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Development of A Solar-Powered Slider-Crank Mechanism for Hand Pump in Rural Areas

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Abstract— *The demand for alternative water pumping mechamism needed to overcome the challenges facing people in the remote areas is on the increase. The conventional manually operated hand pump requires a large amount of energy before quality water can be pumped for domestic and irrigation purposes. This limits its usage by the average persons, the elderly and the disabled. This study presents the development of a solar-powered slider crank mechanism, a more energy friendly drive system. Slider crank mechanism with connecting rod 70 mm, radius of crank 14.8 mm and a frame with width, breadth and height of 70 mm, 70 mm, 134 mm, respectively was fabricated using mild steel. Solar panel, charge controller, battery and low speed motor were used to power the mechanism. The performance of the solar powered slider-crank aided system for pumping water was evaluated in terms of actual and theoretical discharge, as well as volumetric and pumps efficiencies with values of 0.01693 m^3/s, 0.01302 m^3/s, 76.905%, 73.26%, respectively. Conclusively, the solar powered slider-crank aided water pumping system is about 24% better in terms of performance compared to the conventional manually operated hand pump.*

Keywords— ***Hand pump, Rural areas, Slider-crank mechanism, Solar-powered, Water supply***

I. INTRODUCTION

One of the four interrelated basic needs with a significant effect on socioeconomic progress and the quality of life is access to adequate water [1]. Since it significantly affects both public health and living standards, water is essential to life. For basic human functions like nutrition, respiration, circulation, excretion, and reproduction, water is a crucial component. Scarcity of water on the other hand reduces biodiversity in both aquatic and terrestrial environments, jeopardising the human food supply [2]. Due to a lack of access to clean and safe water, people suffer from starvation, dehydration, and die from diseases that may be prevented in some regions of the world.

The demands for freshwater on a global scale has been rising significantly as economies and populations have expanded. The negative consequences of global population growth are putting growing pressure on our essential water resources is causing significant water stress in many countries.

Over the past century, great progress has been made in providing millions of communities and billions of people with access to clean drinking water. However, billions of people still lack access to drinkable water, primarily in developing nations and their rural areas.

The common technological method of getting water from its natural sources is by drilling of borehole connected to a pump (either centrifugal or submersible pump, or reciprocating pump). Due to a borehole water systems pump needing electricity to operate, mechanical hand pumps are adopted and are very predominant, most especially in rural areas. According to Ottoson [3], over 4 million hand pumps have been erected in Africa, India, and Asia over the last two decades, and at least 1 billion people rely on hand pumps to get their daily water needs met worldwide. The India Mark II hand pump, which may be seen in Figure 1, is the mechanical hand pump system that is the most widely produced. It was created by UNICEF in 1978. Over 2.6 million India Mark hand pump systems are reportedly in operation in India [3]. The India Mark II hand pump (figure 1) is utilized all over the world.

The reciprocating pump is the most used among these hand-operated pumps [1]. In comparison to centrifugal pumps, reciprocating pumps are more expensive to install and maintain, making them obsolete for industrial applications. However, hand-operated pumps still find wide application [4]. The structure of the reciprocating systems has the crank-slider as the key component, and The design of reciprocating systems is based on a dynamic analysis of the crank mechanism. A mechanical device called a slider-crank mechanism can change straight-line motion into rotary motion, such in a reciprocating piston engine, or the other way around [5].

The common hand pump is mostly operated using a lever system operation. One of the main disadvantages of using lever-powered handpumps is the physical effort required for pumping the water. The human effort plays a major role in sucking the water from the depth (lower heads) to the higher heads. Due to the effort required, these pumps are not long-term usable for the normal person, aged and disabled people are unable to operate them, and an increase in fatigue is usually experienced. Additionally, because of its low capacity, the water demand is not satisfied, especially when demand is strong, which causes long lines to form at the pump location [1].

The quick return mechanism was found to be more effective and dependable in the study done by Wen-Hsiang and Chia-Heng [6], conserve energy, and enhance the capacity of the reciprocating pump by at least 42.7% to service a huge population in record time. Additionally, it will remove operator fatigue from pumping water, need simpler, more reliable maintenance, and reduce the energy (effort) needed to pump water by at least 19%.

