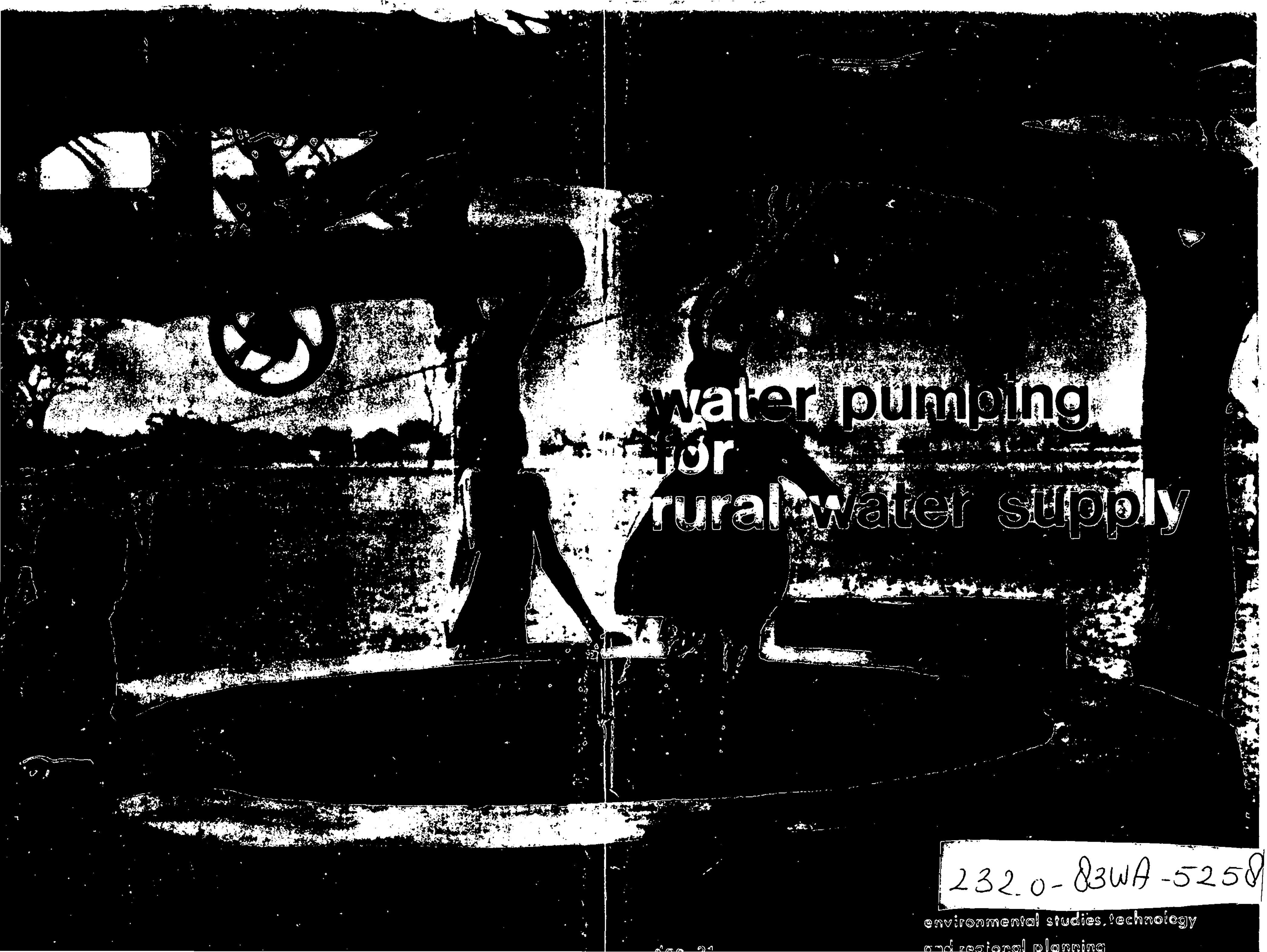

water pumping for rural water supply

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  - eco-development and the region ;
  - infra-urban environment and socio-spatial disparities
  - petty producers and combined technologies.

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  - **« African Environment - environmental studies and regional planning bulletin »** : quarterly bulletin and supplements in the form of **occasional papers** (see over).
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water pumping for rural water supply

by E.H. HOFKES

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WATER PUMPING FOR RURAL WATER SUPPLY

by E.H. HOFKES

1. INTRODUCTION

A great variety of devices exist for pumping water ; indeed, our first ancestor who cupped his hand and fetched water from a stream chose the best water lifting technology available to him. Water pumping technology provides a rich and varied spectrum of techniques and innovations.

History shows that water pumping technology developed parallel to the available power supplies. Centrifugal, axial and turbine pumps have reached a high state of development, and are used widely in industrial countries, *only* because suitable power sources such as diesel engines and electrical motors became available.

For water pumping in rural areas of developing countries, human and animal power often are the most readily available sources of energy. In those areas, manual pumping is the mode of water lifting most widely used(1). Under suitable conditions wind power is of relevance. Solar energy can have potential for pumping water. Diesel and petrol engines, and electric motors should only be used, if the necessary fuel or electricity supply is secured, together with an adequate supply of spare parts and proper maintenance.

Innumerable water pumping devices have been built over the centuries. Those that had merit survived, others perished.

Whilst the technology of water pumping is important, the successful design and use of water pumps depends to a large extent on non-technical factors. The involvement of the users in maintaining their pumping units, and the possibilities of manufacturing the pumps locally are examples.

2. POWER SOURCES FOR WATER PUMPING

Human Power

Using human power for pumping water has certain features that are important under the conditions of small and rural communities in developing countries :

i) the human energy requirements for pumping can be provided from within the user's group in a rural village, or even at the smallest farm : the costs of other energy sources continue to rise sharply, electricity is often not available, and there is a continuing shortage of fuel particularly in rural areas ; and it is in these areas that labour is typically surplus ;

ii) the capital cost of hand - or foot - operated water pumps is generally low as are the operating costs ;

iii) the discharge capacity of one or a few handpumps is usually adequate to meet the drinking and domestic water needs of a small community. Most handpumps can provide water at a rate of 12-20 litres/minute which would be adequate for communities of up to 100 persons and more.

(1)A manual pumping device, is any simple device powered by human energy for lifting relatively small quantities of water ; this includes devices operated by foot.

Very few measured data of human energy effectively used for work such as water pumping have been obtained under field conditions. The power available from the human muscle depends on the individual, the environment, and the duration of the task. Most pumps used for domestic water supply are operated by many users, each pumping only a few minutes at a time. The power available for work of long duration, for example 8 hours a day, by a healthy man, is often estimated at 60 to 75 watts (0.08 to 0.10 horsepower), but other estimates are also used (1).

This value must be reduced for high temperature, or high humidity of the work environment. Where the pump user and the pump are poorly matched, much of the power input is wasted ; for example, when a person operates a pump from a stooped position.

The human power available during short periods of work is greater than the values mentioned, but in handpump design it is prudent to allow a generous margin for ease and convenience of pumping.

An interesting arrangement using a swing to operate a reciprocating pump, is shown in Fig. 1.

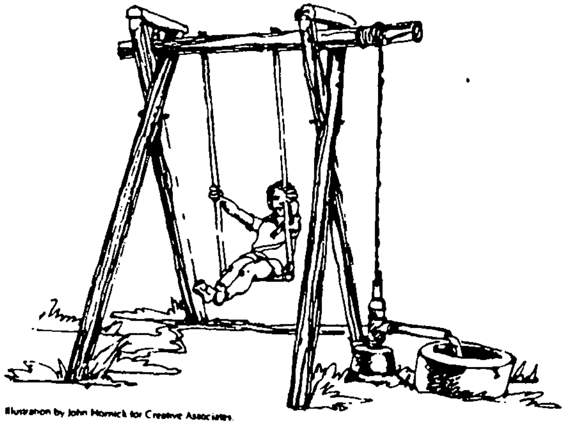


Illustration by John Hornick for Creative Associates.

Fig. 1 Swing-operated Pump.

Animal Power

Draught-animals are a common and vital source of power in many developing countries. Animal power is poorly suited to operate small-diameter pump devices fitted on covered wells or tubewells. Animals are widely used for lifting irrigation water from large-diameter, open wells but these should not be used for community water supply purposes.

The most efficient use of animals is at fixed sites where they pull rotating circular sweeps or push treadmills. Both methods require gears and slow-moving, large-displacement pumps.

(1) For example, in Indonesia a value of 50 watts is employed in energy analysis for handpump design.

When a skin bucket is used with a rope moving over a pully, it is mostly pulled up by draught-animals. This method of water lifting is still being used extensively in many countries, mainly for drawing water from medium-depth, open wells. Normally the bucket is of leather, with a capacity of 10-60 litres.

Windpower

The use of windpower for pumping water should be feasible if :

- winds of a least 2.5 - 3 m/sec. are present 60 % or more of the time ;
- the water source can be pumped continuously without exessive drawdown ;
- storage is provided, typically for at least 3 days' demand, to provide for calm periods without wind ;
- a clear sweep of wind to the windmill is secured, i.e. the windmill is placed above surrounding obstructions, such as trees or buildings within 125 metres ; preferably the windmill should be set on a tower 4.5 to 6 metres high ;
- windmill equipment is available that can operate relatively unattented for long periods of time, for example six months or more. The driving mechanism should be covered and provided with an adequate lubrification system. Vanes, and sail assemblies should be protected against weathering.

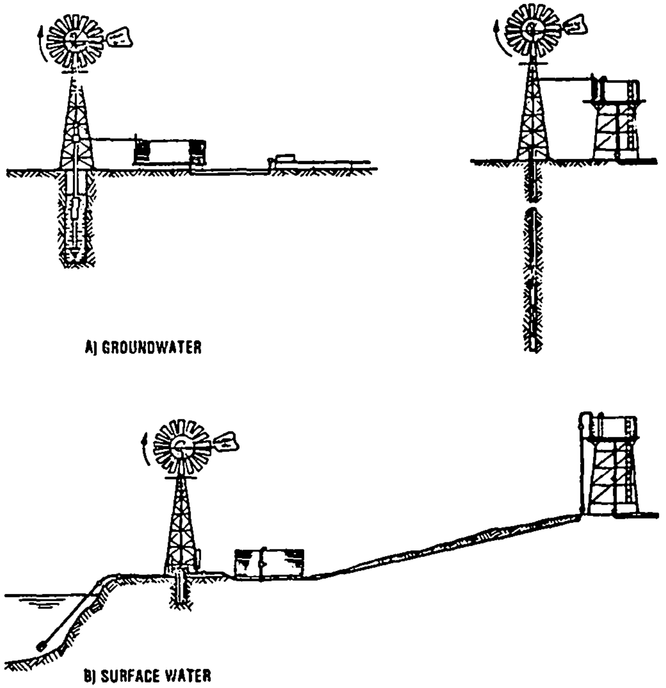


Fig. 2. Windmill - pump water supply systems.

By far the most common type of wind-powered pump, the slow-running wind wheel is driving a piston pump. The pump is generally equipped with a pump rod that is connected to the drive axis of the windmill. Provision may be made for pumping by hand during calm periods.

The wind wheels range in diameter from about 2 to 6 metres. Even though the windmill themselves may have to be imported, strong towers can usually be constructed from local materials.

Modern windmills are designed to ensure that they automatically turn into the wind when pumping. They are also equipped with a "pull-out" system to automatically turn the wheel out of excessive wind, stronger than 13-15 m/sec., which might damage the windmill. The "sails" or fan blades can be so designed that they furl automatically to prevent the wheel from rotating too fast in high winds. The windmill will normally not begin pumping until the wind velocity is about 2.5 - 3 m/sec. Fig. 2 shows several typical arrangements for windmill-pumped water supply systems.

Small windmills with wheels having a diameter of less than 5-8 m. cannot easily utilize the control systems developed for the large windmills.

Electric Motors

Electric motors generally need less maintenance and are more reliable than diesel and petrol engines. They are, therefore, to be preferred as a source of power for pumping if a reliable supply of electric power is available. In such cases, electric motors can be used to drive pumps. The electric motor should be capable of carrying the work load that will be imposed, taking into consideration the various adverse operating conditions under which the pump has to work. If the power requirement of a pump exceeds the safe operating load of the electric motor, the motor may be damaged or burnt out. Attention must also be paid to the characteristic of the motor and the supply voltage.

There is a tendency to use general-purpose motors offered by the manufacturers without giving due consideration to the characteristics of the particular pump used, and this results in frequent failure or burning out of the motor. Squirrel-cage motors are mostly selected for driving centrifugal pumps as they are the simplest electric motors available.

Diesel Engines

Diesel engines have the important advantage that they can operate independently at remote sites. The principal requirement is a supply of gasoil and lubricants and these, once obtained, can be easily transported to almost any place. Diesel engines, because of their capability to run independent of electrical power supplies, are especially suitable for driving isolated pumping units such as raw water intake pumps.

