67	
10	First Stage Gear ratio (washing)	G Rw	0.56	
11	First Stage Gear ratio (rinsing)	G Rr	0.43	
12	First Stage Gear ratio (spinning)	G Rs	0.33	
13	Second stage gear ratio	G R	2	
14	Overall gear ratio (washing)	O G Rw	1.12	
15	Overall gear ratio (rinsing)	O G Rr	0.86	
16	Overall gear ratio (spinning)	O G Rs	0.67	
17	Actual length of belt	l	0.937	m

18	Belt center distance	c	0.277	m
19	Contact lap angle	α	18.7	o
20	Belt speed (spinnig)	Vw	0.894	m/s
21	Belt speed (spinning)	Vr	1.149	m/s
22	Belt speed (spinning)	Vs	1.508	m/s
23	Tight tension (maximum)	T1	248. 28	Nm
24	Slack tension (maximum)	T2	129.92	Nm
25	Torque on shaft	T	7.11	Nm
26	Pulley power output	P	268.05	W
27	Overall efficiency	η	84.98	

5. PERFORMANCE EVALUATION

Performance evaluation test was carried out on the machine to test for its effectiveness to wash, rinse and spin-dry cloth material. The machine power output is dependent on the user which may vary over a range of weight and input speed. The average adult weight was projected at 50kg producing a speed of 60rpm and a cranking power of 125W which is capable of delivering a power of 268.05W as the machine output. The washing, rinsing and spinning speed is considered over a range of speeds and the performance is indicated below.

Table 4: Table of Input speed and the output speeds

Input Speed	Washing speed	Rinsing Speed	Spinning Speed
20	71.11	91.43	120
30	106.67	137.14	180
40	142.22	182.86	240
50	177.78	228.57	300
60	213.33	274.29	360
70	248.89	320.00	420
80	284.44	365.71	480
90	320.00	411.42	540
100	355.55	457.14	600