In order to create water pumping capabilities that can be used in place of electrical pumps, water pumping mechanisms utilizing windmills have been devised [7, 8]. In most cases, the cost of installing a new windmill is comparable to that of a solar-powered system for pumps. However, these are typically more reliable and require less maintenance [9].

In the present study, a solar-powered quick return mechanism was developed to aid the pump in rural areas. This would in no small measure ease the stress of getting water and making it available. The following is the paper's outline: The first section covers the introduction; the second section discusses methods; and the third section discusses the outcomes. Conclusion and a suggestion are presented in the final part.

Fig.1: Image of an India Mark II hand pump [3]

II. METHODOLOGY

This section provides an in-depth explanation of how the system was developed interms of system design, materials selection, fabrication and assembling.

2.1 SystemDesign

System design involved the design of various components required, as well as modules that are connected to one another, interfaces and mathematical explanations. All of these elements are necessary for the system to meet the required goals of a functionaltechnology.

2.2.1 Software Design

Autodesk inventor CAD software was utilized to verify the relative functioning of the interconnections prior to the actual implementation of the system using hardware components.Figure 2(a) shows the hand pump design snippet fromAutodesk Inventor.The designed solar powered slider crank hand pump is also shown in figure 2 (b) while the exploded design of the solar-powered slider crank mechanism design pump is shown in Figure 2 (c):

Fig.2 (a): Hand Pump Design Snippet

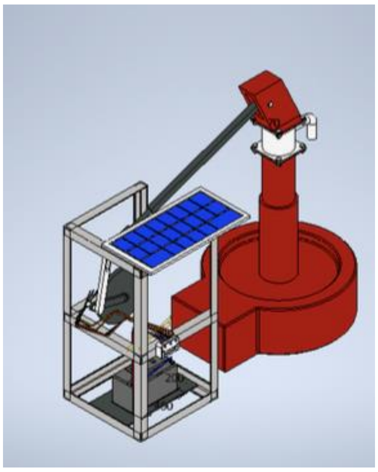

Fig.2 (b): Solar Powered Slider Crank Hand Pump Design

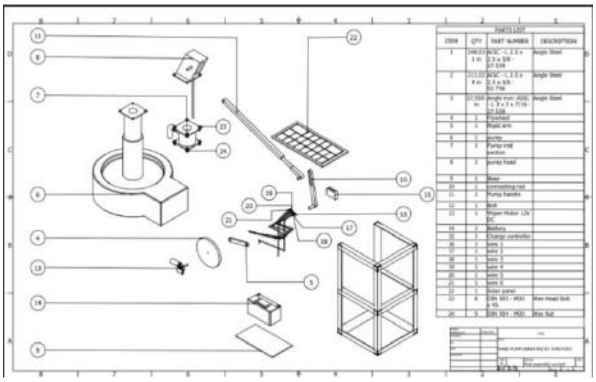

Fig.2 (c): Autodesk exploded design of the solar-powered slider crank mechanism design

2.2.2 Hardware System Design

Hardware design makes use of physical components that may be described by their form, size, and feel. The term "machinery" or "equipment" is often referred to as hardware of a system. Components of the system's hardware are selected with great care to ensure that they meet the requirements of the system's overall design and maximize its effectiveness. The selected components for Solar Powered Slider Crank Hand Pump include:

I. **Solar Panel:** A 26Volts (V) with a rated power of 85 Watts (W) solar panel shown in Plate 1 was acquired for the powering of the DC motor as well as charging of the battery. The array of the solar panel was utilized to harvest the sun energy required in powering the whole system setup after the energy conversion. The selected panels have higher resistant to wear and tear.Solar panels usually wear out slowly.

Plate 1: Solar Panel

II. **Steel Pipe:** A cylindrical hollow steel pipe of 28mm diameterand 150 mm length (Plate 2) was incorporated to firmly hold the lever of the hand pump during operation, through the holes drilled 50 mm from both ends on a centre lathe. The steel pipe utilized has high strength, good weldability and high resistance to cracking.

Plate 2: Steel Pipe

III. **Fasteners:** Bolts and nuts (Plate 3) were used to hold the connecting rod and rigid arm firmly, as well as connecting the crank on the motor to the rigid arm.

