CHAPTER 9

Pumping systems

The choice of a pumping system must be made bearing in mind not only the technical constraints (pump type, energy, head, flow, turbidity), but also the constraints of the socio-economic context (appropriate pumping system, availability of spares, ease of maintenance). This chapter presents the theoretical background for the choice and installation of pumps for medium and long-term interventions, illustrated by practical examples.

1 General

Table 9.I shows the pump types most widely used. All pumps are made up of three different parts:
– the motor, which provides the power necessary for pumping;
– the transmission, which conveys the power to the hydraulic component;

Table 9.I: Types of pump.

Type of pump	Normal application	Technology
Manual	Wells and boreholes	Surface suction pump → piston Medium and high-lift pump with the hydraulic component submerged (also exist as motorised models) → piston → hydraulic balloon → screw (also exist as motorised models)
Submersible electric	Wells and boreholes for flows > $2m^3/h$ Pumping tests	Lift pump → multi-stage centrifugal
Dewatering pump	Pumping out excavations (digging wells below water table) Pumping surface water	Lift or suction-lift → centrifugal → pneumatic membrane
Surface motorised pump	Pumping surface water Pumping from reservoir to network or other reservoir	Suction-lift (suction head limited to 7 m) → centrifugal

– the hydraulic component, which transmits the power to the water in order to move it (to pump it in or out).

Table 9. II shows the working principle of the different types of pump.

Table 9.II: Working principles of commonly-used pumps.

	Drive	Transmission	Hydraulic component
Manual	Hand Foot	Mechanical (rod and lever) Hydraulic (water pipe)	Volumetric pump (with submerged or non-submerged piston, or balloon)
Motorised pump (surface)	Internal combustion engine (diesel, petrol) Direct drive or via generator & motor	Shaft and bearings	Centrifugal pump
Electric pump (submersible)	Electric motor	Shaft	Multi-stage centrifugal pump
Dewatering pump (pneumatic)	Compressor	Compressed-air line	Volumetric pump (membrane)

2 Motorised pumps

There are two main types of motorised pump: centrifugal and volumetric. The latter are suitable for lifting small water flows at high pressure (e.g. high-pressure washers).

For drinking water, the only volumetric pumps commonly in use are handpumps (see Section 8).

2.1 Working principles of centrifugal pumps

Centrifugal pumps belong to the turbo-pump family (Figure 9.1). In a turbo-pump, a rotor, fitted with blades or paddles driven by rotary movement, transmits kinetic energy to the fluid, some of which is transformed into pressure by reduction of velocity in a component known as the stator. Different types of turbo-pumps have different shaped rotors (Figures 9.2 and 9.3).

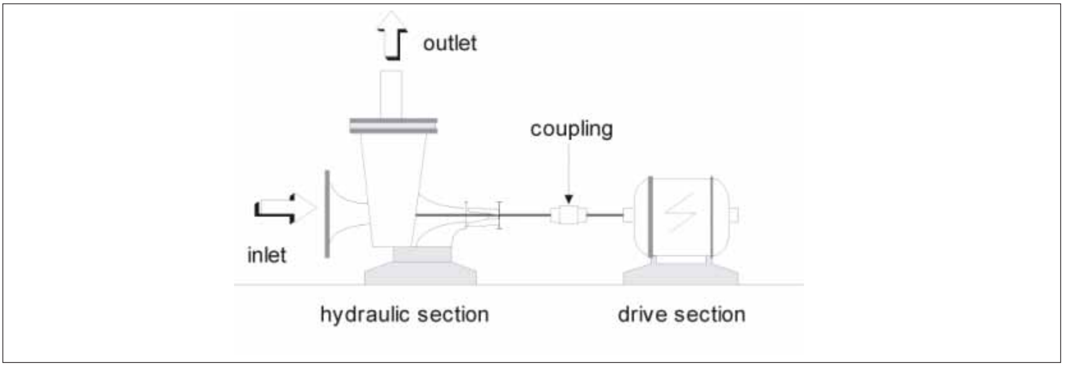


Figure 9.1: Electric centrifugal pump (surface).