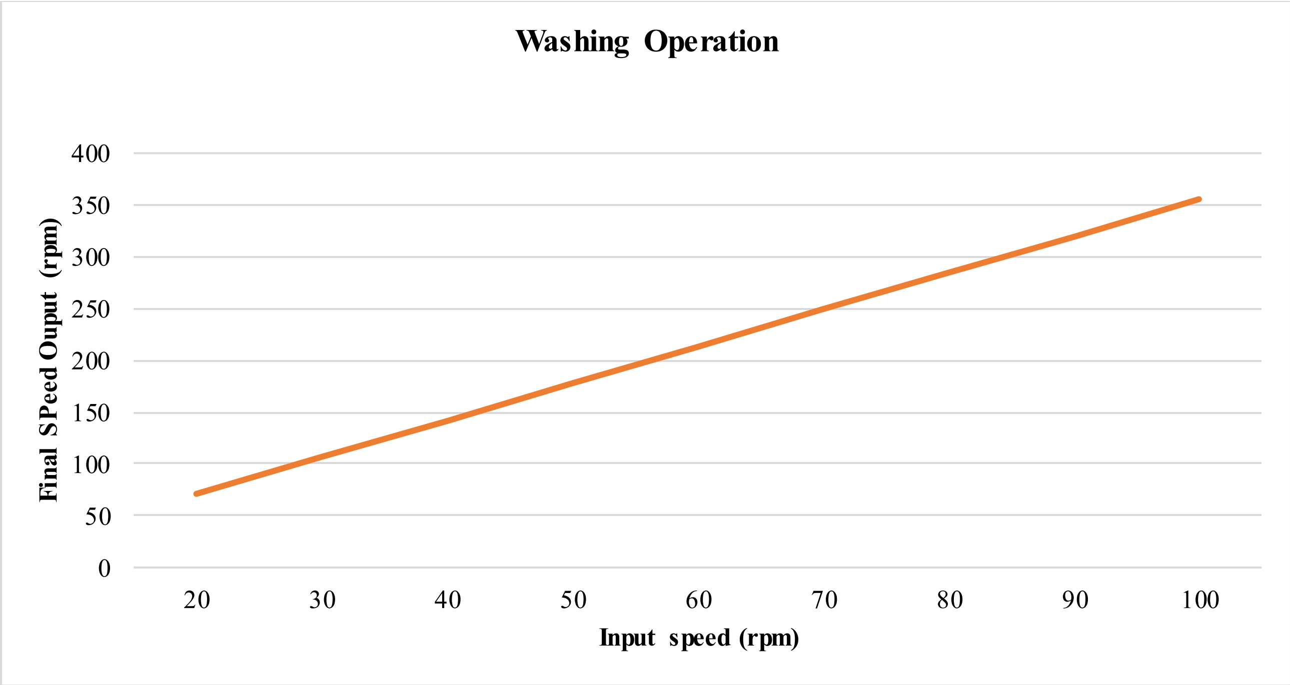


Figure 8: Graph of Input speed against the output speed during washing

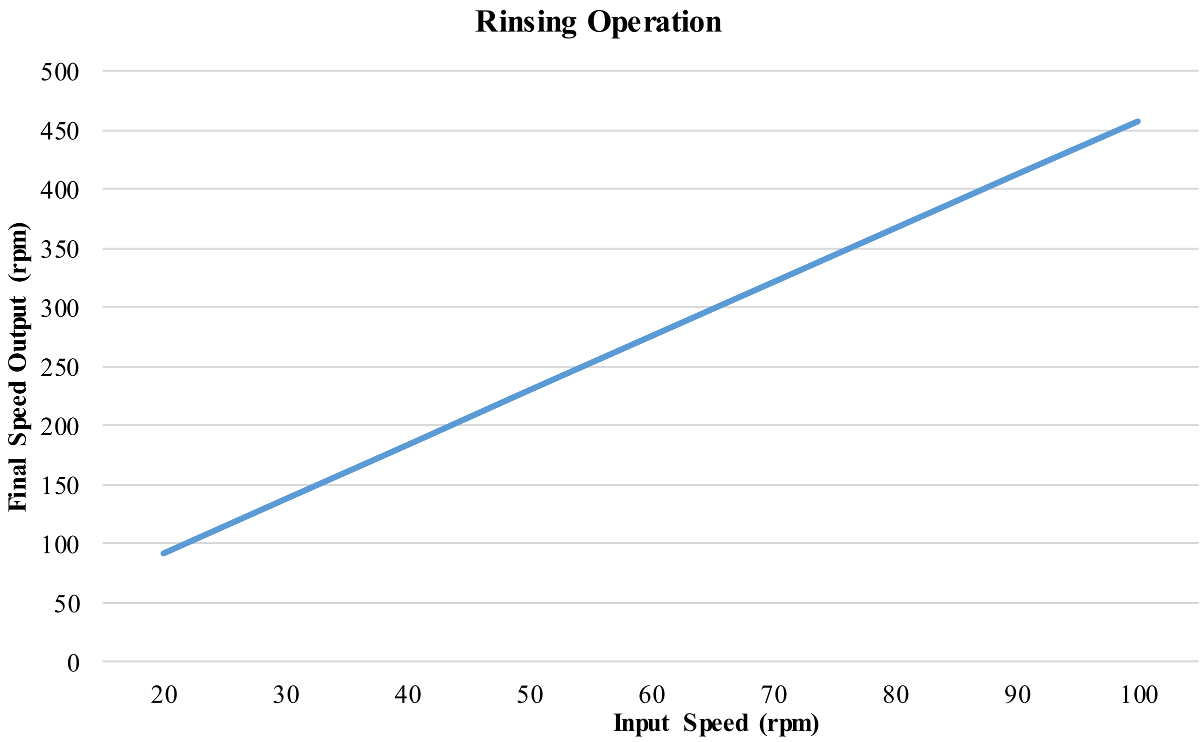


Figure 9: Graph of Input speed against the output speed during rinsing operation

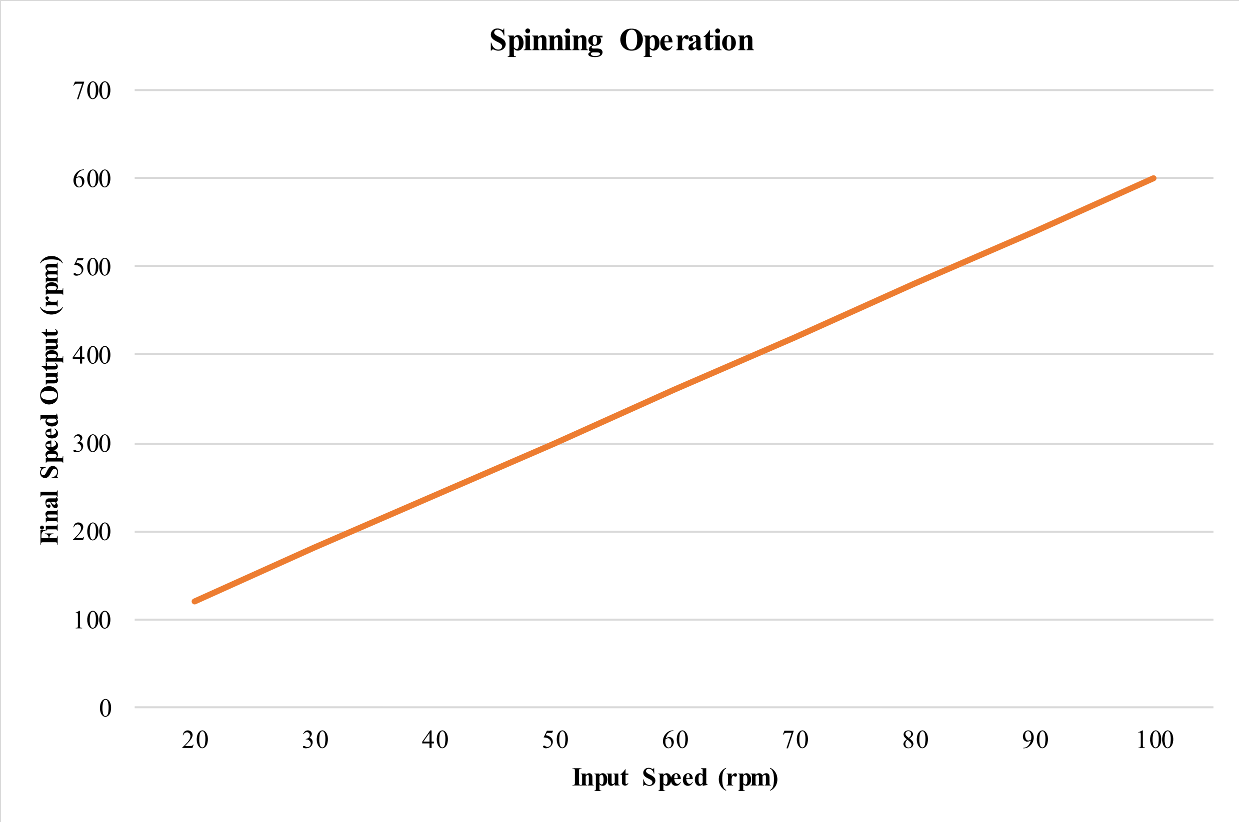


Figure 10: Graph of Input speed against the output speed during spinning operation

The machine is environmentally friendly in that it does not emit any form of toxic gas to the surrounding and can be position at a communal point of convergence for shared usage. The machine is capable of driving a total mass 5kg cloth and water at once. This mass is the average mass of cloth usage for a family of four with two change of cloth daily. The safety of the machine is assured as the machine is during the pedaling operation and through the process of the laundry. The machine was design to be durable and with the estimation of 3½ years of consistent use without failure if properly maintained by lubricating the cog set and bearings, necessary part are coated to prevent corrosion during the laundry operation.

6. CONCLUSION

It is easier, more efficient and less time taken to wash cloth using a pedal power washing machine in that it is capable of washing more than one cloth at a time compared to manual washing. It is more comfortable, less messy and safer to use considering the dipping of hand into a detergent solution when washing manually and requires less energy. Also, the machine can be use in rural and low income urban areas because of its affordability and also can be jointly used or share between families or community. Materials can be source locally for construction and maintenance is easy. Finally, the machine is highly useful because it can also be used for exercise purposes which can improve the health and well-being of the operator.

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