A diesel engine operates through compression of air to a high pressure, in its combustion chambers. As a result of the high compression, the temperature of the air rises to over 1,000°C. When gasoline is injected through nozzles into the chambers, the compressed air-gasoil mixture ignites spontaneously.

Diesel engines may be used to drive reciprocating plunger pumps as well as centrifugal pumps. Gearing or another suitable transmission connects the engine with the pump. For any diesel-driven pump installation, it is generally prudent to select an engine with 25-30 % surplus power to allow for a possible heavier duty than under normal conditions.

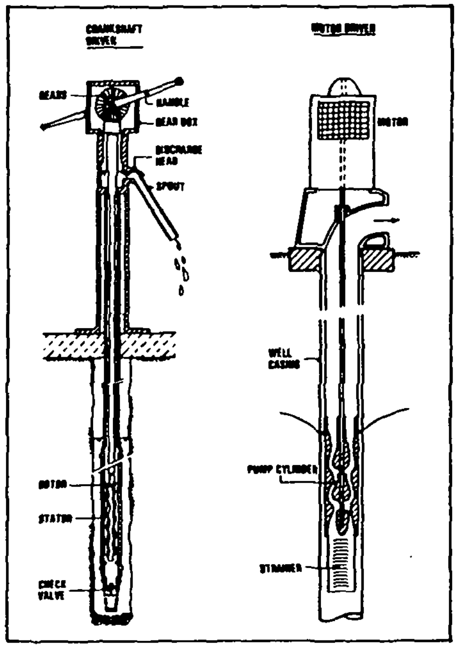


Fig. 3. Pump-drive arrangements.

3. HISTORY

Although many manual pumping devices exist, the type used most frequently for community water supply purposes is the reciprocating (positive displacement) plunger pump(1). This type of pump has an ancient history. A study of literature (Ewbanks, 1971) reveals that a certain Ctesibius invented, around 275 BC, a reciprocating pump. His pump was a twin cylinder lift type, with external valves and without any special seal between the plunger and the cylinder wall.

It was used for fire fighting. Hero (2nd Century BC) and Vitruvius (1st Century BC) were familiar with this pump. Archeological remnants of reciprocating pumps from later Roman times are occasionally found. They were in widespread use in medieval Europe.

(1) *Reciprocating pumps have a plunger (or piston) which moves up and down (reciprocates) in a closed cylinder for positive displacement of water. On the upward stroke the plunger forces water out through an outlet valve, and at the same time water is drawn into the cylinder through an inlet valve. The downward stroke brings the plunger back to its starting position, and a new operating cycle can begin.*

Ewbank (1972) states that a reciprocating pump of wood was used as a ship's pump in the early Greek and Roman navies. The construction of these pumps is uncertain, but they may have been similar to those descibed in old books.

Agricola (English edition, translated from Latin, 1950) clearly shows that the design was used in Saxony in the sixteenth century. At this time, in addition to the colonial leather plunger or bucket, plungers in the form of perforated wood or iron discs were commonly used, the perforations being covered by a disc of leather which acted as a valve.

The foot valve typically was a hinged metal flap and was attached to a metal seating. The pump was usually made to three sections, the middle being the working barrel, while the short bottom section contained the suction valve. These early wooden pumps were of the lifting type, but when made in metal, in order to economise material and the cost of manufacturing the working barrel was usually placed at the top and a narrow suction pipe was used. The suction valve was placed at the bottom of the barrel.

In 17th - century England, reciprocating pumps made of wood or lead and with the plunger packed with leather, were in common use. It was not until about the middle of the nineteenth century that improved transport and communication made it economical to manufacture cast, machine made, metal handpumps for distribution over a wide area.

In the late 19th and early 20th centuries, a tremendous number of different pump models were produced. Perhaps 3000 manufacturers produceds handpumps in the U.S.A. alone. They were primarily used on farms by single families and their livestock. Windmills were in-creasingly used to drive pumps.

All these pumps were designed on the basis of the same operating principles, and they differed little from the traditional models. In the period since Ctesibius (some 2250 years) little was done to improve the manually operated reciprocating pump. In the industrial countries, interest in this type of pump virtually disappeared, when they found less and less use. Over the last few years, it has been recognized that manual pumping units have an important role to play in providing adequate supplies of water for domestic use in rural areas of developping countries. Water supply authorities in these countries and the international organizations and bilateral agencies providing development assistance are how pursuing, the newly developed technology of rural village water pumping, with vigour.

4. TYPES OF PUMPS

The main application of pumps in small water community supply systems are:

- pumping water from wells;
- pumping water from surface water intakes;
- pumping water into storage reservoirs and the distribution system, if any.

Based on the mechanical principles involved, these pumps may be classified as follows:

- reciprocating;
- rotary (positive-displacement);
- axial-flow (propeller);
- centrifugal;
- air lift.

Another type of pump with limited application in water supply systems is the hydraulic ram.

Table 1 gives information on various types of pumps.

Table 1

INFORMATION ON TYPES OF PUMPS

Type of Pump	Usual depth range	Characteristics and Applicability
1. RECIPROCATING (plunger)		low speed of operation; hand, wind or motor powered; efficiency low (range 25 - 60 %)
a. Suction (shallow well)	up to 7 m.	capacity range : 10-50 l/min.; suitable to pump against variable heads; valves and cup seals require maintenance attention
b. Lift (deep well)		
2. ROTARY (positive displacement)		low speed of operation; hand, animal, wind powered;
a. Chain and bucket pump	up to 10 m.	capacity range : 5-30 l/min.; discharge constant under variable heads
b. Helical rotor	25 - 150 m. usually submerged	using gearing; hand, wind or motor powered; good efficiency; best suited to low capacity - high lift pumping
3. AXIAL - FLOW	5 - 10 m.	high capacity - low lift pumping; can pump water containing sand or silt
4. CENTRIFUGAL		high speed of operation - smooth, even discharge; efficiency (range 50-85 %) depends on operating speed and pumping head
a. Single-stage	20 - 35 m.	requires skilled maintenance; not suitable for hand operation : powered by engine or electric motor
b. Multi-stage shaft-driven	25 - 50 m.	as for single stage. Motor accessible, above ground; alignment and lubrication of shaft critical; capacity range 25-10,000 l/min.
c. Multi-stage submersible	30 - 120 m.	as for multi-stage shaft-driven; smoother operation; maintenance difficult; repair to motor or pump requires pulling unit from well; wide range of capacities and heads; subject to rapid wear when sandy water is pumped.
5. AIR LIFT	15 - 50 m.	high capacity at low lift; very low efficiency especially at greater lifts; no moving parts in the well; well casing straightness not critical.

4.1. *Reciprocating Pumps*

The type of pump most frequently used for small water supplies, is the reciprocating (plunger) pump.

Several groups may be distinguished :

- Suction Pumps (Shallow Well)
- Lift Pumps (Deepwell)
- Force Pumps
- Diaphragon Pumps

Suction Pumps (Shallow Well)

In the suction pump, the plunger and its cylinder are located above the water level usually within the pump stand itself (Fig. 4).

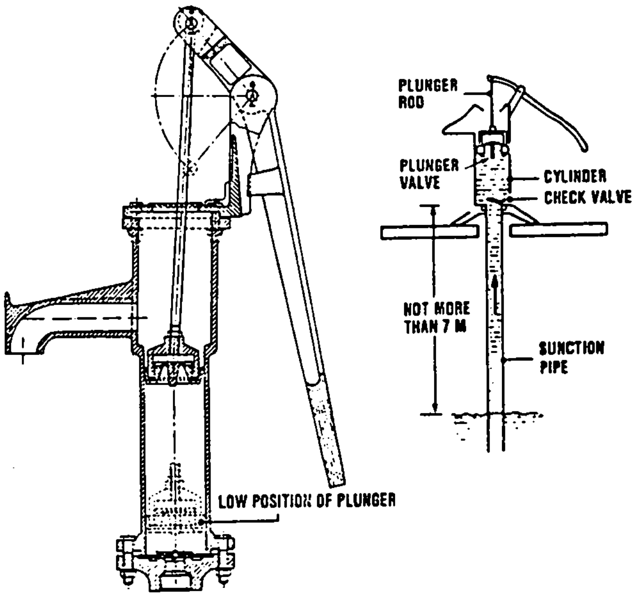


Fig.4. Suction Pump (Shallow Well)

The suction pump relies on atmospheric pressure to push the water upwards to the cylinder. Contrary to popular belief, this type of pump does not "lift" the water up from the source. Instead the pump reduces the atmospheric pressure on the water in the suction pipe and the atmospheric pressure on the water outside the suction pipe then pushes the water up. Because of its reliance on atmospheric pressure, the use of a suction pump is limited to conditions where the water table is within 7 metres of the suction valve during pumping. Theoretically, the atmospheric pressure would allow a suction pump to draw water from as deep as 10 metres, but in practice 7 m is the limit.

Fig. 5, shows a typical shallow well handpump, the "Bandung" pump used in the West-Java Province, in Indonesia.

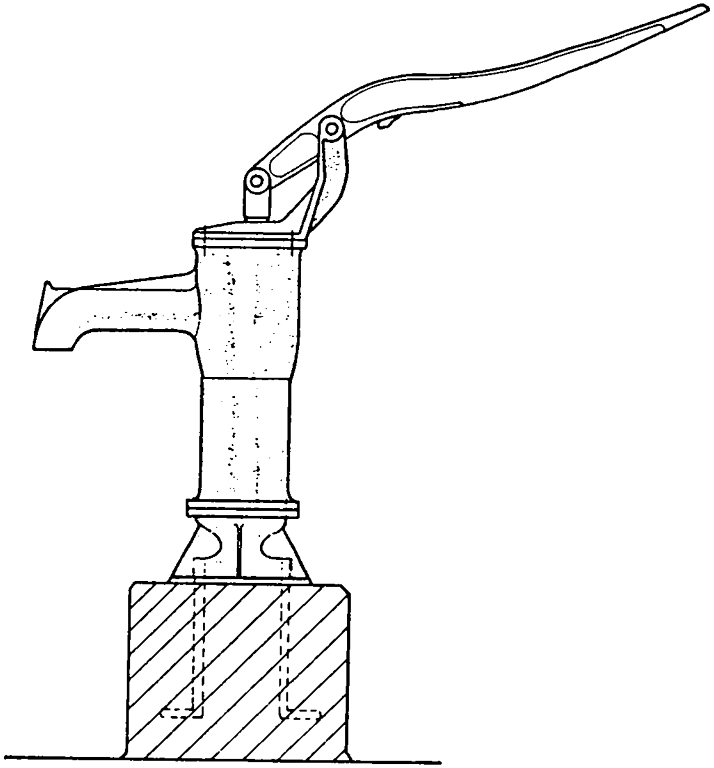
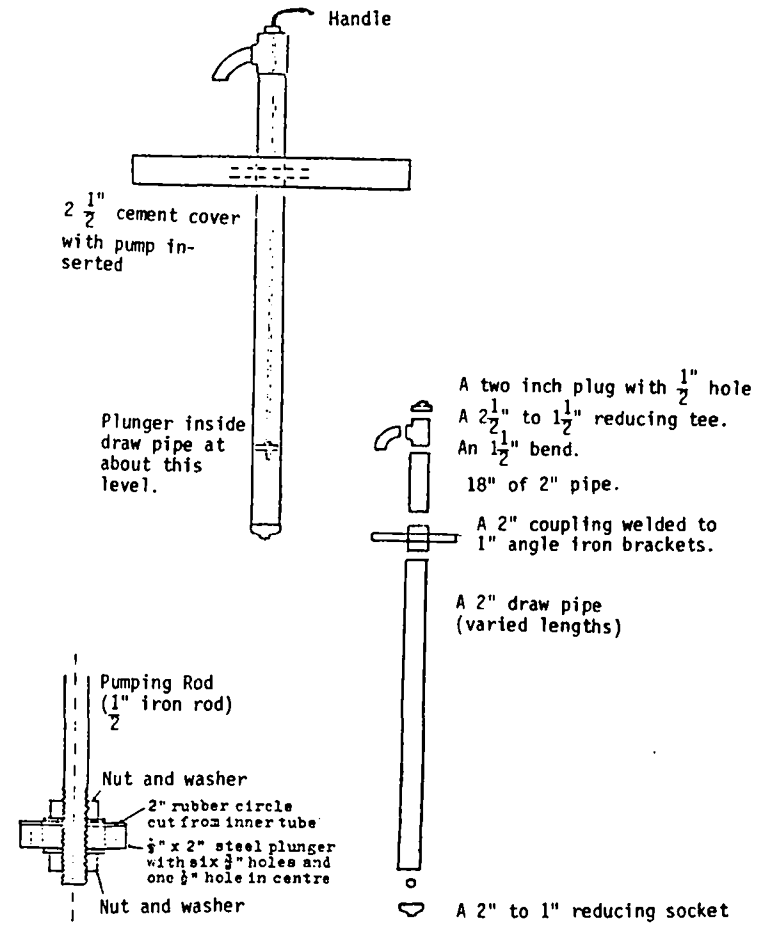


Fig.5. "Bandung" Shallow Well Handpump

A simple pump in which the pump rod is pushed and pulled directly at a handle (with no lever), is shown in Fig. 6,



DETAIL OF PLUNGER ASSEMBLY

Fig.6. Simple handpump operated by handle directly connected to pump rod.

