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Design and Development of Pedal-Operated Washing Machine for Off-Grid Communities in Developing Countries

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Abstract:

In Third World nations like Ethiopia, washing is still a burdensome and tedious exercise, left in most cases to women and children who endure chronic exposure to aggressive chemical surfactants and physical exhaustion. Lack of electric washing machines due to unaffordability, unstable electricity supply, and poor water pressure exacerbates the chore. To overcome these challenges, a pedal-powered washing machine has been created, which can wash up to 12 kg of clothes in one cycle within 20–45 minutes.

This revolutionary design addresses the drawbacks of conventional washing, including excessive wear and tear on garments, high expense, long washing times, ergonomic strain, and high water and energy usage. The device is made for sustainability and affordability, employing easily accessible local materials and simple assembly and repair by local welders. As a functional, low-cost, and eco-friendly solution, the pedal washing machine offers a ground breaking alternative to off-grid and resource-scarce communities in developing countries.

Keywords **—pedal-operated, washing machine, off-grid, local manufacturing**

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I. INTRODUCTION

In developing countries like Ethiopia, washing laundry is a difficult, time-consuming task that falls solely on women. Mothers and daughters typically spend more than 6 hours each week scrubbing each piece of their family's clothing and wringing out the harsh washing solution by hand. Operated washing machines exist, but they are impractical in most regions because initial cost of the machine, cost of running water and electric are expensive or unavailable. There is also a large technology gap between traditional hand washing and electric washing machines. Even if people had the initial purchasing power, many times they cannot afford the electricity required to operate these machines. The lack of sufficient water pressure in many developing countries also deteriorates utility of most electric washers. Thus, it is more common for women to wash clothes by hand. In Ethiopia, and most likely in many other countries, some women earn their livelihood by washing clothes by hand for wealthier households. For these women especially, the effects of harsh chemicals and agitation are magnified because they wash clothes very frequently. Moreover, the fact that hand washing is time-consuming means that their productivity and income are narrowly limited.

The pedal-operated washing machine is an affordable and efficient alternative to conventional machines, built from simple, reliable, and commonly available scrap materials. It resembles a commercially available horizontal axis washer. This machine generates power through human pedalling, which is converted into the rotary motion needed to operate the internal drum. The design of this machine is notable for its simplicity and modernity (Hakizimana et al. 2020). With low-cost components and minimal maintenance requirements, it is accessible to a wide range of people and has a minimal environmental impact. The pedal-operated washing machine operates on a compound gear system and is capable of washing, and rinsing clothes, offering efficient and consistent spinning with little effort. It is especially useful in areas without access to electricity (Tandale et al. 2015; Ajay and Choudhary 2014; Mogaji, Jayeola, and Echoga 2020)

Previous studies on pedal-driven washing machines have generally focused on small-sized models designed for individual use. While these machines offer a practical solution for rural areas with limited or no electricity, they often lack detailed mechanical design, which can compromise their efficiency and ease of operation. Additionally, these models typically have limited capacity, making them less suitable for communal use (Ali et al. 2019).

The objective of this manuscript is to develop a larger pedal-operated washing machine that addresses these limitations. This new design is a low-cost, pedal-operated machine built using readily available, locally sourced parts. Its innovation lies in the simple design, which utilizes inexpensive plastic drums and bicycle components. The machine is reliable, easy to operate, and requires no electricity. Since all parts can be sourced locally, it can be manufactured and repaired within the community, reducing reliance on imported goods. The machine provides an affordable, eco-friendly alternative to electrically operated devices and those relying on fossil fuels. It is specifically designed for use by communities or groups, ensuring larger load capacities, while maintaining low operating costs and minimizing environmental impact.

II. DESIGN AND WORKING PRINCIPLES

Our design resembles a commercially available horizontal axis washer. The inner drum which holds the clothes is constructed by modifying a plastic utility tub. The inner drum should be perforated, so that spinning the drum will extract water from the garments. There are also three triangular ribs inside the inner drum that lift and drop the clothes during the wash cycle.