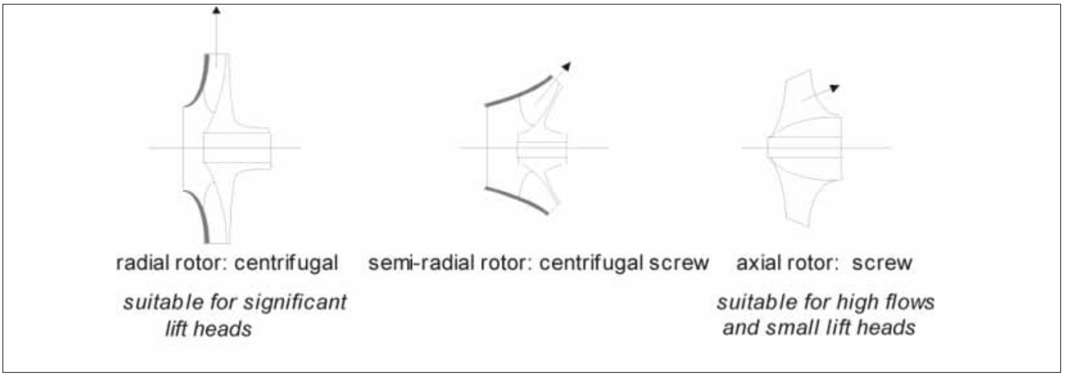


Figure 9.2: Rotor designs in turbopumps.

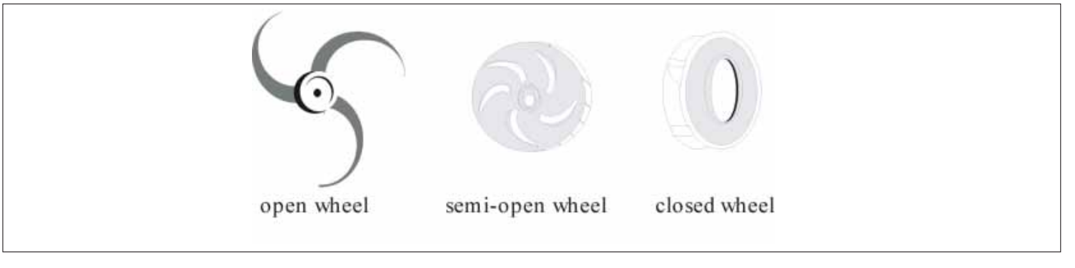


Figure 9.3: Rotor designs in centrifugal pumps.

The driving force to the shaft can be supplied by an internal combustion engine, an electric motor (either submersible or surface-mounted), or by any other force, such as a turbine in a river.

2.2 Centrifugal pump sealing

The drive shaft passes into the pump casing in which the rotor turns, through a sealing system consisting of packing (graphite), wrapped around the shaft and retained by a gland.

The packing seal is not perfect: it always leaks a little and so lubricates and cools the shaft. Therefore the gland should not be tightened too much, because that would wear out the packing quickly. Once the packing is worn out, it can be added to without removing the old one.

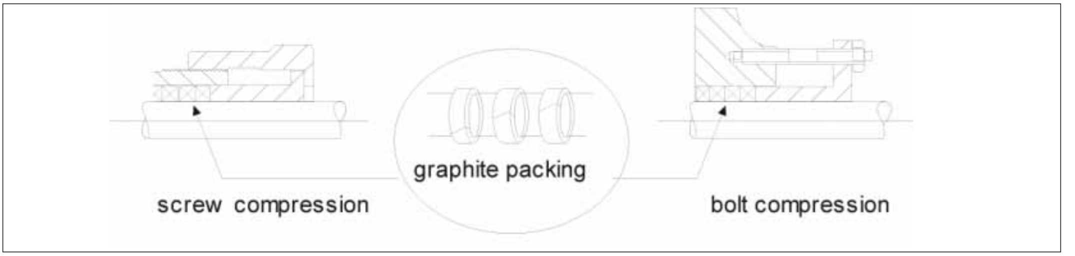


Figure 9.4: Packing.