Plate 3: Bolt Nuts –Fasteners

IV. **Charge Controller:** A solar charge controller shown in Plate 4 controls the voltage and current on the solar panel to the battery. This keeps the battery from getting too charged. The solar panel was connected to the first 2 ports of the charger controller using a solar panel cable, the battery was connected to the next 2ports while the motor was connected to the last 2 ports using normal cables. It was used to control the charging process by indicating whether the battery was fully charged, halfway charged, or discharged. It was also utilized for powering the DC motor.

Plate 4: Charge Controller

V. **Low-Speed Motor (Wiper Motor):** Synchronous low-speed motor (Plate 5) provides speed control that is very exact, spinning at low speeds, and rapid rotation in both directions.The motor operates a connection that oscillates the crank and rigid arm.

Plate 5: Wiper motor

VI. **12V Lithium Rechargeable Battery:** A solar battery (Plate 6) is an addition to solar power system that stores the extra electricity generated by your solar panels. When there is no solar energy harvesting, the power stored in the battery is utilized. The system is powered by stored energy.

Plate 6: Lithium Battery

2.3 Mode of Operation

The mode of operation is shown in figure 2. The solar panel absorbs solar energy and transmits it to the charge controller. The controller supplied the motor with the necessary power to start cranking the slider mechanism while simultaneously charging the battery. The mechanism needed to drive the handle of the water pump for water delivery then transformed the rotating motion of the crank into the reciprocating action of the connecting rod.

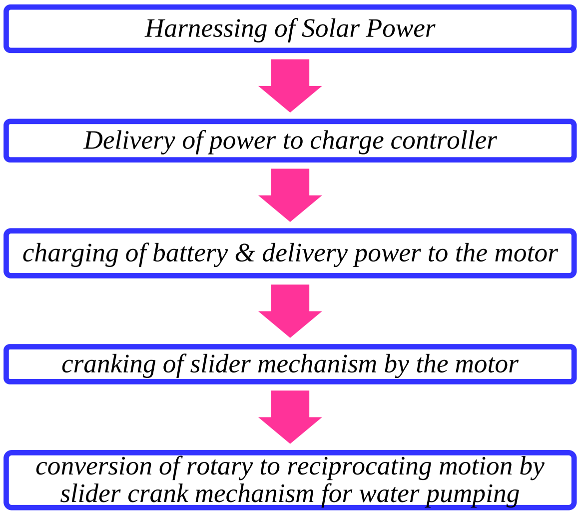

Fig.3: Mode of operation

2.4 Design and Fabrication Analysis

2.4.1 Slider CrankSystem Mechanism

It is essential that any slider crank mechanism have the correct design in order to produce the desired level of output force for the given level of input force. Figure 4 is the kinematic arrangement utilized in the present work. Calculating the stroke and length of the crank arm, as well as the connection between the two, is consequently necessary for many research works using a slider crank in order to satisfy a certain capacity. The following design calculations were considered:

A. **Radius of crank:** Calculating for radius of crank

The diameter of the crank (Figure 4) is

$$D = mn/\pi \ (mm)$$

$$Crankradius, R = mn/2\pi \ (mm) \qquad (1)$$

Where, distance between TDC and BDC is mm

B. **Velocity of the piston:** Three (3) readings were taken to determine the mean velocity of the piston for an average person, and this was obtained using the relation:

$$v_{ave} = \sum_{n=1}^{n=3} \frac{n}{t} rev/sec \qquad (2)$$

Thus, in one minute,

$$v_{ave} = N = \left(\sum_{n=1}^{n=3} \frac{n}{t}\right) \times 60rpm$$

Thus, Average velocity of the crank disc, $\boldsymbol{\omega} = \frac{2\pi N}{60} rad/sec$ (3)

Where N = No of revolutions per min.