The schematic drawing of Pedal Operated Washing Machine is shown in Fig. 1. The inner drum is mounted on a beater which is supported by two bearings on each side. Rotational force turns the drum via a drive gear attached to one end of the beater shaft. A bicycle chain connects the gear at the drum to a set of pedals mounted on the frame. The pedals are mounted close to the ground so that the operator can pedal the machine while seated. There is an outer barrel that surrounds the inner drum and contains all the water. In our current design, the outer barrel is constructed using a common steel oil drum. The operator loads and unloads clothing from the inner drum through a cutout on the side of the outer barrel. The operator drains the soapy water and rinse water by opening a drain value at the bottom of the barrel.

The most important aspect in the design of the machine is its ability to perform as a device that eases the task of washing clothes. The machine is aimed be able to deliver the same quality of washing without adding excessive overheads (in terms of water use, clothing wear, effort required to operate, etc.). The ability to spin-dry clothes would increase water economy by requiring fewer wash cycles, and could relieve the strenuous task of manually wringing the clothes before they are hung to dry. If the machine was to be used in a home, ensuring its portability of would allow it to be shared among families, transported close to a water source for operation, or used in households where space is limited.

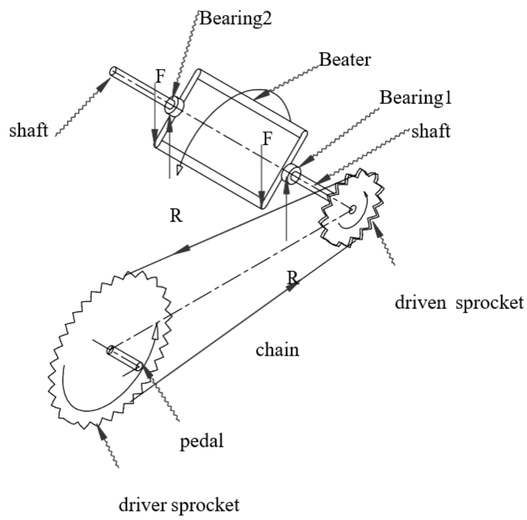

Fig. 1. Schematic drawing of Pedal Operated Washing Machine

The Specification of the machine includes:

- The capacity of the machine is

estimated to be between 3kg and 12kg of clothes in one cycle of washing.

- The drum volume is 120 liters
- Active pedaling time for effective washing: between 20 and 45 minutes in one cycle.
- Weight: Maximum 45kg with its wheels (1 person can move it indoors).
- Materials: local (plastic, wieldable metals, oil drum, bicycle parts, etc.)

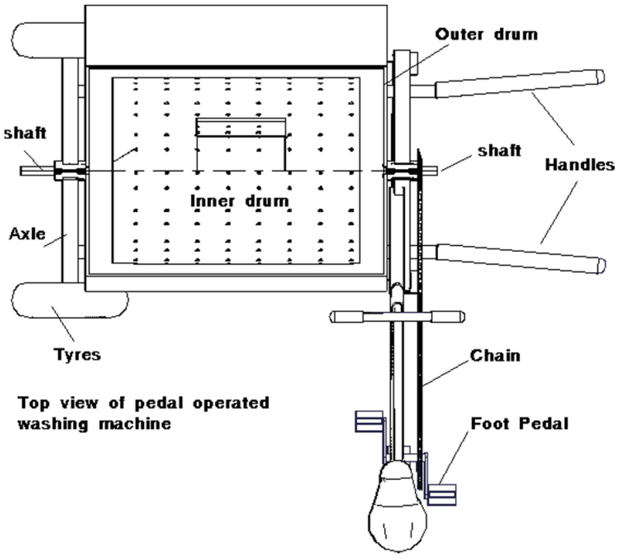

Fig. 2. Top view AutoCAD model of pedal operated washing machine

The selection of a proper material, for engineering purposes, is one of the most difficult problems for the designer. The best material is one which serves the desired objective at the minimum cost. The following factors should be considered while selecting the material:

- Availability of the materials,
- Suitability of the materials for the working conditions in service, and
- The cost of the materials.
- Corrosion Resistance
- Material Strength