Another example is shown in Fig. 7.

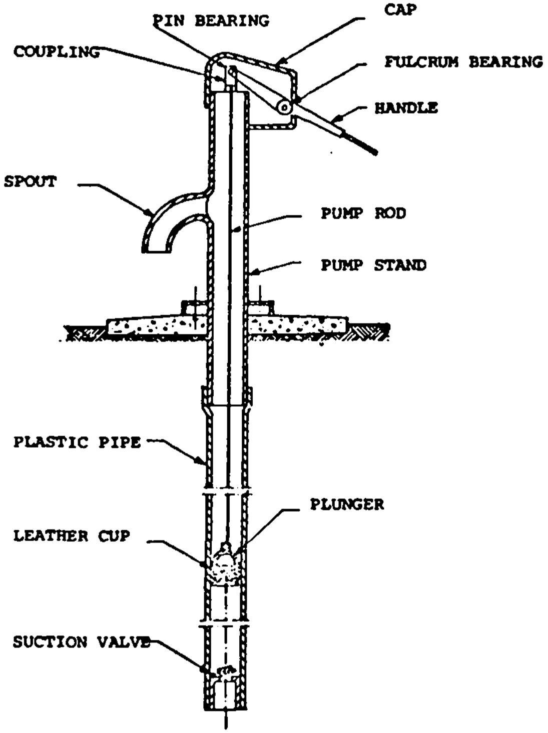


Fig.7. U.S.T. Handpump (Ghana)

The limited requirements of suction pumps in regard to their mechanical loading and hydraulic efficiency allow those pumps to be assembled of locally available materials (Fig. 8) or off-the-shelf commercially available parts (Fig. 9.).

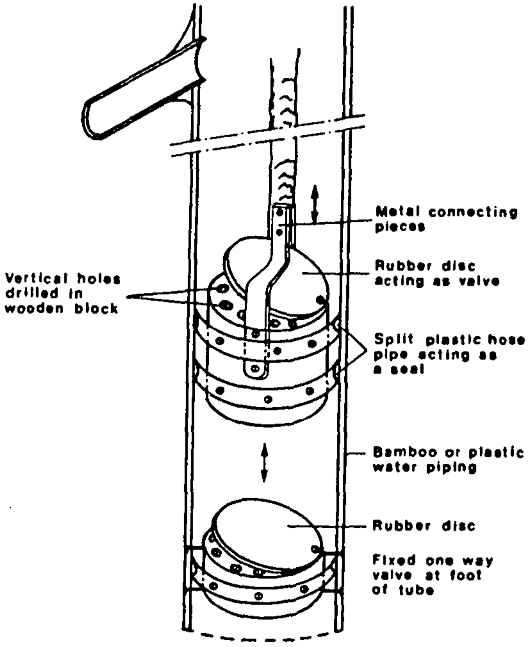


Fig.8. Plunger assembly made of locally available materials (Turkey).

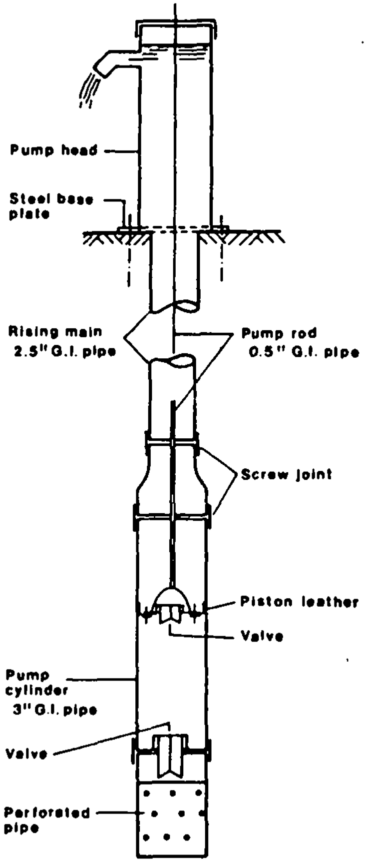


Fig. 9. Handpump made of galvanised iron pipe (Zambia)

Deep or shallow well, in terms of pump selection, refers to the depth of the water level in the well, not the depth to the bottom of the tubewell or the lenght of the casing.

In the deep-well pump, the cylinder and plunger are located below the water level in the well. This pump can lift water from wells as deep as 180 m. or even more. The forces created by the pumping work increase with the depth to the water table, and the problems associated with reaching the cylinder, deep in the well, for maintenance and repair are much more difficult than in shallow well pumps. Thus the design of pumps for deep well use is more critical and complicated than for suction pumps.

An example of a (deep well) lift pump is shown in Fig. 10. Another example is shown in Fig. 11.

The principal characteristic of all (deep well) lift pumps is the location of the cylinder down in the well. The cylinder should preferably be submerged in the water, in order to assure the priming of the pump.

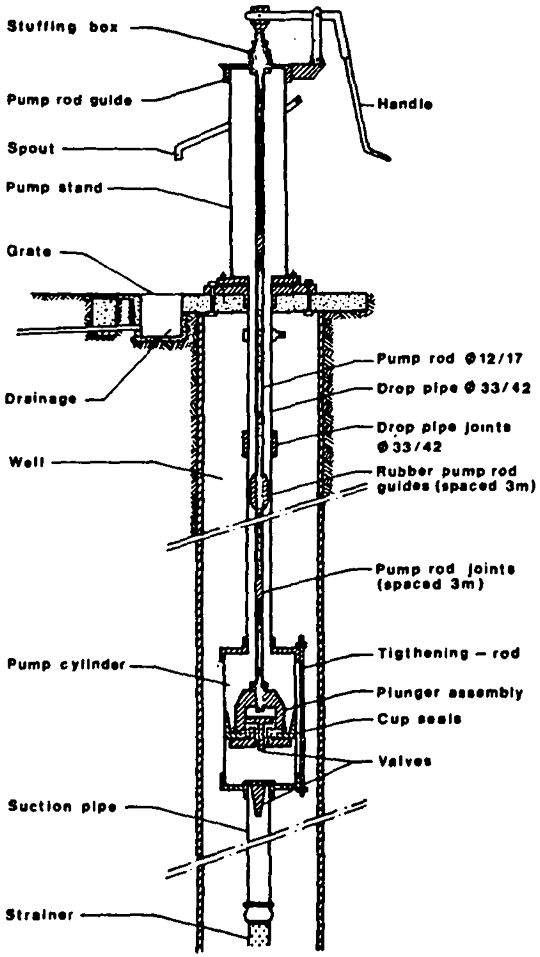


Fig. 10. "Mandritsara Deepwell Handpump (Madagascar).

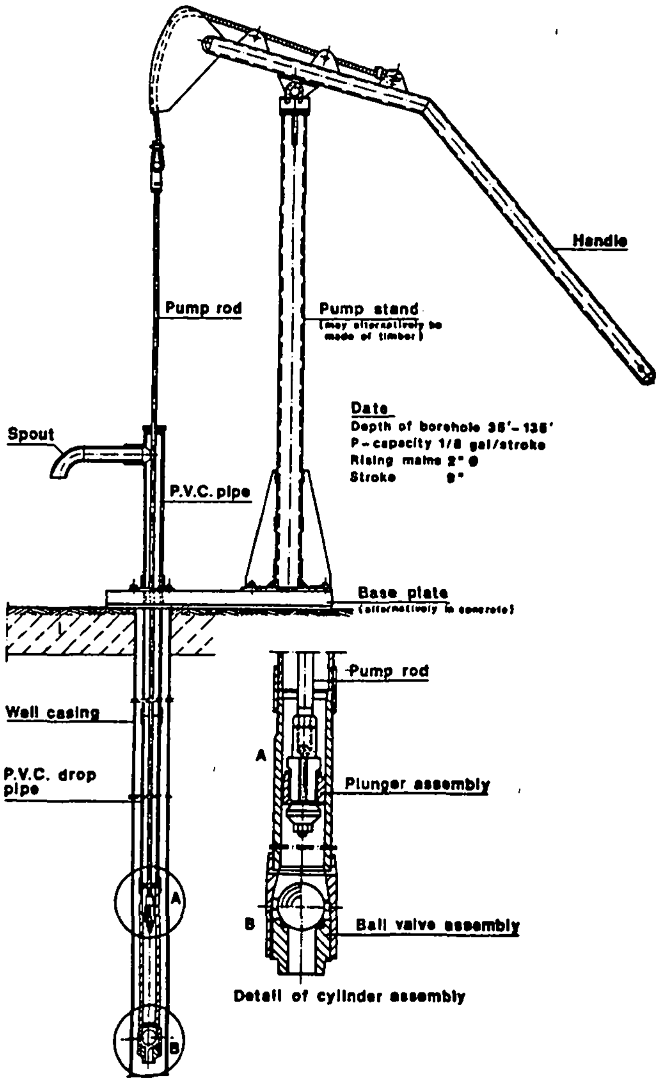
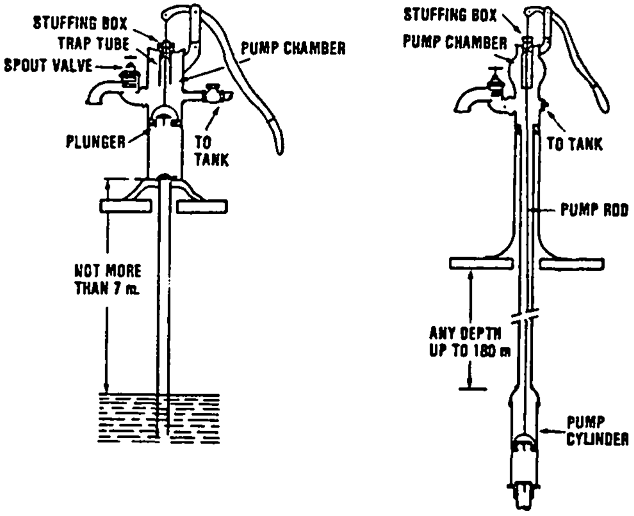


Fig. 11. Deepwell Handpump "Africa"
(Ivory Coast).

Force Pumps

Force pumps are designed to pump water from a source and to deliver it to a higher elevation or against pressure. All pressure-type water systems use force pumps. They are inclosed so, that the water can be forced to flow against pressure. Force pumps are available for use on shallow or deep wells (Fig. 12).



A) FORCE PUMP ON SHALLOW WELL

B) FORCE PUMP ON DEEP WELL

Fig.12. Force Pumps.

A shallow-well force pump is shown in Fig. 12a. Its operating principle is the same as that of the reciprocating plunger pump earlier discussed, except that it is enclosed at the top and, therefore, can be used to force the water to elevations higher than the pump. For this, either a separate connection or a hose or pipe is fitted to the spout.

Force pumps usually have an air chamber to even out the discharge flow. On the upstroke of the plunger, the air in the air chamber is compressed and on the downstroke the air expands to maintain the flow of water while the plunger goes down. The trap tube serves to trap air in the air chamber, preventing it from leaking around the plunger rod.

The operation of a deep well force pump (Fig. 12b) is the same. The principal difference is in the location of the cylinder. With the cylinder down in the well, the pump can lift water from depths greater than 7 m.

Diaphragm Pumps

Diaphragm pumps are positive displacement pumps. The main part of the pump is its diaphragm, a flexible disc made of rubber or metal. Non-return valves are fitted at the inlet and outlet (Fig. 13).

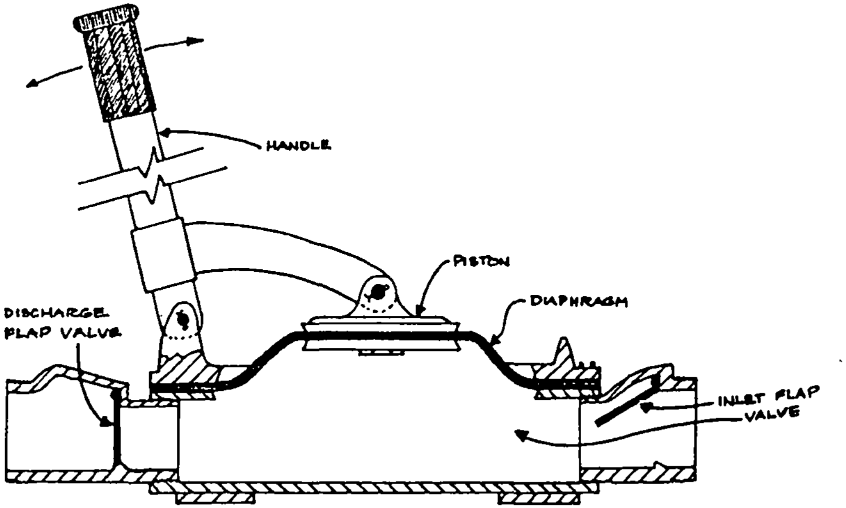


Fig.13. Diaphragm Pump.