3 Pumping hydraulics

3.1 Power

In order to transfer a certain quantity of water from one point to another, the pump must transmit energy to it. This quantity of energy is the same whatever the pumping technology, and is generated by the pump drive. This energy is calculated using Bernoulli's theorem (see Annex 12A), taking into account all the parameters of the energy balance of the system, such as pump altitude, head, length and diameter of the pipes. However, in order to simplify calculations in practice, two parameters that characterise any pumping system are used: the flow (Q) and the Total Manometric Head (TMH), (see Section 3.3 for definition of TMH). The power absorbed at the pump shaft is therefore given by the following equation (the specific gravity of water is 1):

$$P_{ef} = \frac{Q \text{ x } TMH}{367 \text{ x } \eta}$$

where P_{ef} is the effective power (kW, 1 kW = 1.36 HP), TMH the total manometric head (mWG (metres water gauge)), Q the flow (m^3/h) and η the pump efficiency. The optimum efficiency (between 0.8 and 0.9) lies in the working range of the pump (efficiency curve provided by the manufacturer).

The motive power necessary to drive the hydraulic section is always higher than the power absorbed by the shaft, bearing in mind various losses due to transmission, calculation uncertainties, head-losses at the pump level, and starting torque.

3.2 Suction head

The suction head is theoretically limited to 10.33 m, which corresponds to the suction pressure necessary to create a vacuum (expressed in water column height at normal atmospheric pressure) inside a pipe and to lift water.

In practice, however, suction head is less than that, because some of the pressure is required to transfer the required velocity to the water, and some is absorbed by head-losses in the suction pipe.

Furthermore, the suction pressure inside the pipe must not be less than the value at which the water vapour pressure is reached (water evaporation). For drinking-water pumps (temperature less than 20°C), the water vapour pressure is around 0.20 m head: beyond that point there is a risk of entraining water vapour. The water vapour bubbles thus formed in the suction pipe are re-compressed in the hydraulic section, which causes excessive rotor wear. This phenomenon, known as cavitation, reduces pump efficiency, and makes a characteristic noise caused by the implosion of the water vapour bubbles. Theoretically, at the pressure necessary to move water (at 20°C):

$$\text{Suction head} = 10.33 - 0.2 \text{ J (head-losses)}$$

Generally, the suction potential of a surface pump, depending on its characteristics and installation conditions, are determined by the NPSH (net positive suction head). This parameter is given by the

Table 9.III: Suction head depending on the pump type.

Types of surface pump	Maximum suction head	Examples of pumps
Surface-mounted manual piston pumps	7 – 10 m depending on model	Type VN6
Small electric centrifugal pumps	8 m maximum	All makes, all origins
Large electric centrifugal pumps	See NPSH	All makes Grundfos, KSB, Voguel
Surface-mounted centrifugal motor-driven pumps (petrol)	Up to 10 m with careful use	Robin, Tsurumi, Honda engines
Large surface-mounted centrifugal pumps (diesel)	See NPSH Max 7 m	Pumps with Lister engines

manufacturer depending on the pump output and installation conditions. The static suction head (Table 9.III) plus the head-losses must always be lower than the NPSH required for the pump.

In order to raise water beyond that height, it is necessary to use a submersible lift pump, rather than a suction pump.

All things being equal, the suction head also affects the total pressure head of the pump.

Suction pumps with a hydroejector are a particular kind of surface suction pump that can lift water beyond the theoretical suction head. One part of the water supplied by the pump is in fact pumped back into the hydroejector (2nd tube in the borehole) in order to be able to attain heights of water greater than 10 m; the pump efficiency is however somewhat reduced.

3.3 Flow and Total Manometric Head (TMH)

These two parameters are related directly to the usable flow and the height to which the pump can lift. This height, plus head-losses and the residual pressure at the end of the pipe, is expressed as follows:

$$TMH = (h_s + h_d) + J + Pr$$

where TMH is the total manometric head (mWG), $h_s + h_d$ is the suction head + the delivery head (m), J (m) is the head-loss due to piping and accessories (valves, bends) and P_r the residual pressure (mWG), i.e. the pressure at the outlet from the delivery pipe.

3.3.1 CHARACTERISTIC CURVE OF A PUMP

For a given pump, the higher the TMH, the less the flow provided by the pump. The various pairs of points (TMH-flow) form the characteristic curve of the pump. Outside this curve, the pump is not within its optimum configuration, which causes a drop in efficiency (Figure 9.5).

