Treadle Pump Operation with Rotary Motion

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1 Introduction

Hand pumps are in use since many years for pumping water from the ground. It consists of a cylinder fitted with a piston and a pushing mechanism for the up and down motion of the piston. A pipe connects the pump to the water source. At the end of the pipe, a non-return valve is fitted that allows water to enter the pipe and stops it from flowing back into the source. When the piston is pushed down, the water is pushed through a small valve in the piston to fill up space above it. When the piston is raised again the water comes out from cylinder to irrigation channel. The downward stroke of the piston once again pushes water through the small valve into space above the piston and the process is repeated. This is a very simple principle used for centuries for lifting water from streams and wells. The amount that can be lifted in this way is usually small, however, because pumps that use this idea are hand operated and the effort required to lift water is considerable [1–3].

To overcome the above-mentioned problems with the pump, hand operated driving mechanism is replaced by the foot operated mechanism. In this improved mechanism, power input is given through treadles. The advantage of this mechanism is that input can be given by comparatively stronger foot muscles. By providing treadles not only effort is minimized but also one can operate this for a longer period. A frugal model of treadle pump is shown in Fig. 1. Based on the principal of operation mentioned above a model has been developed under RuTAG (Rural Technology Action Group) IIT Delhi with certain modification.

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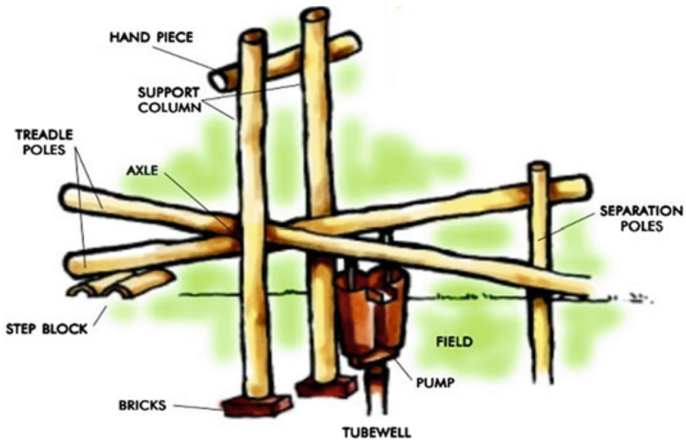

Fig. 1 Existing treadle pump model (*Source* water and sanitation program, write media)

The idea of treadle pump has been skilfully adapted to this model for use in irrigation, where much greater volumes of water are needed. In this treadle pump, two cylinders are used. Each piston moving in the cylinder is connected to a treadle. The operator stands on the treadles and presses them up and down, and treadles follow a reciprocating motion. All parts used in this model are standard hand pump and pumping parts available in the market. Parts are made detachable so that they can be replaced as per the need. With the current modification now the operation is much smooth than previous models (Fig. 2).

Though providing the driving force for feet and leg made the operation easier, but yet it is not a fully optimized solution. This motivated us to look for an improved design for the following reasons—

1. Providing continuous power even by reciprocating motion through treadles is a tough task.
2. Use of renewable energy resources such as wind/solar in rural areas.
3. To enhance the capacity to lift water from a higher depth and higher overall discharge.
4. Capability to have discharge as continuous.

These points show that there is need to develop a hybrid model which can be operated either by foot or by solar input. Based on these initial observations a 3D model has been developed in Solid Works to convert reciprocating motion into rotary motion (Fig. 3).

A detailed literature survey was done to understand the issues. Fraenkel [1] observed that a reasonably fit, well fed human being between 20 and 40 years old could produce a steady power output of around 75 W for long periods. He summarizes his findings and observations by calculating the discharge and head for an input power of 75 W at 50% efficiency as shown in Table 1.

Fig. 2 Treadle pump (*Source* RuTAG IIT, Delhi)

Orr et al. [2] indicated that output from a pump depends on a variety of factors, including a suction lift, cylinder diameter, variations in internal friction, occasional air leaks in the installation, hard filters, skills and care of the installation team and the weight and ability of the operator. By their key findings, they have proposed a relationship between suction lift, cylinder diameter, and discharge which is listed in Table 2.

On the basis of their research IDE (International Development Enterprises) has given some pump design feature which is presented in Table 3.

As given in IDE data a typical diameter for the cylinder of the pump is observed to be 100 mm. There are two strokes which are to be considered while designing treadle pump the foot stroke length and the piston stroke length. The foot stroke length is the vertical distance between the feet when one foot is raised, and the other is at its lowest point. If the stroke is too short, the leg muscles tire quickly; if it is too long, the leg muscles are strained. An optimized stroke length can be approximated distance between two bicycle paddles which are around 340 mm.