The edge of the diaphragm is bolted to the rim of the water chamber but the centre is flexible. A rod fastened to the centre moves it up and down. As the diaphragm is lifted, water is drawn in through the inlet valve, and when it is pushed down, water is forced out through the outlet valve. Pumping speed usually is about 50 - 70 strokes per minute. These pumps are self-priming.

The diaphragm pumping principle is used in a number of novel handpump designs. These pumps are being field tested and developed for use in rural water supplies (e.g. Hydropompe Vergnet ; Petro Pump).

Diaphragm pumps offer several advantages :

- no sliding friction of a plunger seal (cup) rubbing against the pump cylinder wall, as in a reciprocating piston pump ;
- particles as large as the valve openings can be pumped, without damage to the pump ;
- a small capacity pump of this type may be easily manufactured by a local machine shop.

There is also an important disadvantage :

- the diaphragm is unevenly loaded, causing it to wear more quickly around the place where the piston is fixed to it.

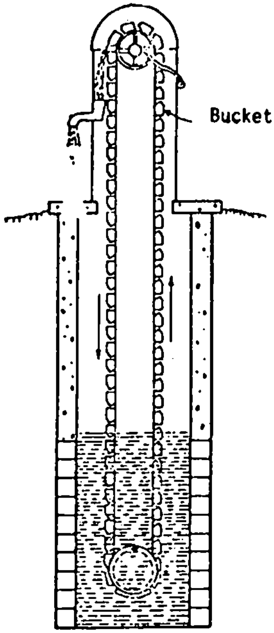
ROTARY (POSITIVE DISPLACEMENT) PUMPS

Bucket Pumps (1)

One type of a positive displacement, hand-operated pump is the bucket pump (Fig. 14).

(1) Not to be confused with the name "bucket pump" sometimes given to reciprocating well pumps, whose plunger seals are sometimes called "bucket".

Fig. 14. Bucket Pump



Small buckets attached to an endless chain are rotated over sprockets as shown, so that each bucket dips water from the source at the bottom, carries it to the top, and empties it into the spout as it passes over the top sprocket. At least one manufacturer makes a pump, using a spong-like belt in stand of the buckets, with a squeegee at the top to remove the lifted water. Another handmade version uses a rope, driven by a bicycle wheel, with a sharp bend at the top to discharge the water by centrifugal force. These pumps are used mostly on cisterns and shallow dug wells.

Chain Pumps

In the chain pump, discs of a suitable material (e.g. rubber) attached to an endless chain running over a sprocket at the top, are pulled upward through a pipe to lift water mechanically up to the spout. This type of pump can only be used on cisterns and shallow dug wells. It can be readily adapted for manufacture by village artisans (Fig. 15). A small chain pump using a pipe of 20 mm diameter, with rubber discs spaced at 1 m intervals, will discharge water at a rate of 5 to 15 l/minute depending on the speed of rotation of the operating wheel (30 to 90 rpm.).

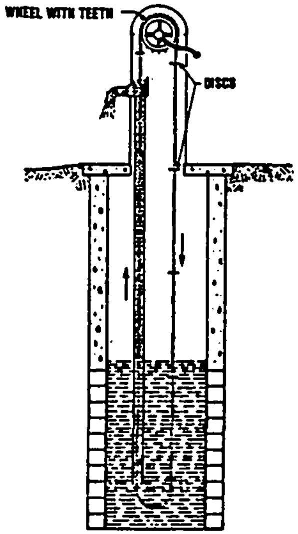
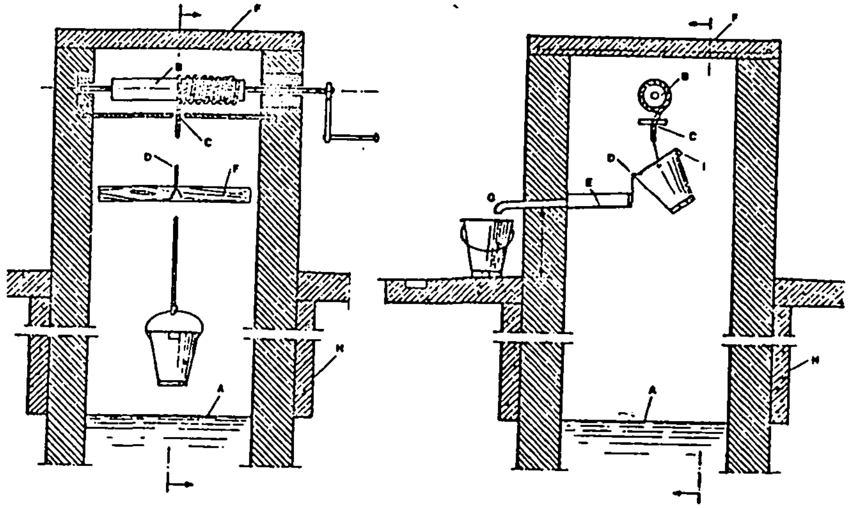


Fig.15. Chain Pump

Sanitary Rope and Bucket Pumping Mechanism

The design developed by WHO (Wagner and Lanoix) and shown in Fig. 15 should not be overlooked. The design, for use with dug wells, is simple to maintain. When carefully built, this simple pumping arrangement gives good service and will protect the well from pollution. Because it is fairly simple, details can easily be changed to fit local conditions. For ease of maintenance, the cover should be removable. A reinforced concrete slab four inches (10 cm) thick and three feet (1 m.) in diameter can be moved by two men.

The obvious disadvantage of this type of water-lifting arrangement is its low rate of discharge. But as a village community water source, it may perform satisfactorily.



A = Water level in well
B = Windlass
C = Guide hole for rope
D = Stop hook
E = Trough

F = Tight cover, removable
G = Discharge opening
H = Compacted clay, or concrete grout

I = Weight attached to top side of bucket to make it tilt when bucket is lowered onto water surface

Fig. 16. Sanitary Rope and Bucket Pumping Mechanism.

Helical Rotor Pump

The helical rotor pump consists of a single thread helical rotor which rotates inside a double thread helical sleeve, the stator (Fig. 16). The meshing helical surfaces force the water up, creating a uniform flow. The water output is proportional to the rotating speed, and can be varied simply by changing a pulley. As the rotor and stator provide an effective, continuous seal, the helical rotor pump requires no valves. Helical rotor pumps are avilable for use in 4-inch (100 mm) or larger tube wells. Although relatively expensive, these pumps have given good service on deep wells in parts of Africa and Asia where they are known as the "Mono" pump after its British manufacturer.

Drive arrangements suitable for helical rotor pumps, are : hand operation electric motors, diesel and petrol engines. Different drive heads are available. If there is plenty of space, a standard head with a V-belt drive can be used. Where a compact unit is required, geared heads are installed for diesel engine or electric motor drives.

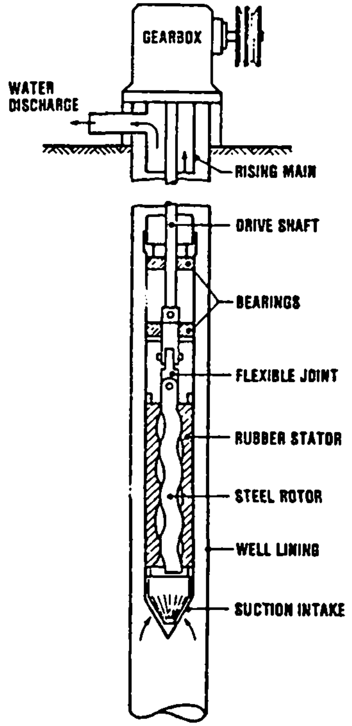


Fig.17. Helical Rotor Pump

Traditional Pumping Devices

There are numerous water lifting devices which could be mentioned : the Archimedes screws ; rope and bucket devices such as the mohte, charsa, ramioko, daly, delu, and mota ; couterpoise lifts,known variously as the shadouf, shaduf, shadoof, khetara, kerkaz, kheeraz, guenina, cigonal, bascule, dhenkali, dhenkli, dhingli, picottah, lat, picotas, guimbalete, swape, sweep, *et al* ; the hinged channel or gutter, doon baldeo balti, and jantu ; paddle wheels ; water ladders ; and the various chain pumps and wheel pumps previously mentioned. These are widely used for low-lift irrigation pumping and many are animal powered.

The shadouf, or counterweighted bailer (see Fig. 18), was modified and effectively used for community water supply purposes in a WHO cholera project (Rajagopalan and Schiffman 1974).

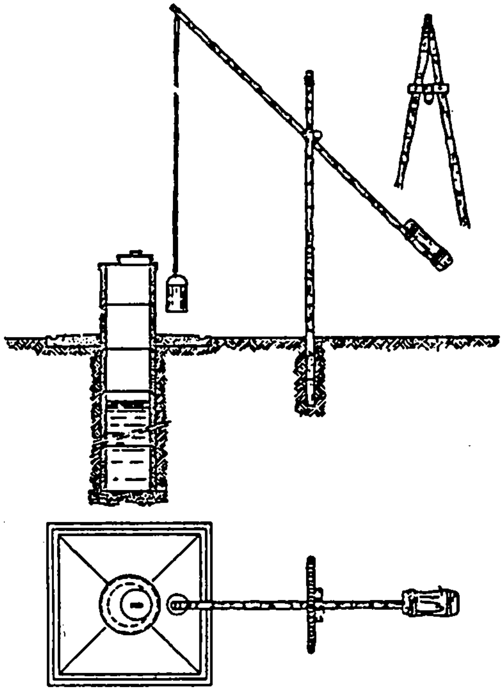


Fig. 18. Counterweighted bailer for drawing water from dug well (as used in the Philippines).

Linked Lift Pumps

The reciprocating movement to operate a lift pump manually, can be tiring and reduces the yield capacity of the pump.

In Nepal, a design has been developed for a simple frame which links two lift pumps and enables a single operator to work the linked pumps at the same time using his feet. This is less tiring and, because two pumps are working, provides a greater and continuous flow of water (up to 3500 litres per hour). Figure 19 shows how the pumps are linked. The treadle is centrally pivoted and the input connections are jointed by a plastic pipe.

Two alternative settings are provided for the pump rod connections to the treadle. At the wide setting, the pumps work quite well at low lifts, but for lifts above 5 m it is an advantage to put the pumps closer together to make pumping easier, with a reduced output. Output is satisfactory to around 67 m but all pipe joints must be airtight.

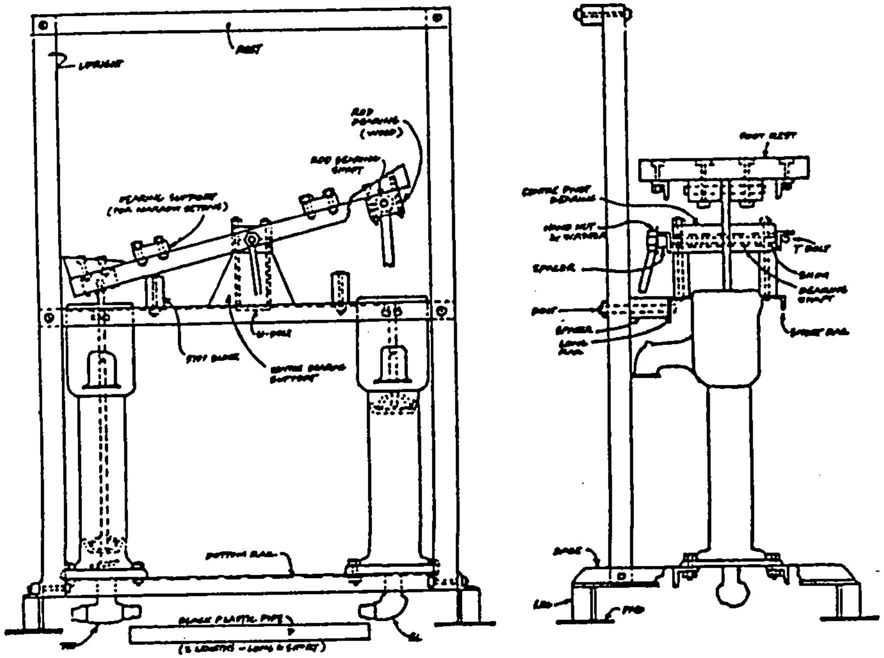


Fig.19. Linked Lift Pump

The frame and the working parts can be made from steel angle (or even wood) with hand tools and the construction should be within the power of a village craftsman. However, as with all mechanical devices, it is the maintenance and care after installation which ultimately decides how useful this machine will be and users should be carefully trained in simple maintenance (which is in this case only a matter of regular lubrification of the pivots and care of the valves and washers in the pumps).