3.3.2 HEAD-LOSSES

The equation used to calculate head-losses (friction of the liquid against the walls, and change of section or direction) is the Colebrook-White formula (see Annex 12A).

In the majority of cases, the head-losses J are functions of linear head-losses (total pipe length Ls + Ld) and secondary head-losses (strainers, bends, valves). The latter can be estimated at 10% of the linear head-losses, except for surface pumps, where the secondary head-losses are calculated precisely in order to determine the maximum suction head (limited by the NPSH).

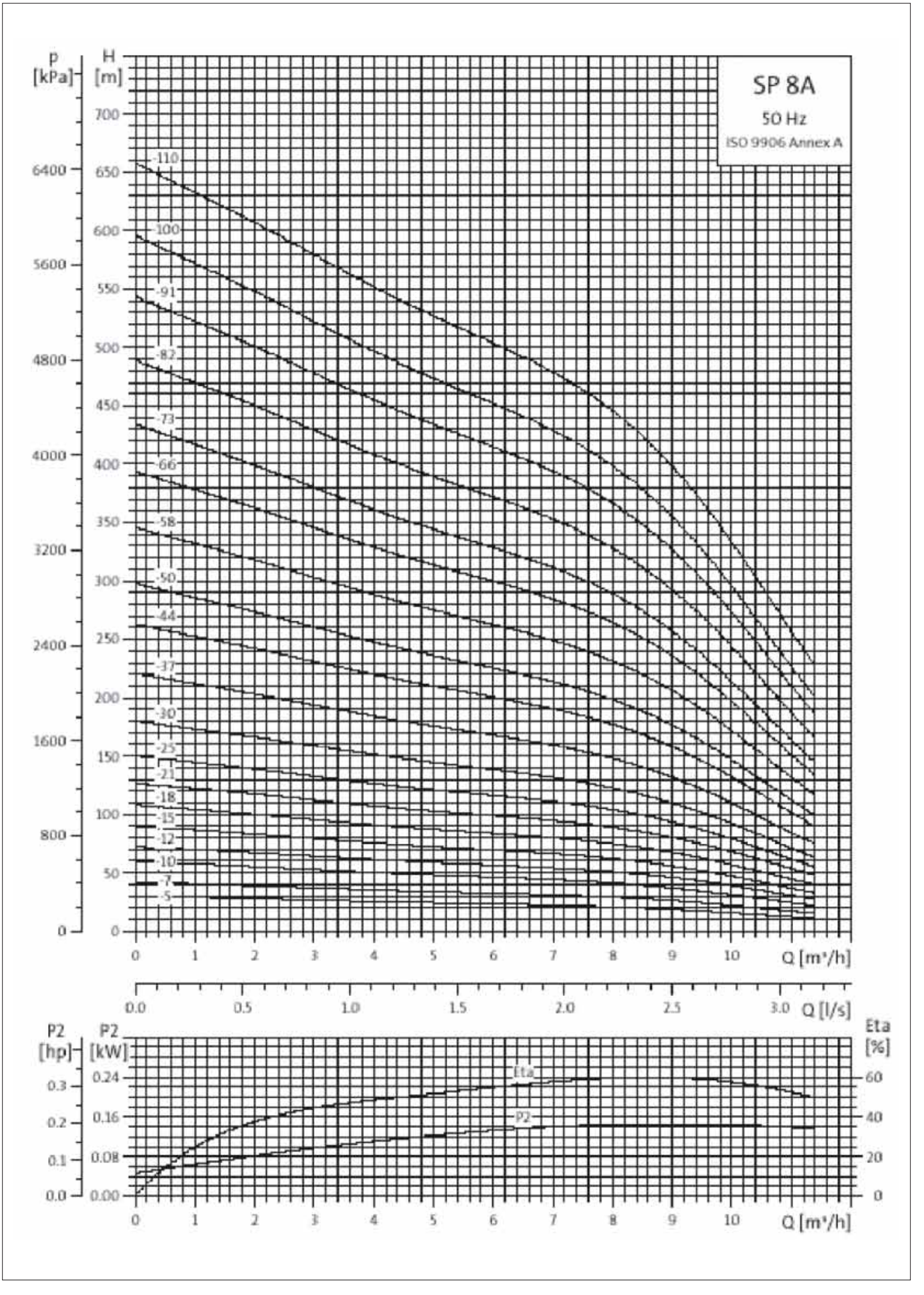


Figure 9.5: Characteristic curve for the Grundfos SP8A range of pumps, and efficiency curves where Q = flow, H = TMH, and η = efficiency.