C. Torque and input power: The Torque, T as well as the power,P required to drive the mechanism shown in figure5were obtained from;

Torque, $T = Fx$ (4)

Where, F = Effort needed to drive the mechanism.

x = length of the hand pump lever

Thus, the power required to drive the mechanism, $P = T\omega$ (5)

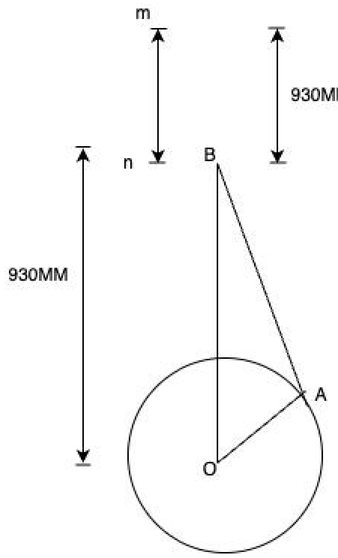

Fig.4: Kinematic Arrangement

Note: *OA is the Crank radius, AB is the connecting rod, m is the TDC, and n is the BDC*

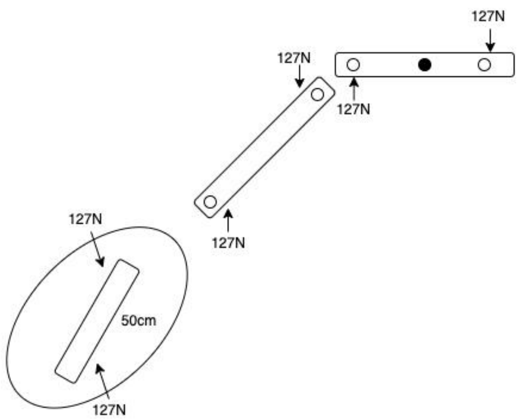

Figure 5: Driven mechanism

D. Length of the connection rod (C): The length of the connection rod, C was calculated (figure 6) as

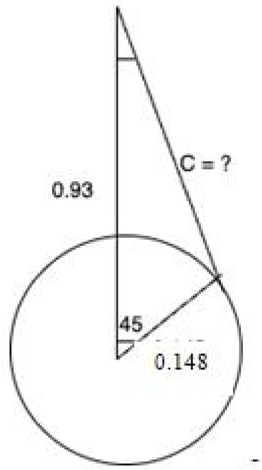

Fig.6: Determination of the length of connecting rod

$$C^2 = a^2 + b^2 - 2abcos\emptyset \qquad (6)$$

Table 1: Parametric specifications

S/N	Parameters		Value	Unit
1	*R*	Crank radius	148	*Mm*
2	*N*	No. of revolutions per minute	113	*Rpm*
3	*ω*	Angular speed of the piston	11.83	$rad.s^{-1}$
4	*F*	Effort required	127	*N*
5	*T*	Torque	18.99	*N.m*
6	*P*	Input power	222.28	*W*
7	*C*	length of the connection rod	0.86	*m*
8	*Ө*	Crank angle	45	*Deg*

The parameters considered in the design as well as their values are as presented in Table 1.

2.4.2 Fabrication and installation of the solar power hand pump

Metal fabrication is the process of putting together, bending, and cutting metal to create structures. It is a process that adds value to raw materials by making machines, components, and buildings. Cutting, drilling, grinding, welding, and installation of the control system in a packing box are all fabrication procedures. The frame houses control system box and the electric motor. The frame also houses the complete linking mechanism.The parts of the slider crank mechanism such as connecting rod, rigid arm and flywheel, were measured and cut. The slot for the hand pump was drilled towards the end of one side of the connecting rod using the specified specifications and holes were drilled at the centre of the flywheel at the edges of the flywheel radius and the other side of the connecting rod.The frame for the slider crank mechanism was built using angle iron. A motor was connected to the crank on the shorter side of the frame with bolts and nuts. The drilled hole on the connecting rod was placed on the other drilled hole on the rigid arm and then bolted with a washer in between (plate 7).The solar panel was then connected to the charge controller and from the charge controller to the battery and also the motor before integrated to the lever of the community hand pump. Figure 8 shows the solar powered slider crank mechanism assesmbly before it was taken to the field for testing. Figure 9 shows the integration of the solar powered slider crank mechanism into the community hand pump.