Inertia Pump

The inertia pump consistsof a long pipe with a check valve and a discharge spout located near the top end. The main pump body (riser) is connected to a prime mover assembly. Part of the function of water lifting by this device is believed to be due to the inertia of the mass of water held in the riser (Dawson 1970).

Operation of the inertia pump requires a steady up and down motion of the main pumping body with the lower (suction) end of the riser immersed in the water. A bicycle drive with flywheel has been developed for operating the pump (Thanh *et al* 1977).

When the pump body moves down, a portion of water or air flows through the check valve (typically a flapper valve). During the upward stroke the valve closes and a suction is created inside the riser so that water is drawn into it from the source.

Volumetric output of an inertia pump can be increased by chosing a larger riser diameter or valve opening size. Pump discharge can also be increased by higher speed of operation, or greater lenght of stroke. The discharge decreases with use of a greater pumping head.

For a bicycle-type drive assembly, a pumping speed of some 150 strokes per minute has been found suitable for extended periods of operation (Thanh *et al* 1977).

Bellow Pump

This is a simple water lifting device using a pair of flexible bellows as the pumping element. The idea was originally evolved at the International Rice Research Institute (IRRI), Philippines, where a prototype design was developed for use in irrigation. A modified design was developed and tested at the Asian Institute of Technology (Thanh *et al* 1977).

The main components of the bellow pump are: a pair of flexible bellows, supporting frame and base plate, discharge box, suction lines with check valves, and foot rests.

The bellows constitute the basic pumping element ; they are supported at the bottom by the base plate fixed to the wooden frame. The suction lines deliver the water to the bellows, and these discharge into the discharge box which is connected to the delivery pipe.

The bellow pump is easy to operate. The operator stands on the foot rests and merely shifts his weight from one foot to another thus expanding one bellow while compressing the other. The expanding bellow sucks in water from the source, while water is forced from the compressing bellow out into the discharge box. Operating the pump in a rhytmic manner produces a continuous flow of water.

Rower Pump (Inclined Pump made of PVC)

This is a simple PVC handpump developed for irrigation purposes in Bangladesh by Mennonite Central Committee (voluntary agency) with CARITAS assistance.

PVC pipe, 2-inch in diameter, 4 feet in length, is used as the pump cylinder. This cylinder is included at an angle of approximately 30' from the horizontal and the operator pushes and pulls directly on a "T" handle at the and of the piston rod. There are no pins or levers in the handle. The pump is operated with a rowing action, hence the name "Rower".

The piston valve consists of a rubber disc secured at the centre. This disc seals on a perforated metal disc on the pumping stroke and folds up on the return stroke. The footvalve is a rubber flap (with stiffener) closing a 1 1/2-inch diameter opening. Both piston and footvalve can be removed and replaced by sliding through the cylinder - no dismantling of the pump is required.

At first, the leather cuff (on the piston) softened up and tore quickly. After changes in size and curing method, however, the leather cuffs have stood up very well. Only minimal signs of wear are seen after a month of daily pumping, and their life has yet to be determined.

Comperative testing showed that at a suction lift of 5 - 6 metres, two men pumping alternately (and paid according to output) averaged a 50 % higher pumping rate (based on 5-hour averages) with the Rower pump than with the New No 6 cast iron pump. The same tubewell was used in both cases, and consisted of 110 feet of 1 1/2-inch pipe and 12 feet of PVC filter. Most of the output difference can be attributed directly to the use of the suction chamber, which has also been used successfully in tests with the No 6 pump.

The pump has also been tested for durability. Three pumps have been operated on tubewells for 5 hours daily for four months without significant wear problems.

It is estimated that this pump can be produced for less than 60 % of the cost of producing the New No 6 pumps in Bangladesh.

AXIAL-FLOW PUMPS

In the axial-flow type of pump, radial fins or blades are mounted on an impeller or wheel which rotates in a stationary enclosure (called a casing) (Fig. 21).

The action of the pump is to mechanically lift the water by the rotating impeller. The fixed guide blades ensure that the water flow has no "whirl" velocity when it enters or leaves the impeller.

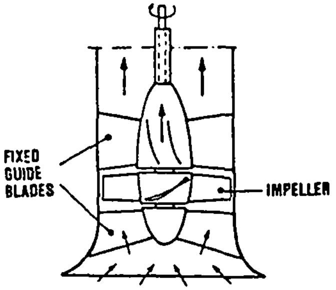


Fig.21. Axial Flow Pump

The essential components of a centrifugal pump are the impeller and the casing (Fig. 22).

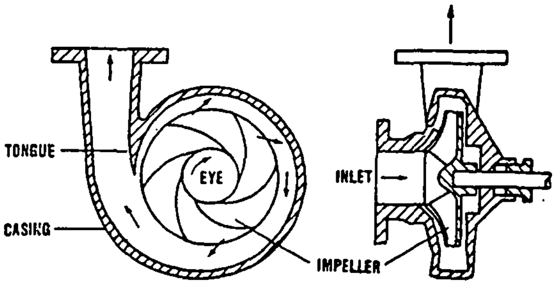


Fig. 22. Centrifugal Pump (Voluta-type Casing)

The impeller is a wheel, having vanes radiating from the centre to the periphery. When rotated at a sufficiently high speed, the impeller imparts kinetic energy to the water and produces an outward flow due to the centrifugal forces. The casing is so shaped that the kinetic energy of the water leaving the impeller is partly coverted to useful pressure. This pressure will force the water into the delivery pipe. The water leaving the eye of the impeller creates a suction ; it will be replaced by water drawn from the source and forced into the casing under static head.

An impeller and the matching section of the casing is called a stage. If the water pressure required in a particular centrifugal pump application is higher than a single stage can practically produce, a number of stages may be placed in series (multiple-stage pump). The impellers are attached to a common shaft and therefore rotate at the same speed. The water passes through the successive stages, with an increase in pressure at each stage. Multiple-stage centrifugal pumps are mostly used for high pumping heads only.

The rotating speed of a centrifugal pump has a considerable effect on its performance. The pumping efficiency tends to improve as the rotating speed increases. Higher speed, however, may lead to more frequent maintenance. A suitable balance between the initial cost and maintenance costs has to be aimed at. A comprehensive study of the pump's characteristic is necessary before final selection.

In centrifugal pumps the angle between the direction of entry and exit of the water flow is 90°. In an axial-flow pump (section 10.6), the water flow continues through the pump in the same direction with no deviation (0°). The term *"mixed-flow pump"* is used for those centrifugal pumps where the change in angle lies between 0° and 90° ; they can be single or multiple-stage.

5. PUMP DRIVE ARRANGEMENTS

Two different drive arrangements exist for water pumping from deep wells : shaft-driven and close-coupled submersible electric motor.

i) *Shaft-Driven*

The crankshaft or motor is placed at the ground surface and powers the pump, using a vertical drive shaft or spindle (Fig. 23). A long drive shaft will need support at regular intervals along its lenght and flexible couplings to eliminate any stresses due to misalignment. The advantage of a drive shaft is, that the drive mechanism may be set above ground or in a dry pit and thus will be readily accessible for maintenance and repair. An accurate alignment of the shaft is necessary ; the shaft-drive arrangement is not possible in crooked tubewells.

ii) *Close-coupled Submersible Electric Motor*

In this pump drive arrangement, a centrifugal pump is connected directly to an electric motor in a common housing, with the pump and motor as a single unit. This unit is constructed for submerged operation in the water to be pumped (Fig. 24).

The pumper-motor unit (often referred to as "submersible pump") is lowered inside the well casing, and set at a suitable depth below the lowest draw-down water level in the well. Submersible pumps are often a "tight" fit in a tubewell, as their outside diameter is usually only 1 - 2 cm less than the internal bored neede, during installation or removal of these pumps.

A waterproof electric cable connects the motor with the control box housing, the on-off switch and the power connection. The electrical control should be properly grounded to minimize the risk of shorting and damage to the motor. Fig. 25 shows a submersible pump in exploded view.

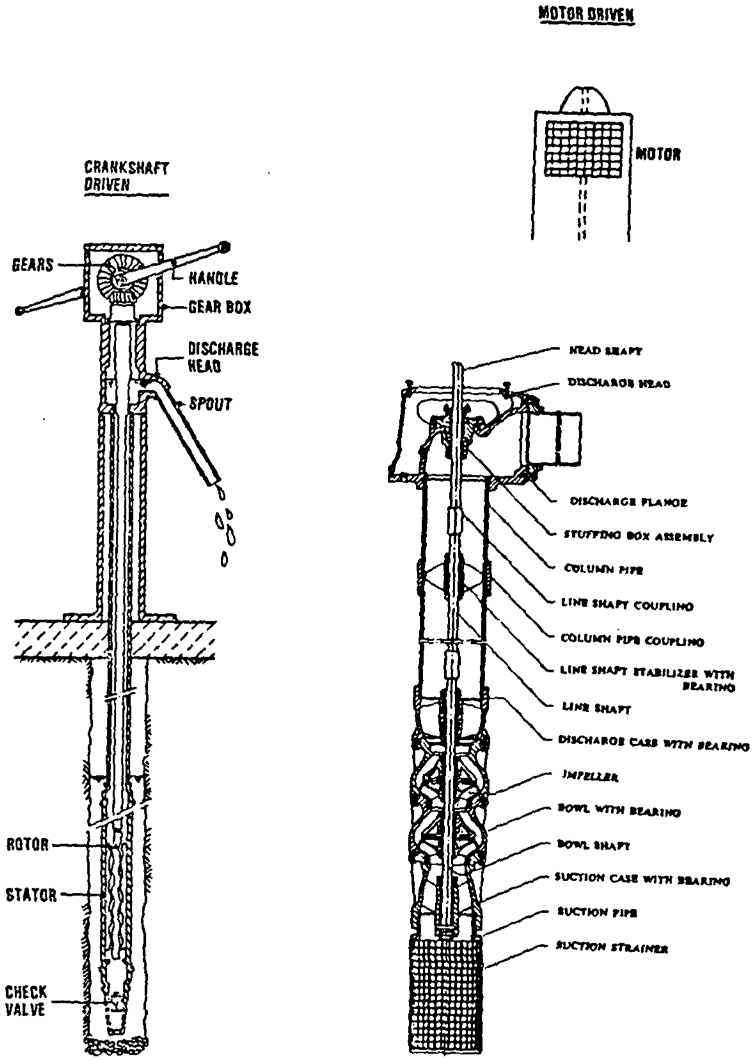
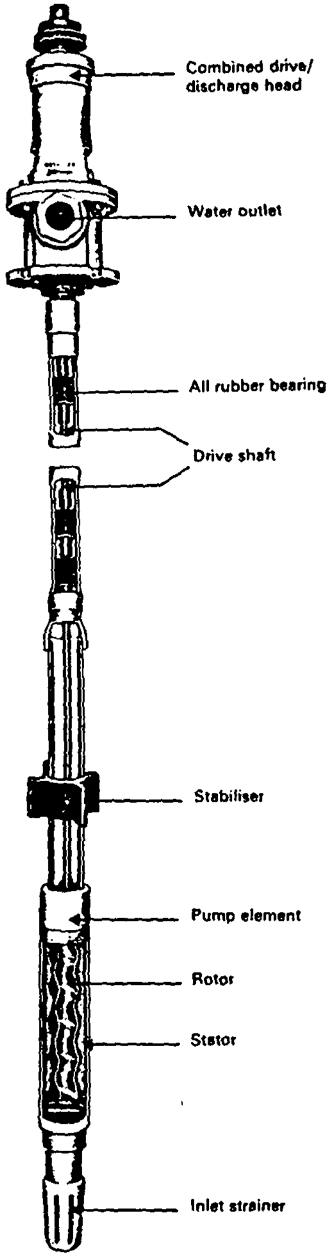


Fig. 23. Shaft-driven Pumps.



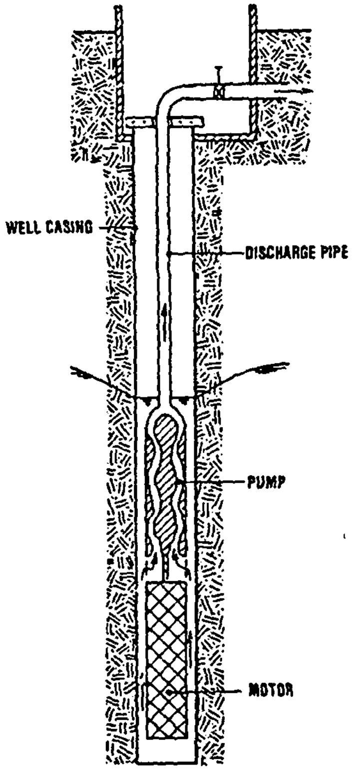


Fig.24. Pump driven by close-coupled submersible electric motors.