3.4 Working point in a pipe system

This point is the TMH-flow pair corresponding to the pump function, taking into account the head-losses in the pipe system. When the pump operates, a particular working point is reached, corresponding to the balance between flow and TMH.

To calculate this working point in advance, a graph representing the characteristic curve of the pipe system is drawn. This graph is obtained by calculating the head-losses for different theoretical flows in the system (Table 9.IV). The intersection point of this curve with the characteristic curve of the pump gives the working point of the pump in the pipe system (Figure 9.6).

Table 9.IV: Head losses as a function of flow Q.

Q (l/min)	Static head (m) ($H = H_s + h_d$)	Head losses J (mWG)	TMH (m) (TMH = H + J)
0	25	0	25
125	25	9	34
250	25	32	57
300	25	44	69
380	25	66	91

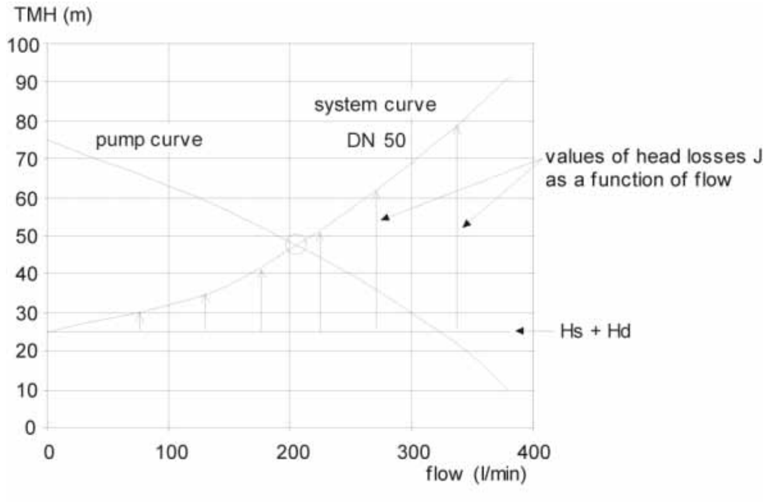


Figure 9.6: Working point (TEF2-50 pump in pipe system).

3.5 Particular characteristic curves

3.5.1 EFFECT OF ROTOR SPEED

The rotational speed of the shaft is usually measured in revolutions per minute (rpm).

If the rotational speed of a given pump rises from n_1 to n_2 rpm, the flow Q, the TMH, and the absorbed power P, change as in the following equations:

$$Q_2 = (n_2/n_1)Q_1 \qquad H_2=(n_2/n_1)^2H_1 \qquad P_2=(n_2/n_1)^3P_1$$

With an internal-combustion engine or a dc electric motor, this speed can be changed in order to adapt to a given situation. Certain manufacturers provide characteristic pump curves corresponding to