III. Design of Mechanical part

A. Drive Train

The maximum transmission ratio is 3:1. Assuming the operator could hold an average steady pace of around 20 RPM at the pedals, the drum itself would see a maximum rotational speed of 60 RPM, this would be an ideal speed for the washing cycle. The rinsing cycle will require the operator to produce a pedal speed of about 80 RPM, this will result in a maximum drum speed of around 240 RPM. The washer needs to be spinning at about 60 RPM, this will allow the clothes to tumble in a desirable fashion, any faster than this and the garments will be forced to the edge of the inner drum and will not fall off the wall of the washer. If the washer is moving too slow the clothing will not climb high enough up the wall before it tumbles, this is also undesirable. The rotation speeds required are determined by the diameter of the inner drum. For the wash cycle, the ideal tumbling motion is achieved when the centripetal acceleration experienced by the clothing is slightly less than the gravitational acceleration (Raduta 2008).

$$W_{wash} = \sqrt{\frac{g}{R}} \qquad \text{Eq 1}$$

Where g is the gravitational constant and R is the radius of the rotating drum. A drum of larger radius requires a smaller angular velocity during the wash cycle.

The spin drying of clothing relies on a forced separation that occurs as the clothes are rotated inside the drum at high speed and experience a centrifugal force. In order to see the benefit of this acceleration, the centripetal acceleration the clothes are subjected to must be significantly higher than the gravitational constant which what clothing normally experienced during normal drip drying. The corresponding formula for determining the centripetal acceleration is well known:

$$a_C = W^2 \times R \qquad \text{Eq 2}$$

Where, W is the rotational speed and R is the drum radius. Higher rotational speed and larger drums result in acceleration and faster water extraction as a result.

B. Bearing selection

Our final design utilizes two bearings located at either end of the inner drum so the bearings must be able to jointly support the static weight of the inner drum when filled with wet closing as well as any vibration loads during operation. The static load bearing requirements is determined by the total weight of the drum and the wash load. The size of bearing selected for an application is usually influenced by the size of shaft required (for strength and rigidity considerations) and by the available space. So, a ball bearing no 205 having bore diameter 25mm and outside diameter 52mm is selected for this machine. This bearing has a load rating capacity of maximum ranging between 2.45kN and 5.9kN (Wilson and Schmidt 2020).

C. Power needed on the drive pedals

The power input on the bicycle driving pedal will be 1/3 of the power output on the bearings in which pedaling power is 78 watts Maximum and the power consumption on the pedal at 80 rpm is computed as one third of the minimum power on the bearings, calculated as 19.25 watts. The power needed by pedaling can be approximately between 20watts and 80watts. The DN value is 12480 which is largely less than 45,000. Aside from their low cost, iolite bearings have the advantage of being moisture resistant, and they can easily be obtained off the shelf in the market.

D. Power source

A person can generate four times more power (1/4 horsepower (hp)) by pedaling than by hand cranking (Wilson et al. 1987). At the rate of 1/4 hp, continuous pedaling can be done for only short time about 10 minutes. However, pedaling at half of this power (1/8 hp) can be sustained for around 60 minutes. Maximum power produced with legs is generally limited by adoptions within the oxygen transportation system. On the other hand, the capacity for arm exercise is dependent upon the amounts of muscle mass engaged and that is why a person can generate more power by pedaling than hand cranking. Powering the wash cycle for 12kg of laundry was subjectively estimated to require 60-80 watts of continuous power and lower for a smaller load size. The requirement during the spin dry process is much lower 20-30watts. The power requirement of 60-80W is within the limit generally recommended for human operated devices according to (Wilson and Schmidt 2020). The operating range of 60-240 rpm is also within the capabilities of generic multi-speed derailleur driver.

E. The inner drum

Most often a cylindrical shape, the drum may contain 3-5 internal ribs/3 in our case/ that engage the clothing, providing agitation as the drum rotates.

F. The outer drum or water basin

The requirements for the outer drum are minimal: it must hold water, be larger than the inner drum and allow access to the inner drum. An outer drum that is closely matched to the inner drum will result in increased water economy. A simple construction can use a 120L steel tub.