We cannot keep our piston stroke length equal to bicycle stroke length because it will need more power and will slow the operation. If a choice is given, an operator would usually choose a short stroke length for high heads so that input power can

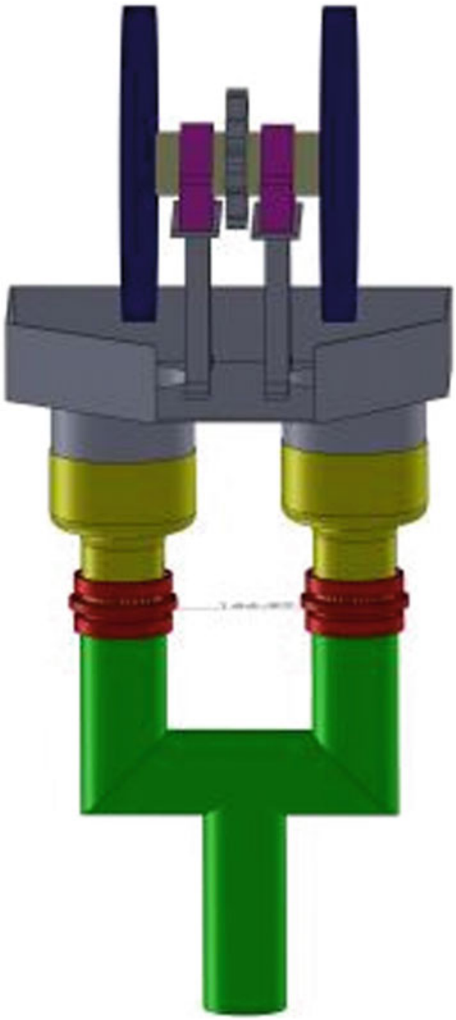

Fig. 3 A 3D CAD model of improved Treadle Pump

Table 1 Relationship between discharge and head [1]

Head (m)	0.5	1	2.5	5
Discharge (l/s)	7.6	3.8	1.52	0.6

Table 2 Relation between suction lift, discharge and cylinder diameter [2, 4]

Pump cylinder diameter (mm)	76	89	120	152	178
Suction lift (m)	7–8.5	5–7	2.5–5.5	2–2.5	0.5–2
Sustainable discharge (l/s)	1	2	3	4	5
Volume per stroke (l)	1.2–5	1.7	3	5	7

Table 3 Pump design features

Piston diameter (mm)	75–150
Foot stroke length (mm)	100–350
Cadence	About 60 rpm
Foot force	15–50 kgf (150–500 N)
Mechanical advantage	from 0.5 to 4
Treadle spacing (mm)	175–200

Source IDE South Africa

be reduced and a longer stroke for low heads where we need to put comparatively lower effort. As the foot stroke length of the operator is limited to approximately 350 mm, one-third of it is approximated as a suitable piston stroke length. It is found that a cadence up to 60 cycles per minute is comfortable for operation. To make pump suitable for men, women and children foot force limit should be 150–500 N according to their average weight. Suggested mechanical advantage ranges between 0.5 and 4. But to get a higher mechanical advantage one will have to cross the practical upper limit. This might lead to the overturning of the pump. Treadle spacing is the spacing between two treadles which is again approximated with the spacing between two paddles in bicycle and ranges from 175 to 200 mm which is matching with IDE data provided. Theoretically, treadle pump can lift water by suction up to 10.3 m, but in practice, a reasonable limit is 7 m considering all possible losses.

Our assumptions on the basis of literature review

- Head = 5 m
- Average Force = 250 N
- Diameter of piston = 100 mm
- Piston stroke length = 100 mm
- Foot stroke length = 340 mm
- Sprocket = 19.2 mm
- Rpm provided = 40
- Treadle spacing = 180 mm

Calculations

$$
\begin{aligned}
P &= \omega \times T \text{ (Power supplied)} \\
\text{Power supplied} &= \text{ power required} \\
\omega \times T &= \Phi g Q h \\
Q &= (\omega \times T \div \rho g h)\, m^3/s \\
&= 75 \div (1000 \times 9.81 \times 5) \\
&= 0.001529 \\
&= 1.5290\, l/s
\end{aligned}
$$

Here symbols have their usual meanings. Discharge calculated is theoretical discharge considering 5 m as head and 75-W power as an average power that can be easily produced manually for a longer period. Through our present model, we are getting an approximate discharge of 0.6 l/s.