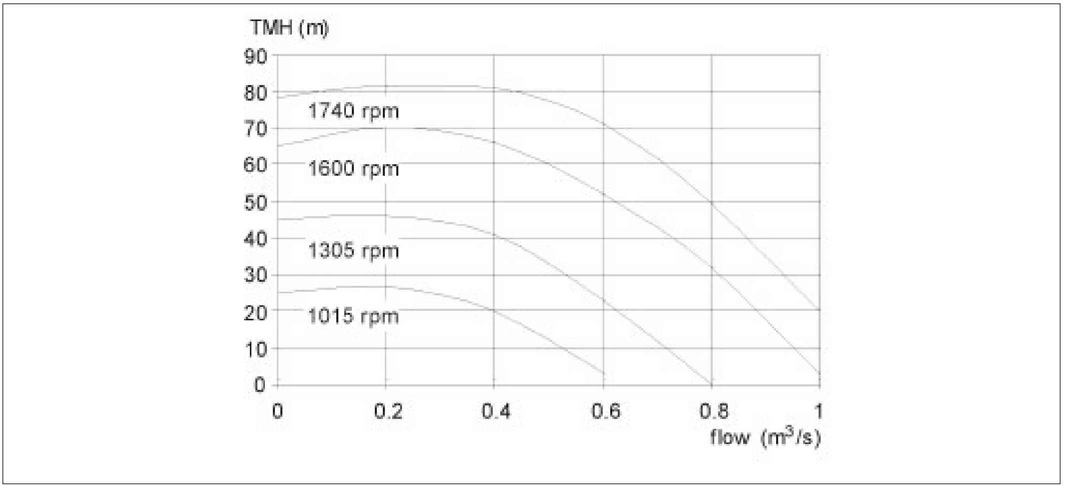


Figure 9.7: Characteristic curves for a centrifugal pump as a function of rotational speed.

specific rotational speeds (Figure 9.7). Usually, electric pumps have rotational speeds of 3 000 rpm for bipolar asynchronous motors (rotational speed = frequency / number of pairs of poles of the motor). This is the case for all submersible pumps without a speed regulator.

3.5.2 THROTTLING DELIVERY PIPES

By throttling delivery pipes with valves, it is possible to reduce the pump flow by increasing head-losses. This results in an immediate reduction in efficiency of the pump, and an increase in power requirement. Therefore, at larger pumping stations, using valves to reduce flow increases energy consumption considerably.

Also, too great a restriction risks operating outside the design range of the pump, thereby increasing mechanical stresses.

3.5.3 MOUNTING TWO IDENTICAL PUMPS IN SERIES

Mounting two pumps in series (Figure 9.8) increases the delivery head. If the initial flow of a single pump is maintained, the TMH is doubled. In practice, the TMHs may be added to create the characteristic curve required.

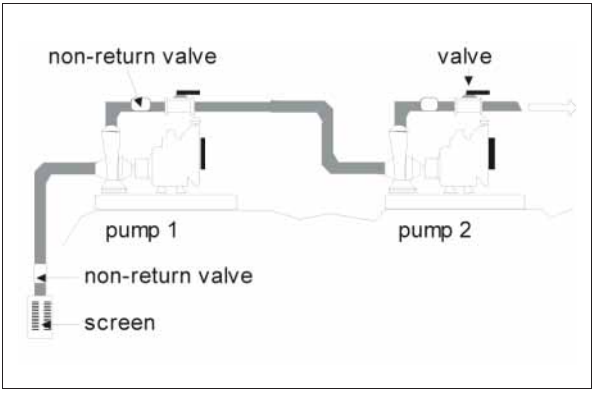


Figure 9.8: Mounting two identical pumps in series.

Table 9.V: TMH and flow for two pumps in series.

Function	Flow (l/min)	TMH (mWG)
Single pump in pipe system	200	50
Pumps in series in pipe system	290	65
Pumps in series with valve-controlled flow	200	100

For example, if two identical pumps, each capable of lifting 200 l/min to 50 m (e.g. Tsurumi TEF2-50 motorised pump, Robin engine) are mounted in series, they can lift a flow equivalent to 200 l/min with a TMH of 100 m. If the flow is not choked, the working point is established within the working curve in the network (Table 9.V and Figure 9.9).

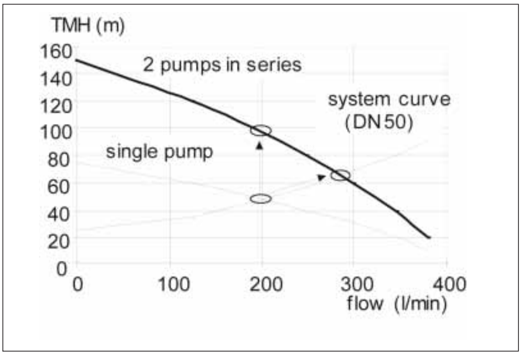


Figure 9.9: Characteristic curves for a single pump and for two pumps in series.

3.5.4 MOUNTING TWO IDENTICAL PUMPS IN PARALLEL

Mounting two pumps in parallel (Figure 9.10) allows the pumped flow in a pipe system to be increased. In practice, the flow of both pumps may be added, while maintaining the TMH, to draw the characteristic curve (Table 9.VI and Figure 9.11). But in a pipe system, head-losses J increase with flow, so it is not possible to double the flow.