G. Ergonomic considerations

Optimum metrics were obtained for operators of different heights and a customizable design of the washing machine is proposed to enhance the ergonomics of the machine. All design decisions were made based on anthropometric data of an average person. The main ergonomics feature in this design is the presence of a comfortable driving mechanism that suits for all age and sex groups of people. The bicycle has no connecting member between the seat and the steering/ handle/ so that it will be easy for women and children to mount without any obstacle.

IV. MANUFACTURING PROCESS

Bearing housing can be constructing by two round steel tube each having 57mm external diameter and 52mm internal diameter their length is 50mm as shown in Fig. 3.

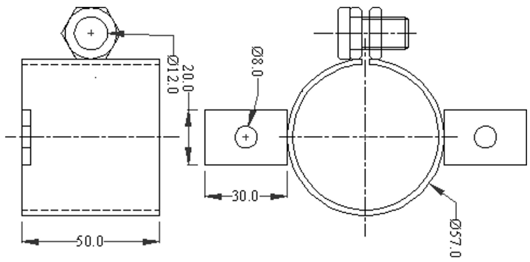

Fig. 3. Bearing housing

The beater is constructed by galvanized round tube having 25mm diameter (see Fig 4).

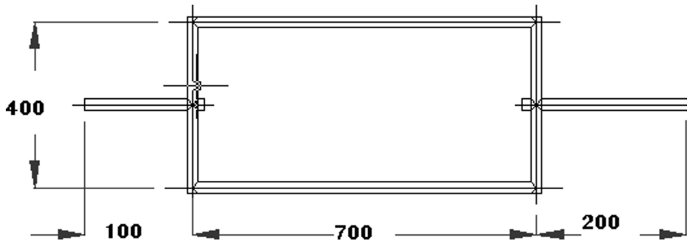

Fig 4. Beater

Three ribs and six flat stocks indicated in Fig. 5 can be construct by aluminium sheet metal with developed pattern and tightening the rib and flat stock with inner drum together by riveting.

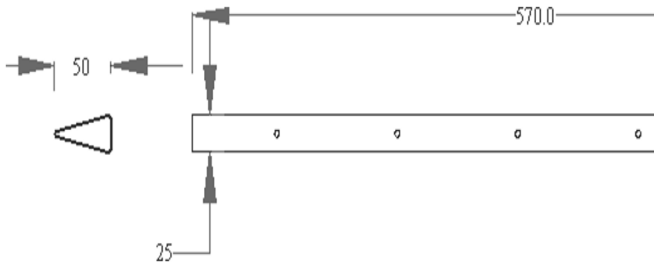

Fig. 5. Ribs

The housing and drum support frames indicated in Fig. 6 are constructed by steel square tube having 40x40x2mm thickness, and first cut the steel square tubes with proper length and then welded together.

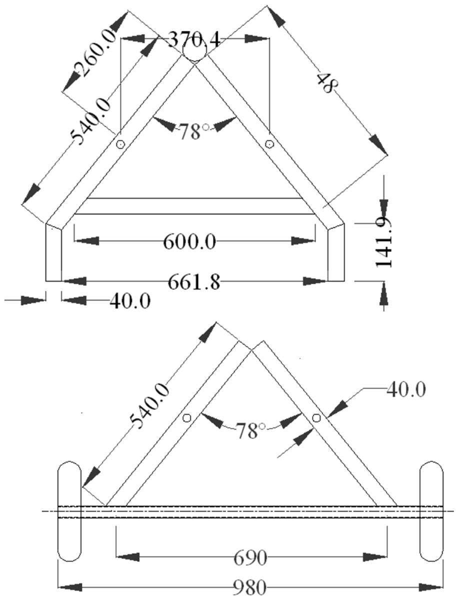

Fig. 6. Front frame (top) and Rear frame (bottom)

The outer drum illustrated in Fig. 7 is made from a steel oil barrel commonly found in local markets, with standard dimensions of ø60x1000mm. For this application, the barrel is cut to a size of ø60x800mm, and one end is welded to ensure it is waterproof. The top portion of the outer barrel is then carefully cut using an electrical hand cutting and grinding machine, following specified dimensions, to create a space capable of holding water and detergent. Additionally, two hinges are welded between the top and bottom sections of the outer barrel to facilitate movement and functionality.