Use of this pump will affect the rural areas in various ways. Some important effect that can be observed by using this pump can be listed as—

1. Land area under irrigation will increase
2. Easier than bucket irrigation and time-saving
3. Proper irrigation will improve productivity and quality
4. Reduce the level of pollution (Fig. 4).

Places, where this pump can be used, are—

1. Water level up to 7 m
2. Small level irrigation fields where water can be provided with manual work
3. Vegetables and flower forming
4. Small and marginal level crop production
5. Where discharge of around 1 l/s is sufficient

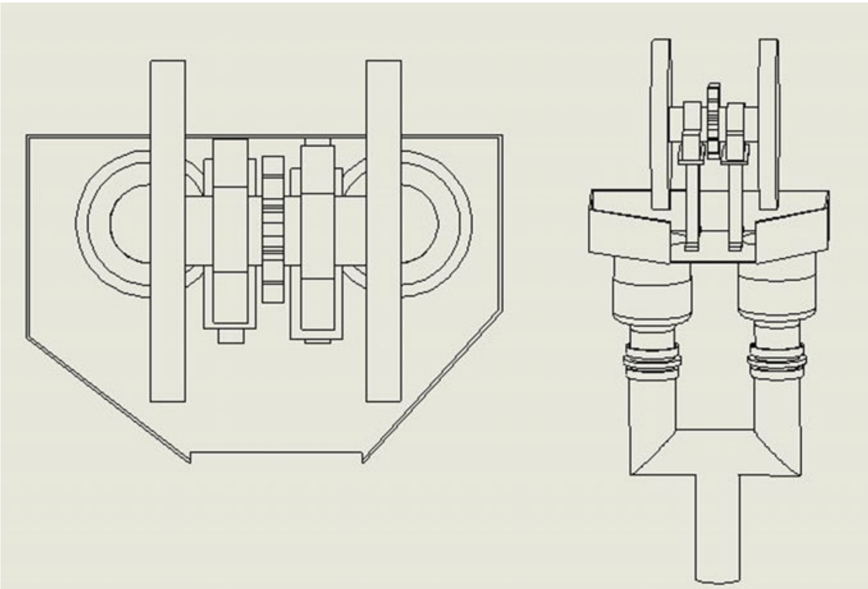

Fig. 4 Top (*left*) and Isometric (*right*) view of modified Treadle Pump

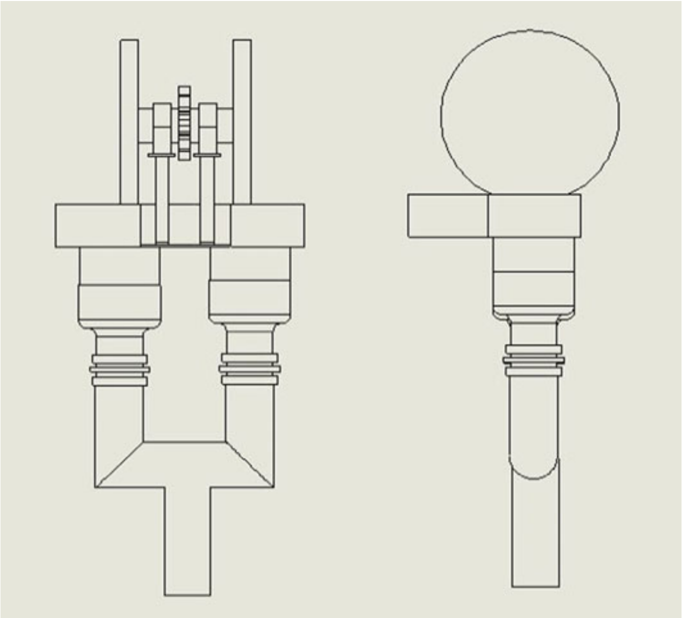

Fig. 5 Front and Side view of modified Treadle Pump

A modified treadle pump with rotary motion was at display in IIT Delhi at the Open House (Fig. 5). An additional sprocket has been provided for connection with battery/solar power driven motor depending on the availability (Fig. 6).

Suggestions for future work

1. We have made arrangement for solar operated model too but it is yet not tested with our model.
2. The present volumetric efficiency is around 40%. This needs to be enhanced.
3. Adjustable seat can be redesigned or improved by considering all aspects of ergonomics.
4. Effort to make the flow continuous is needed.
5. Overall cost of the project is 7000 Rs, which can be further reduced to make it available for all.

Fig. 6 Display in Open House 2016, at IIT Delhi

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