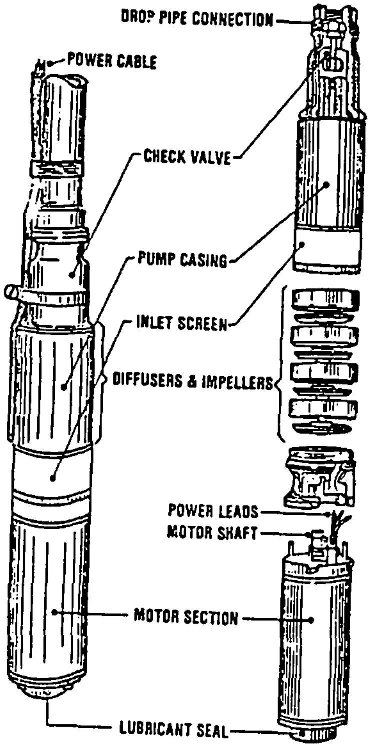


Fig. 25. Submersible pump (exploded view).

The submersible pump-motor unit is a usually supported by the discharge pipe which conveys the pumped water to the connecting pipeline or tank.

When sand is found or anticipated in the water source, special precautions should be taken, before a submersible pump is used. The abrasive action of sand during pumping would shorten the life of the pump considerably.

6. AIR-LIFT PUMPS

An air-lift pump raises water by injecting small evenly distributed bubbles of compressed air at the foot of a discharge pipe fixed in the well. This requires an air compressor. The mixture of air and water being lighter than the water outside the discharge pipe, the water/air mixture is forced upward by the hydrostatic head (Fig. 26).

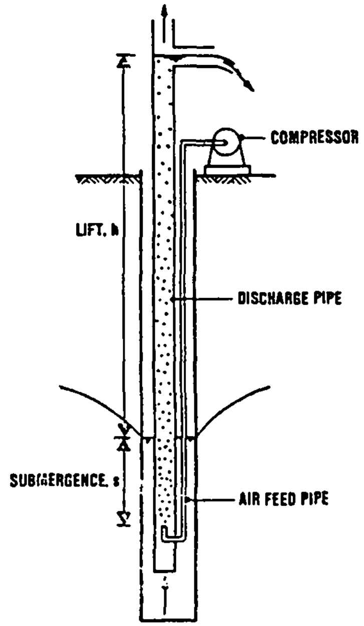


Fig.26. Air-lift Pump (Schematic)

The pumping head (h), against which an air lift pump can raise water, is related to the submergence (s) of the discharge pipe. The point of injection of the air into the water has to be at sufficient depth below the dynamic water level in the well. A high lift requires a considerable submergence, to a depth under the lowest drawdown level of the water in the well. The point of injection of compressed air is also at this depth, so that a sufficiently high air pressure is needed. The major drawback of air-lift pumps is their low mechanical efficiency in utilizing the energy supplied for lifting the water. The efficiency of an air-lift pump itself is about 25 - 40 %. Additional are the energy losses in the compressor. Overall, not more than 15 - 30 % of the total power consumption is effectively utilized.

However, air-lift pumps also have important advantages. They are simple to operate and not affected by sand or silt in the pumped water. All mechanical equipment (the compressor) is above ground. A number of air-lift pumps installed in adjacent wells can be operated using a single compressor. Water can be air-lift pumped from wells as deep as 120 m, at a considerable rate. Thus, air-lift pumps should be considered for those applications where their advantages will outweigh the drawback of high power consumption due to the low mechanical efficiency. They should be particularly considered in areas where the groundwater carries much sand or silt, and for pumping water that is acidic (low pH).

7. HYDRAULIC RAM

The hydraulic ram needs no external source of power. The ram utilizes the energy contained in a flow of water running it, to lift a small volume of this water to a higher level. The phenomenon involved is that of a pressure surge, which develops, when a moving mass of water is suddenly stopped. A steady and reliable supply of water is required with a fall sufficient to operate the hydraulic ram. Favourable conditions are mostly found in hilly and mountainous areas. Hydraulic rams are not suited to pump water from wells.

A typical small hydraulic ram will lift about 2 litres/minute to heights up to 50 - 60 m. The drive pipe should be of a lenght about three quarters of the vertical height between the pump and the final delivery point.

Example :

Hydraulic ram to lift water to a delivery head 25 m above the pump, using a supply head of 4.5 m from the water source. Drive pipe about 3/4 x 26 m = 19 m of lenght, e.g. 25 mm dia galvanised steel. Delivery pipe e.g. 250 long, and 15 mm dia G.S. Pumping rate : 2 litres/minute. Head tank holding 12 hours supply : 12 x 120 = 1500 litres.

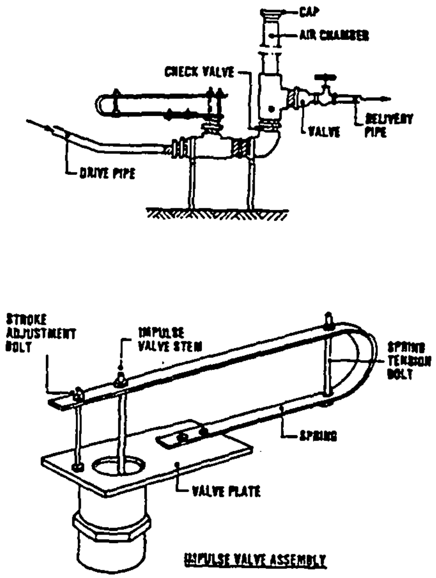


Fig.27. Typical hydraulic ram

Source: S.B. Watt
A Manual on the Hydraulic
Ram for Pumping Water,
I.T. Publications Ltd., 1974.

The ram operates on a flow of water running from the source down through the drive pipe into the pump chamber. The water escapes through the opened impulse valve is fast enough, the upward force on the valve will exceed the spring tension of the valve adjustment and the impulse valve is suddenly shut. The moving mass of water is topped with its momentum producing a pressure surge along the drive pipe. Due to the pressure surge, water is forced through the non-return (delivery) valve and into the delivery pipe. Water continues to pass the non-return valve until the energy of the pressure surge in the drive pipe is exhausted. The air chamber serves to smooth out the delivery flow of water, as it absorbs part of the pressure surge which is released after the initial pressure wave.

When the pressure surge is fully exhausted, a slight suction created by the momentum of the water flow, together with the weight of the water in the delivery pipe, shuts the non-return valve and prevents the water from running back into the pump chamber. The adjustment spring now opens the impulse valve, water begins to escape through it, and a new operating cycle is started.

Once the adjustment of the impulse valve has been set, the hydraulic ram needs no attention, providing the water flow, the supply source is continuous, and at an adequate rate, and no foreign matter gets into the pump, blocking the valves.

An air valve is provided to allow a certain amount of air to bleed in and keep the air chamber charged. Water under pressure will absorb air and without a suitable air valve the air chamber would soon be full of water. The hydraulic ram would cease to function.

The advantages of the hydraulic ram are:

- no power sources are needed, and there are no running costs;
- simple to make. Local materials and simple workshop equipment can be used;
- it has only two moving parts.

A small supply of water with plenty of fall will enable a hydraulic ram to lift as much water as a large flow of water with a small fall. Most hydraulic rams will work at their best efficiency if the supply head is about 1/3 of the delivery head. The higher the pumping head required, the smaller the amount of water delivered.

The maintenance required for a hydraulic ram is very little and infrequent. It includes:

- replacement of the valve rubbers when they wear out;
- adjusting the tuning;
- tightening holts which loose.

Occasionally, the hydraulic ram may need dismantling for cleaning. It is essential that as little debris as possible enters the drive pipe. For this reason, it is necessary to provide a grate or strainer to keep back floating leaves and debris.

9. COSTS OF HANDPUMPS

For a cost analysis and comparison of different handpump designs, *all* the relevant costs should be considered, i.e. the full "life-cycle" costs including the initial (capital) costs, as well as the future costs of maintenance and replacement of parts.

The discharge capacity of different pumps is usually not the same. Some pumps have a higher discharge capacity than others. If there exist a demand for the extra water from the pump with the higher discharge capacity, a straight comparison of the pumps in terms of cost-effectiveness will be impossible. In such cases the benefit of the extra water need to be taken into account, and a *cost-benefit* analysis is required. For example, if pump A has a discharge capacity of 4000 litres/day whereas pump B produces 4500 litres/day, then pump B has an additional benefit of 500 litres/day assuming the extra 500 litres will be fully utilised.

However, for practical purposes the discharge capacities of alternative pumps often are such, that they can be assumed to produce the same quantity of water, i.e. in a day or an hour. The actual output of these pumps can then be taken as equal, and in such cases the cost comparison of pumps may be based on the "life-cycle costs". This is called cost-effectiveness analysis.

It is a common error to use in the cost analysis of handpumps as the paramount criterion, the initial capital cost only. This is not correct. The initial capital cost of a pump may be not more than 15 - 25 % of its total "life-cycle" costs. Frequently, the cost analysis of handpumps involves the comparison of a pump with high initial capital cost, but low future maintenance and repair costs, and other pumps which have lower initial capital costs but which will entail substantial future expenditure for the maintenance, repair and replacements. The objective of the costs analysis for handpumps is to determine a common denominator for each pump under consideration in order to objectively compare the pumps.

The "life-cycle" costs of each handpump involve costs (expenditures) at different points in time. In order to make a valid comparison, it is necessary to convert the relevant cost figures at different points in time into equivalent figures, based on the principle of "time-value of money". The different costs involved in the entire "life-cycle" of a handpump can thus be expressed as a single figure using either of the two following methods:

1) Present worth of costs;
2) Annual equivalent costs.

The first method is generally used by economists whereas the second method is often prefered by engineers.

The two cost analysis methods are illustrated for the following examples (1).

EXAMPLE:

Three handpumps, A, B and C are compared which all can satisfy the specific requirements of design, discharge capacity, reliability, convenience of use, and acceptability to the users.

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(1) *The problems of determining the cost and other data for use in the analysis are recognised; these are discussed in the following paragraphs.*

Given (1)

	Pump A	Pump B	Pump C
1. Initial capital costs	$P_A = \$ 300$	$P_B = \$ 600$	$P_C = \$ 700$
2. Economic life	$n_a = 6$ years	$n_b = 10$ years	$n_c = 11$ years
3. Replacement of vital parts involving lump sum costs	$R_a = \$ 100$ on the 2nd and 4th year	$R_b = \$ 120$ on the 3rd 6th and 9th year	$R_c = \$ 150$ on the 4th and 8th year
4. Annual maintenance and operation	$m_a = \$ 100$	$m_b = \$ 80$	$m_c = \$ 60$
5. Rate of Discount (i)	10 %	10 %	10 %

The results of the "Present worth of Costs" analysis are :

	(based on market or observed prices)
Pump A	\$ 1319,81
Pump B	\$ 1339,59
Pump C	\$ 1249,00

The results of the "Annual Equivalent Costs : analysis are :

Pump A	\$ 203,22
Pump B	\$ 206,27
Pump C	\$ 192,32

Data to be used in Cost analysis

The use of market prices or observed prices in the cost analysis of handpumps, may lead to incorrect results. In many developing countries such prices bear little relation to real economics costs (viz. opportunity costs to the national economy) of any resource used.

Therefore, a valid cost comparison of handpumps should use "shadow prices" (i.e. true opportunity costs) of different components rather than their market prices.

The differences between market prices and shadow prices of any handpump component arises from the following reasons :

(1) Market prices include the transfer payments such as taxes (sales tax or value added tax) and duties (import duties, exice duties, etc.) which are not true resource costs from the point of view of the national economy.

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(1) *The problems of determining the cost and other data for use in the analysis are recognized; these are discussed in the following paragraphs.*

(2) The nominal market price of foreign exchange (i.e. exchange rate) for imported components for any equipment such as a handpump may be too low as they are not based on "Demand" and "Supply" considerations of foreign exchange, but on other considerations by a developing country thus favouring technology with a high import content.

To avoid these biases in the cost analysis of handpumps, shadow prices are to be used which may be defined as the prices which would prevail in the economy if pure opportunity costs were allowed to express themselves in market prices.

Data on maintenance and replacement costs are sparse. These costs are to a large extent dependent on local circumstances. Very often they are under-estimated. Sometimes, cost estimates are based on historical data without recognising that these may represent the cost of an inadequate level of maintenance.

Service Life Expectancy of Pumps

In determining the service life expectancy of various pump models the economic life rather than the technical life should be used(1). Even though a handpump manufacturer or supplier often claims that their pump will last for 15 - 20 years under "normal" operating conditions, in practice such a life is very rare under the prevalent conditions of service and the existing levels of maintenance especially in rural areas of the developing countries.

It is, therefore, difficult to predict the "service-life" or "economic-life" particularly of those handpumps which are newly introduced. It may be necessary to collect data on yearly repair and maintenance costs for similar kinds of handpumps used in the country before, and use a calculation model for arriving at the "economic-life".