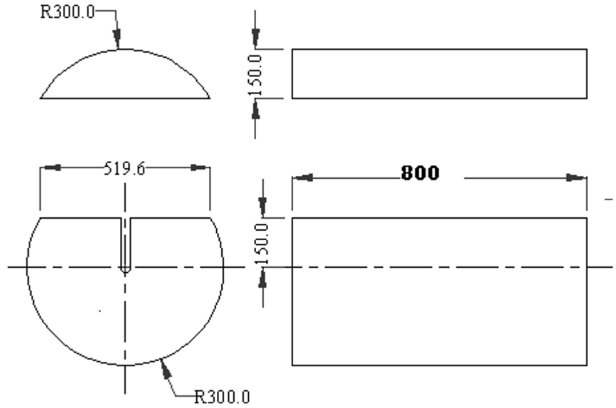

Fig. 7: Outer drum and top cover

The inner drum is construct by plastic oil drum having ø50x600mm length and is perforated accordingly as shown in Fig. 8.

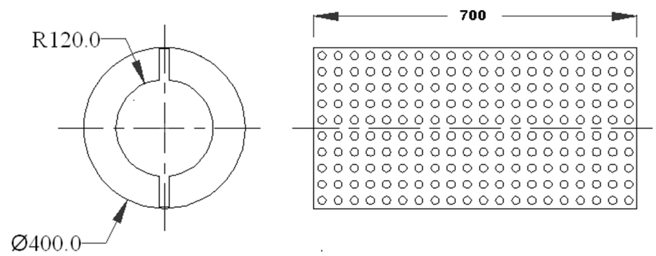

Fig. 8. Inner drum

Fig. 9 shows the Frame and drum support used to carry the whole structure of the washing machine.

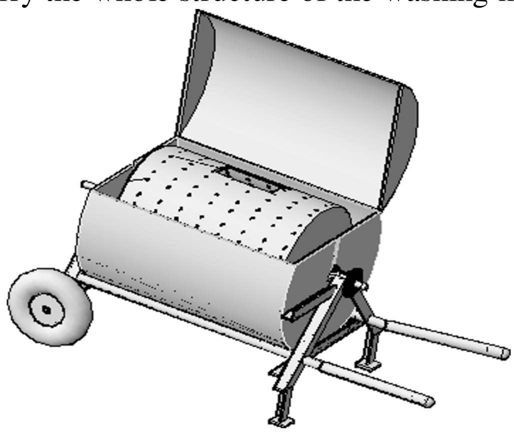

Fig. 9. Washing drum and frames subassembly

The final assembly of Pedal operated washing machine with the driving mechanism and is performed as shown in Fig. 10.

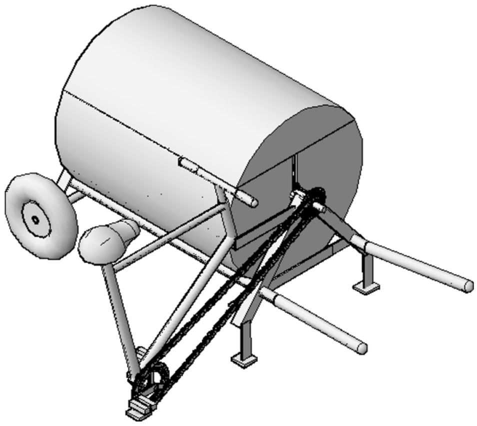

Fig. 10. Final assembly

V. COST ANALYSIS

The costs of the machine can be compared with actual costs previously incurred for similar work, the cost or pricing data received from other vendors, and independent cost estimate breakdowns. With the exception of a few, the materials utilized were ones that would be easily found where domestic or commercial materials are purchased. Most of the materials used will not corrode in a high relative humidity, nor contaminate the dress. The product cost analysis is based upon local market stores found in Maichew town.