Plate 7: Different views of the fabricated solar-powered slider crank hand pump system

Plate 8: Solar-powered slider crank mechanism assembly before field test

Plate 9: Solar-powered slider crank mechanism assembly during field test

Table 2: Bill of Engineering Measurement and Evaluation (BEME) for the solar powered slider crank mechanism for hand pump

S/N	Part Name	Description	Qty	**Amount** (₦)
1	Connecting Rod	Steel [Flat Bar]	2	4,000.00
2	Crank Disk	Steel plate	Off cut	5,000. .00
3	Angle Iron		1	5,000.00
4	Bolt and Nut		10pcs	10,000.00
5	Cutting Stone	Abrassive	1	1,500.00
6	Electrode		1	2,500.00
7	Motor	Wiper type	1	8,000.00
8	Paint	1 gallon	1	3,000.00
9	Solar Panel	85 W	1	70,000.00
10	Battery	12 V	1	70,000.00
11	Charge Controller		1	25,000.00
	TOTAL			**199,000.00**

2.4.4 Performance Evaluation Parameters

A. Theoretical discharge (Q) of the pump: This depends on the stroke (l_s), number of revolutions per minutes (N), diameter of the piston (*Dp*) and the volumetric efficiency, η_{vol} [1] and was computed using the continuity equation stated in eqn. (7) $$Q_{th} = A_p \times v \quad (7)$$

Where, A_p is the piston area; $A_p = \frac{\pi}{4} D_p{}^2$ (m^2)

V is the crank speed of the mechanism (m/s); $v = 60Nl_s$

D is the diameter of the piston (m)

N is the crank speed in rpm

l_s is the length of stroke (m)

B. **Volumetric efficiency(η_{vol}):** This isthe percentage of actual to theoretical discharge [10]. This was computed using Eqn. (8).

$$\eta_{vol} = \frac{Q_{act}}{Q_{th}} \times 100\% \quad (8)$$

C. **Pump efficiency (η_{pump}):** This is the percentage of actual output volume to the actual input volume of the water. This was computed using Eqn. (9).

$$\eta_{pump} = \frac{O_{v,act}}{I_{v,act}} \times 100\% \quad (9)$$

Where, $I_{v,act}$ is the volume of water discharged per unit period of test; $I_{v,act} = \frac{\pi}{4} D^2 (x_i - x_f)$ (10)

D = diameter of the well (m)

x_i= initial level of water in the well before pumping

x_2= final level of water in the well after pumping

$O_{v,act}$ is the volume of water collected per unit period of test; $O_{v,act} = \frac{\pi}{4} d^2 z$

z= depth of water in the collector (container) in meters

d= diameter of the collector (container) in meters

III. RESULTS AND DISCUSSION

3.1 Pump testing and evaluation procedure

The pump was initially tested manually and operated by an average sized operator at a certain suction head under normal conditions of operation.This was done to obtain the actual and theoretical discharge, volumetric and pump efficiencies. The manual testing was undertaken by eight (8) different operators by body weights.

3.1.1 Manual Pumping Result

Figure7shows that the actual discharge of the pump increase as the weight of operator increases when the hand pump was operated manually under several attempts, that is, without the integration of the developed solar slider-crank mechanism to the hand pump. Manual testing serves as the basis of comparison against the newly developed solar slider-crank mechanism.

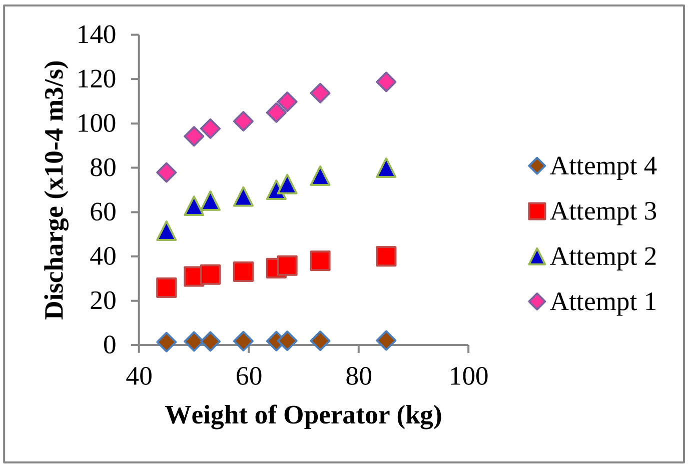

Fig.7: Discharge against weight of operator

3.1.2 Solar powered slider crank mechanism operated pump result

Figure 8 shows that the actual discharge of the pump increase as theinput power of the solar powered slider crank mechanism operated pump increases under several attempts. In addition, the actual flow rate decreases as the number of attempts increases which is an indication that the power require for operating the mechanism reduces after several attempts and thus affect the actual discharge of the pump.