Limitation of Cost Analysis of Handpumps

Each handpump has a number of components. Several of these may last many years with little or no maintenance. Others have a limited life span because of wear, or vulnerability to breakage. As with any mechanical device, a handpump has wearing parts which require replacement periodically in relation to the intensity of use. Vandalism and accidents result in the need to replace damaged units from time of time.

In a cost analysis, the "service-life" of a pump does not refer to the longest lasting component but to the pump as a functional unit.

Some parts may have to be replaced economically only once, others may justify replacement several times during the service life of the pump as a whole. In fact, this would imply a separate economic costing of each pump component over the design period. An estimate may have to be made of the number of times that individual components will need replacement taking into account the operating conditions.

---

(1) *Theoretically a handpump can be used for a long period by replacing worn-out parts one by one as and when it is required to do so. On this basis technical life can be quite long up to the time when every part has been replaced once. But it is generally very uneconomic to use a pump for such a long period and hence the necessity of arriving at the "Economic Life" for cost analysis.*

It should be clear that unit prices of handpumps, as given in manufacturers' documentation, tender documents or bids, should *not* be the sole criterion in comparing pumps. Obviously, the pump with the lowest initial cost, few wearing component parts and requiring the least maintenance, would be the most economical unit. However, the situation seldom is so straight forward.

Regardless of the handpump selected, some maintenance will always be involved in keeping it in satisfactory operating condition. Some of the most significant costs associated with maintenance, do not pertain to the handpumps themselves, but to the trucks, motor cycles, fuels and personnel required for inspection, servicing and repair of pumps.

10. SOCIAL AND CULTURAL FACTORS

A water pumping unit for a community water supply is a small technical device in a complex economic and socio-cultural system.

Water supply alone, whether by handpumps or otherwise, cannot be expected to bring the desired health benefits unless accompanied by training for personal hygiene, health education, and sanitary excreta and waste disposal. To achieve the goal of better health conditions or improved agricultural yields, it is require that generous attention is paid to the social and cultural factors. Such factors may be difficult to define, but they are inherent in every installation programme of pumping devices, and become especially manifest in the operation and maintenance of the pumps.

Acceptance by the Users

Water supplies, being a vital need, are often vested with deep cultural meanings and traditions. Many pump installations in rural areas have failed, or have been abandoned by their users, either because they did not have the skill and resources to keep them going, or because of mistrust in the agencies providing the pumping devices. The users' preferences must be one of the most important considerations if the pump is to perform its desired function. In practice, the reliability and durability of a manual pumping device interact with the social environment in which the pump operates. In this respect, a "bottom-up" approach should be followed involving the local people, to the maximum extent possible, in the design and installation of the pump. The social factors influencing the acceptance of the pump by its users, should be recognized so as to avoid frustration, sabotage and pilferage.

The ultimate success of the handpump installation will depend on users acceptance. Thus site selection should also consider such factors as community preferences for the pump, proximity to users, ethnic or caste differences among users, and exposure to vandalism or pilferage. An extensive number of users per pump with long waiting lines or long distances to walk may discourage users, particularly if alternative sources are nearby. Where usage is heavy, provision of two or more handpumps should be considered. This also provides a standby pump in the event of one breaking down.

Local Organisation

An effective pump installation programme is a conglomerate of technology, institutions and people - individuals who must plan, design, manufacture, finance, purchase, install, operate, maintain, supervise and use the pumps. In addition to the central agency, some organizational structure should be developed at the local level in the form of a committee or some other entity which is usually found in the country. The importance of a local committee is that it represents the users, directly involves the community leadership in the day to day operation and administration of the system, and hopefully, helps motivate the users of the pumping devices.

Maintenance

When selecting or developing a pumping device for use in community water supply, it should be carefully considered whether the expected involvement of the users in the maintenance of their pumps is realistic. The envisaged division of responsability for maintenance tasks should be clearly stated.

Without adequate information, the users cannot be expected to be cooperative in ensuring the proper maintenance of their pumps. Without support, i.e. supply of spare parts, it will be impossible for them to contribute their part to the servicing of the pump. Certain requirements are simply beyond the local capacity, at least under present conditions.

The poor quality of pump design and manufacture was to a considerable extend, the results of many years of trimming weight, bearing sizes, etc., in seeking low bids (tenders) in the absence of strict specifications. Much pump procurement has an inherent bias towards low initial capital cost and ignore the total costs over the life-span of a pump.

The high rate of abandoned or defective manual pumping units is not simply a reflection of poor quality pumps, but also of inadequate maintenance and repair. Many authorities contend that maintenance may provide some insight into possible improvements. Maintenance issues includes :

i) the usual technology makes frequent lubrication mandatory. Iron and steel journals and bearings, poor fits and large clearances, lack of lubricant stocks, exposure to weather, etc. ;

ii) underestimates or lack of appreciation of the structural and bearing loadings in deep well pumps ;

iii) large variety of pumps in use with accompanying need for many different spares. Limited interchangeability of spare parts, sometimes, even between different pump models of the same manufacturer ;

iv) little feedback from maintenance to design engineering, and procurement personnel. Little analysis, for example, of the most common failures. Record keeping is often inadequate ;

v) poor maintenance skills, lack of training, inadequate tools (for example, few village maintenance men have a clevis for pulling up pump rod, drop pipe, and colander), lack of transport and lack of supervision are characteristic of many programmes.

Most pump maintenance systems can be characterized as a one or two level system. The one level system is one that in which all maintenance is the responsibility of the central organization. In the two level system, maintenance is shared with local communities or individual users.

In both systems the central organization usually installs the pump. The well may be the task of another central agency. For dug wells the village may provide labour under central agency supervision. The central agency usually handles major repairs or replacement of the pumps in both systems. It maintains stores or parts and lubricants and provides transport, warehousing, and training. When the central agency provides routine maintenance, it often employs a roving maintenance man or team with a vehicle which services from 20 to 200 pumps on a repetitive basis.

In the two level system, the local community or a resident employed by the central organization assumes responsibility for all lubrication and minor repairs, for example replacement of cup seals ("leathers"). Where villagers deal only with the basic maintenance tasks requiring frequent attention, the backup service could visit the pump at regular intervals (e.g. every three months) for a thorough servicing. This system is found in parts of India.

In some programmes, certain users may be given a thorough training in pump maintenance and virtually all responsability left in their hands. This approach is being tried, for instance, in Kenya and Tanzania. Each village is required to nominate a person before the well is sunk, who will go to the district office for two weeks to learn about well construction and particularly for maintenance of the pump. He will then be responsible for the well once it is sunk, and will keep a small stock of leather components and other spare parts in his house. If a major breakdown occurs he will contact the district office and either get the parts needed to carry out the repairs himself or else get the district's mechanics to do the job.

Some people have suggested that if a pump could be designed capable of being made by a village craftsman,using simple tools and locally available materials, then the maker of the pump would always be on hand to repair it when necessary. This argument is supported by the observation that many low-lift irrigation pumps of traditional design are built and maintained by village craftsmen. These pumps are not suitable for community water supplies as they were designed, built and used for small-scale irrigation where they have had varying success, but most have been unsuccessful in intensive community use.

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ANNEX 1

HANDPUMP DESIGN

THEORY

1. HYDRAULIC ANALYSIS

The theoretical discharge capacity of a reciprocating handpump (single acting) is a function of the cylinder volume swept by the plunger during its upward, pumping stroke, and the number of strokes per unit of time. This is illustrated in Fig. 1.

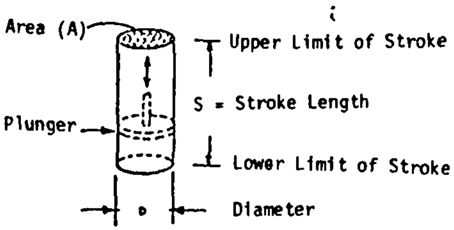

Fig.1. Swept cylinder volume

The swept cylinder volume (V) is the product of the (horizontal) cross sectional area (A) and the length of the plunger stroke (S). The cross sectional area (A) can be written in terms of the cylinder diameter (D) :

$$A = \frac{\pi}{4} D^2$$

The discharge capacity (Q) for a given number of pumping strokes per unit of time (N) may be calculated with the equation

$$Q = \frac{\pi}{4} D^2 .S.N.$$

The theoretical discharge of a particular (single-acting) reciprocating plunger pump can be read from the nomograph in Fig. 2.

The actual rate of discharge normally varies slightly from the theoretical discharge due to failure of the valves to close instantly when the plunger changes direction and to leakage between the plunger and the cylinder wall during pumping. This difference is known as slip. The slip can be computed with the formula :

$$\text{Slip} = \frac{Qt - Qa}{Qt} \times 100 \%$$

in which : Qt = theoretical discharge capacity of the pump
Qa = actual discharge rate

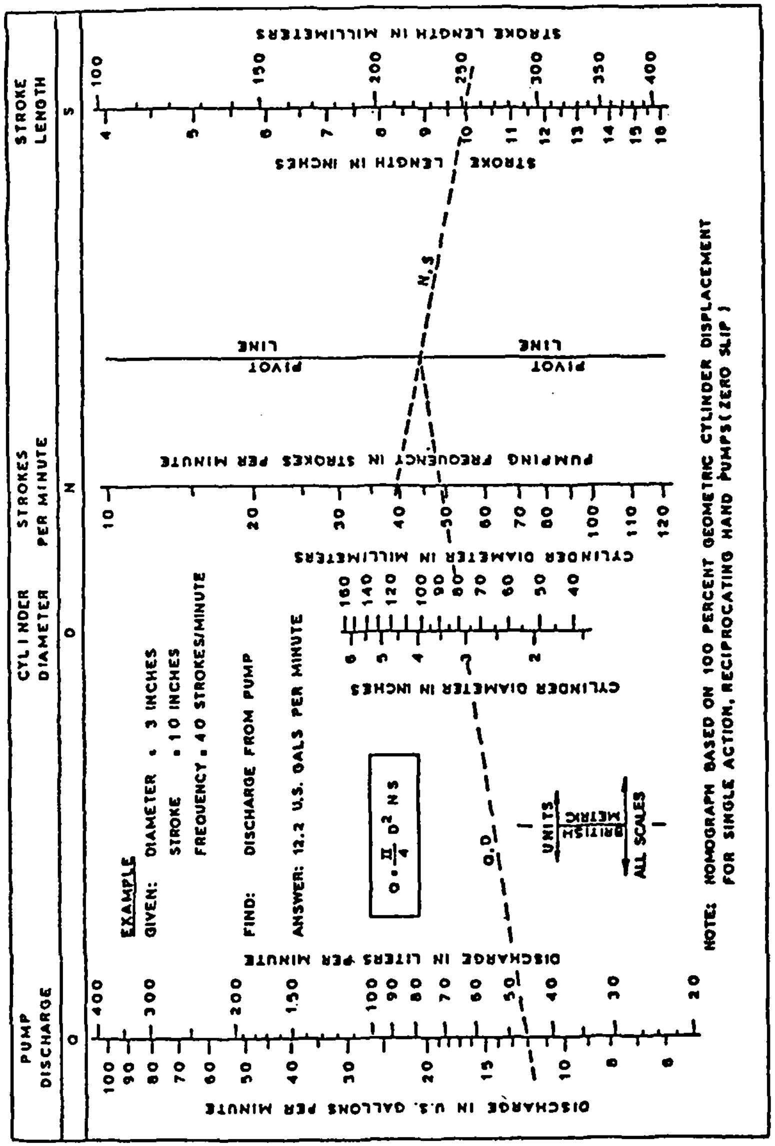

Fig. 2 Nomograph for handpump discharge

Thus, the slip is expressed as a percentage of the theoretical discharge capacity of the pump.

Slip should not exeed 15 percent, preferably 5 percent, in a well designed and maintained pump. Under certain conditions, (e.g. a long suction pipe of small diameter, below the cylinder) the flow velocity may be sufficiently high to keep the plunger discharge valve open during part of its upward movement. In such cases the actual discharge may exceed the theoretical discharge capacity ; this phenomenon is called "negative slip".

Hydraulic efficiency in terms of swept cylinder volume should not be confused with mechanical efficiency which can never exceed 100 %.

2. FORCE AND ENERGY ANALYSIS

2.1. FORCE ANALYSIS

The major force in a reciprocating pump is on the plunger, the pump rod and couplings, the handle assembly and bearings, and the pump stand occurs during the upward (pumping) stroke of the plunger. The load is exerted by the water pressure on the plunger, by the (submerged) weight of the pump rod and plunger assembly, and by the sliding friction at bearings and cup seals.

The hydraulic load (F) on the plunger is the product of the hydraulic pressure (P) and the cross-sectional area (A) that is : (F) = P.A. The hydraulic pressure (P) itself is the product of the pumping head (H) and the specific weight (A) of the water : $P = \varrho H$. For a circular plunger, its area (A) expressed in terms of plunger diameter (D) is $A = \pi D^2/4$. Summarising :

$$F = PA = \varrho \frac{H \pi D^2}{4}$$

To the hydraulic force must be added the submerged weight of the pump rod. The weight of other components can generally be neglected.