The materials cost includes costs of outer barrel, inner barrel, old bicycle mechanism, bearings, round and square pipes, tires, paint, electrodes, cutting and grinding discs and hacksaw blades. This sums up to be 8500 ETB. Labor is charged at hourly rates that include 30 percent benefits in manufacturing industry. The charge rates are Br 50.00 per hour for unskilled labor and 75.00 per hour for skilled labor. The skilled labor rate is generally used with the machining equipment. Labor per manufacturing component for an operation such as welding is calculated by using the work rate on the manufacturing industry. A small amount of extra labor is added to allow for downtime for tasks such as making adjustments and maintenance. This is applicable for general manufacturing industry but our labor estimations have been based upon the hours accumulatively spent on the project as technician earning a 400.00 Birr per day. To start our cost study, we concerned labor expense data from different areas especially in small scale industry around Maichew town. As we have seen most of those industries are one daily wage worker paid only four hundred ETB on the basis of 50 ETB per hour. Approximately 30.45 hours has been spent on the fabrication of the machine. Therefore, the total labor cost is estimated as 1522.5 ETB. The depreciation cost is calculated according to the following equation;

$$D = (C - S)/N \qquad \text{Eq 3}$$

Where C is an original cost, S is a salvage value (scrap) and N is useful economic life in years. Our project uses welding machine to manufacture prototype. The following depreciation cost is calculated based on the above formula for welding machine.

Since the local metal working shops are having mostly portable equipment, we considered the depreciation cost of the welding machine to be the largest and we took its value to be the depreciation cost for the other machines. Another consideration we have taken is the depreciation cost for other tools and equipment to be 25% of machine depreciation.

TABLE 1. DEPRECIATION COST TABULATION

Types of machine	Duration (hr)	Depreciation cost (Br/hr)	Total cost (Birr)
Arc welding	3.5	1.458ETB	5.10
Portable Grinder	0.87	1.458ETB	1.26
Portable drill	3.083	1.458ETB	4.49
Circular saw	1	1.458ETB	1.45
Sum			12.32
Tools and equipment	25% of sum		3.08
Sub Total			15.40

Table 2 shows the electric cost of the process. When calculating the electric cost, we directly referred to the nameplates of each electrical machine used and their power was 5hp, 2.5hp, 2.5hp, and 5hp for arc welding, portable grinder, portable drill, and circular saw respectively. Since it is nowadays charged as birr/kwh in the Ethiopian Electric Light and Power Authority /EELPA/, we need to convert the horsepower to kilowatts by a

conversion factor 1hp=744 watts. And the maximum charge for 1kwhr was found to be 2.00 birr. Finally, the estimated cost of the washing machine is shown in
Table 3.

TABLE 2. ELECTRIC COST

Machine	power(kw)	Duration(hr)	Total kwh	cost/kwhr (Birr)	Total cost (Birr)
Welding	3.72	3.5	13.02	2.00	26.04
Grinder	1.86	0.87	1.6182	2.00	3.23
Drill	1.86	3.083	5.73438	2.00	11.46
Circular saw	3.72	1	3.72	2.00	7.44
Sub Total					48.18

TABLE 3. COST SUMMARY

Item	Cost (birr)
Materials	8500.00
Labor	1522.50
Depreciation	15.40
Electric	48.18
Total manufacturing cost	10086.09
profit 30%	3025.83
selling price before tax	13111.92
tax 20%	2622.38
selling price after tax	15734.30

VI. CONCLUSIONS

The version This project aims to simplify clothes washing by developing a low-cost, pedal-operated washing machine using readily available parts. Designed for easy manufacturing by local welders and user-friendly maintenance, the machine targets the 94% of the population who wash clothes by hand, a task predominantly done by women. Data shows manual washing takes twice as long and uses more detergent than the pedal-operated machine. The affordable design is ideal for shared use among families or communities and can be upgraded to a fully automated system. Testing compared hand washing to the pedal-operated machine using stained t-shirts. While some stains (spicy food, tomato sauce, grass, mud) faded slightly in both methods, the machine achieved cleaner results with less time (7 minutes vs. 15 minutes for hand washing). The spin cycle also effectively removed water, matching hand-squeezed dryness. The project successfully delivered an affordable, practical, and easily distributable washing machine design. The design process offers valuable insights for similar product development projects.

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