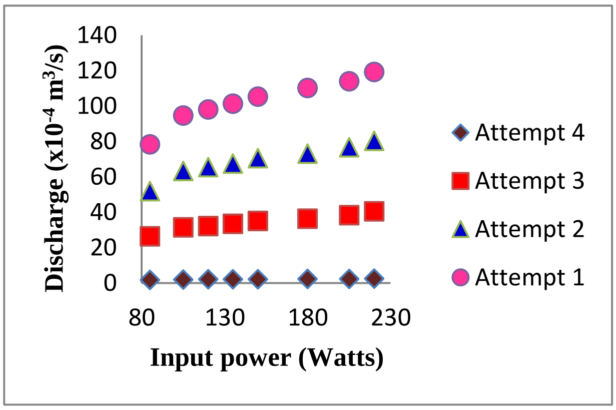

Fig.8: Discharge against input power of the solar powered slider crank mechanism operated pump

3.2 Comparison of Manual Pumping and Aided pumping (with the developed slider-crank mechanism)

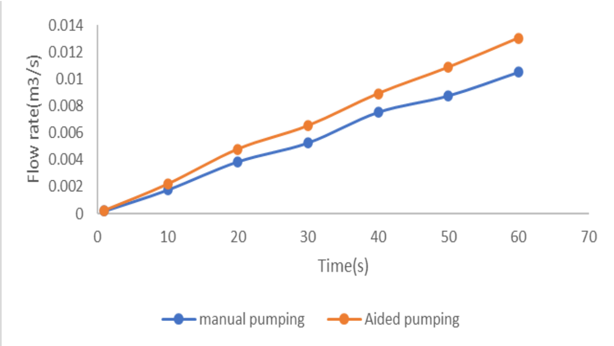

Fig.9: Comparison chart of Time against flow rate between manual and aided pumping

Figure 9 shows the comparison between manual pumping and slider-crank aided pumping. The results clearly show an increase in flow rate when the developed slider-crank mechanism was employed to aid the pumping of water. For instance, at 10 seconds, the average flow rate of manual pump was 0.00175 m^3/s while that of the aided pump was 0.00217 m^3/s. Also, at 60 seconds, average flow rate in manual pumping was 0.0105 m^3/s while 0.01302 m^3/s was obtained when the developed system was employed for the pumping of water.Generally, the developed solar-powered slider crank mechanism increased the flow rate as well as eliminated the stress of hand pumping.

Table 3 shows the performance evaluation results obtained when the slider-crank mechanism was incorporated into the pump.

Table 3: Parametric specifications

S/N	Parameters		Value	Unit
1	Q_{th}	Theoretical discharge	0.01693	m^3/s
2	Q_{act}	actual discharge	0.01302	m^3/s
3	η_{vol}	Volumetric efficiency	76.905	%
4	η_{pump}	Pump efficiency	73.26	%

IV. CONCLUSION

The creation of a slider-crank mechanism powered by solar energy for hand pumps in rural areas has been achieved successfully. The goal of the current design is to lower the amount of effort needed to pump water using conventional lever lift mechanisms to the absolute minimum. A meticulous design process was carried out to precisely determine the machine's dimensions and operational state. Finally, a prototype was created and tested on the field to confirm the pump's viability and accuracy. The experimental result with flow rate of 0.000217 m^3/s and 0.000175 m^3/s obtained when aided with solar powered mechanism and when operated manually, respectively demonstrates how the suggested mechanism can be used to enhance capacity, decrease input effort, and minimize electricity costs. The solar powered slider-crank aided water pumping system is about 24% better in terms of performance compared to the conventional manually operated hand pump.

However, the following recommendations were made from this research:

i. The system design can be improved on to make it suitable for several scenarios of usage.
ii. The prototype development can be improved and produced in a larger case to reduce unit production cost.

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