The weight of the pump rod varies slightly with the type and number of couplings. The weight of the water displaced by the rod should theoretically be substracted but can be ignored, because this weight and the plunger assembly weight roughly cancel each other out.

The above mentioned formula and considerations show that the theoretical force required to operate a pump, is predominantly a function of the pumping head (H), and the cylinder diameter (D). The depth at which the cylinder is set in the well, does not dertermine the pump operating force. The force is, in theory, also *independent* of the discharge rate.

2.2. ENERGY ANALYSIS

In handpumps, the energy requirement (or rate of work) is an important parameter.

$$\text{Energy requirement} = \frac{g}{60} \quad Q.H \quad \text{(watt)}$$

Q = rate of discharge (litres/minute)

H = pumping head (m)

= mechanical efficiency of pump (%)

g = gravitational constant (m/sec^2)

The above equation shows that the energy requirements for operating a pump have an inverse relationship with the pump's mechanical efficiency. The lower the mechanical efficiency, the higher the energy input required for a certain pump discharge rate.

For an assumed effective work input of 75 watt (0.10 HP), a tentative measure of a pump mechanical efficiency can be obtained from the formula :

$$\eta = 0{,}22\ Q.H.$$

with

D = mechanical efficiency of pump (in percent)

Q = rate of discharge (litres/minute)

H = pumping head (m)

<u>Example</u>

Given a handpump with a 3-inch (76 mm) cylinder set a depth of 21.3 metres (60 feet) below ground. The water level in the well is at 13.8 metres (40 feet) below ground. Adding the spout height above ground, and an estimated discharge pressure of the pumped water, the pumping head (H) is found to be 15.2 metres (50 feet). Specific weight of the water 1000 kg/m^3 (62.4 lb/ft^3). The pump rod is steel, 1/2-inch (12.7 mm) in diameter, and weight 1.02 kg per meter (0.685 lb per feet).

Formula for calculation of hydraulic force :

$$F = \frac{H.\pi.D^2}{4}$$

Calculations :

Metric

$$F = \frac{(1000)\quad(15.2)\quad(3.14)\quad(76/1000)^2}{4}$$

Hydraulic force = 68.5 kg

Pump rod weight = 21.3 x 1.02 = 21.4

Total force = 68.5 + 21.4 = 89.9 kg

British

$$F = \frac{(62.4)\quad(50)\quad(3.14)\quad(3/12)^2}{4}$$

Hydraulic force = 157 lb

Pump rod weight = 60 x 0.685 = 42 lb

Total force = 157 + 42 = 199

The calculated force is the average over the pumping cycle. Pump tests using force meters have shown that the actual force may be two or three times the calculated force. Obviously, the pump rod couplings, connectors and pins must have sufficient strenght to withstand the peak forces. Thus generous safety factors are necessary.

Figure 3. Shows how the pump rod force is likely to vary during pumping.

The solid line abc shows performance under "ideal" friction conditions. At position "a" the plunger is at the bottom of the cylinder. The pump road force is nil-the "ideal pump rod and plunger are weightless". Pumping begins, the plunger begins its upward movement. Instantaneously the pump rod force world increase to "b". This force is then constant at "c" as the plunger moves to the top of the cylinder. As the plunger stops at the top of the cylinder no more work is being done and the force returns to level "d".

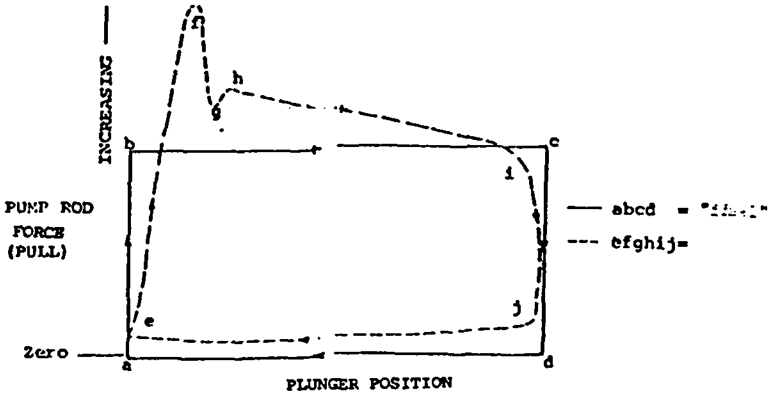

Fig.3. Variation of Pump Rod Force (schematic)

Under real operating conditions the pump rod force at the beginning of the upward plunger stroke does not increase instantaneously. As the plunger accelerates upward, pump rod and coupling slack is taken up and the pump rod force increases rapidly from "e" to "f". The inertial forces required to accelerate the water from "rest" cause the maximum tension "f" to exceed the calculated value "b" (1). From "f" to "g" the now moving water reduces the external force required. The "kink" from "g" to "h" is the closing of the plunger valve. By "i" the plunger is decelerating and has reversed direction by "j". The weight of the pump rod results in some rod force as the plunger returns from "j" to "e".

The force exterted on a pump rod and, through the rod to the pump handle may be as high as 100 kgf (200 lb). However, the muscular force available for continuous pumping by an individual person is generally limited to 10 - 18 kgf (20-40 lb). Through the principle of mechanical advantage, muscle power can be multiplied to operate handpumps against pumping heads as high as 100 metres (300 feet).

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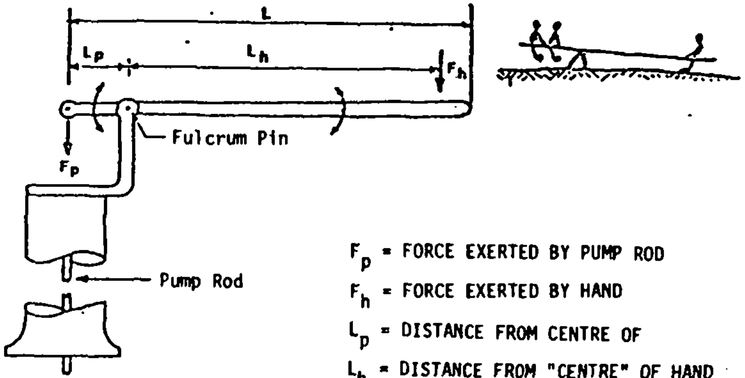
(1)Column of water 100 feet. Water pressure p = 62.4 x 100 = 6240 lbs. To accelerate the mass of water 1 ft/sec² would require a force of 6434 lbs.

The principle of mechanical advantage is illustrated in Fig. 4.



F_p = FORCE EXERTED BY PUMP ROD
F_h = FORCE EXERTED BY HAND
L_p = DISTANCE FROM CENTRE OF
L_h = DISTANCE FROM "CENTRE" OF HAND TO CENTRE OF FULCRUM PIN

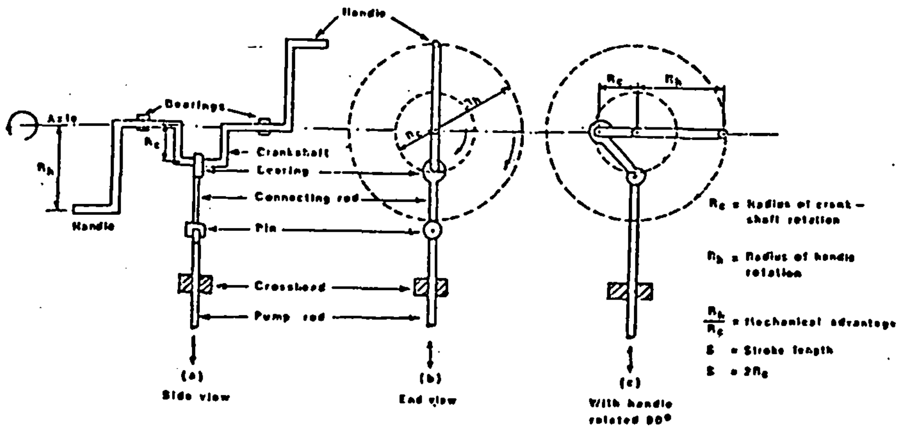
Fig.4. Mechanical advantage of Pump Handle as Lever

Example

Given a pump rod force of 88 kgf (190 lb). What handle force is needed if the mechanical advantage of the pump handle is 4 to 1.

$$F_h = \frac{F_p}{MA} = \frac{88\ \text{kgf}}{4} = 22\ \text{kgf}\quad (48.5\ \text{lb})$$

Mechanical advantage is also used in handpumps operated by rotary crank or wheel drive (see figure 5).



(a) Side view (b) End view (c) With handle rotated 90°

Fig.5. Typical Rotating Crankshaft Mechanism

The mechanical advantage MA for a rotating crankshaft driven by a handle or wheel can be shown to be :

$$MA = \frac{\text{Radius of Handle Rotation} \quad (Rh)}{\text{Radius of Crankshaft Rotation} \quad (Rc)}$$

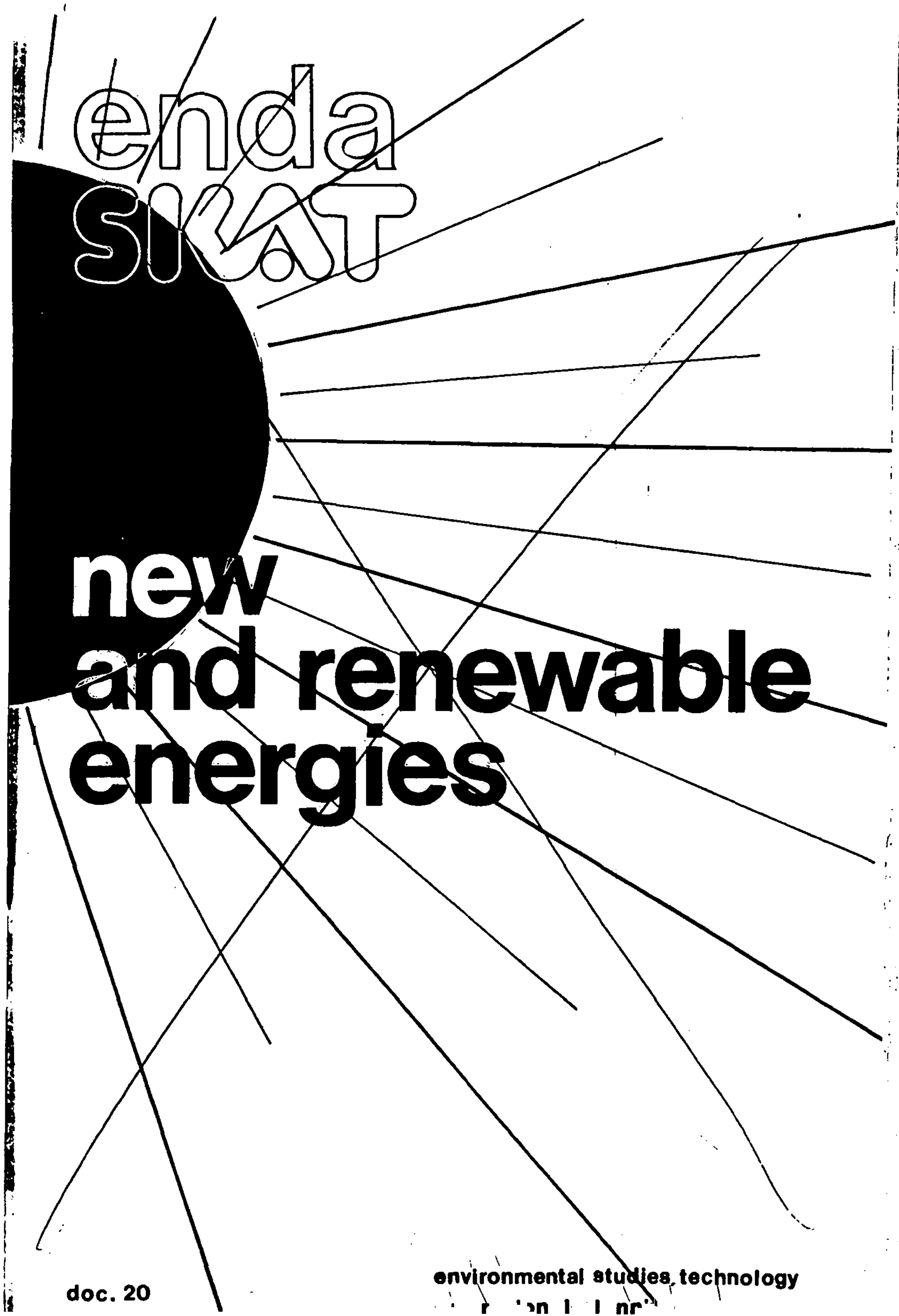
From Fig. 5 it is seen that the force required to operate the pump can be found as follows :

$$Fh = \frac{Fa}{MA}$$

wherein Fh = force handle

Fa = actual pump rod force

MA = Rh : Rc



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