Table 9.VI: Characteristic curves for two identical pumps in parallel.

Function	Flow (l/min)	TMH (mWG)
Single pump in pipe system	240	43
Pumps in parallel in pipe system	320	57

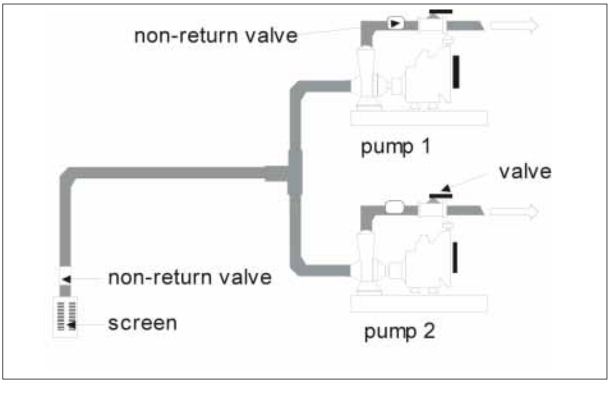


Figure 9.10: Mounting two pumps in parallel.

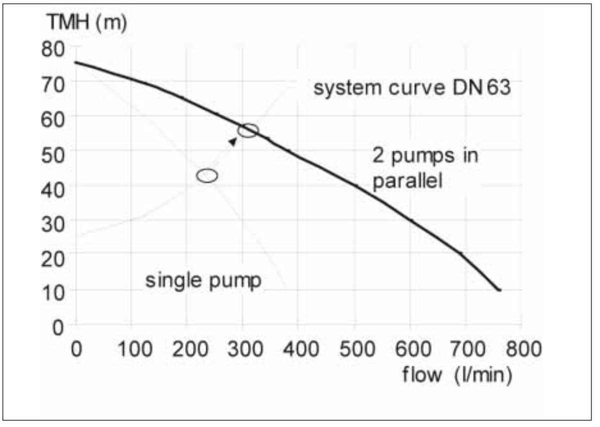


Figure 9.11: Characteristic curves for two pumps mounted in parallel.

3.5.5 MOUNTING TWO DIFFERENT PUMPS

It is possible to mount different pumps in series or in parallel. The principle is the same: in series the TMHs are added, while in parallel the flows are added. The working point can be determined by drawing the characteristic curve of the two pumps and the pipe system. In the example given in Figure 9.12, there is no point in connecting these two pumps for a TMH higher than 30 m; the flow will not increase. For a TMH of 20 m, the pump flow will be 600 l/min, instead of 350 l/min with the TEF2-50 pump used alone.

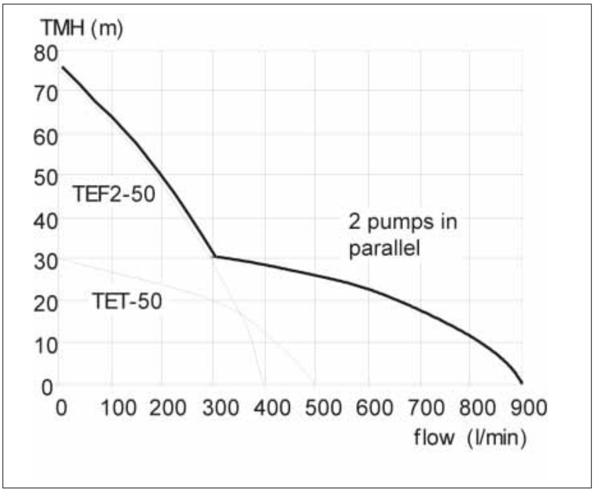


Figure 9.12: Characteristic curves for two different pumps in parallel (types TET-50 and TEF2-50).

4 Choosing a motorised pump

4.1 Surface centrifugal motorised pump

In the example given in Figure 9.13A, the motorised pump takes water from a depth of 5 m (H_s) and delivers it at a height of 25 m (H_d). The pipe used has an inside diameter of 40.8 mm (DN 50); the total length of the delivery pipe is 200 m (L_d), and the total length of the suction pipe is 6 m (L_s). The flow required is 2 l/s, i.e. 120 l/min, with a residual pressure of 1 bar, i.e. 10 m water head. The total manometric generated head is:

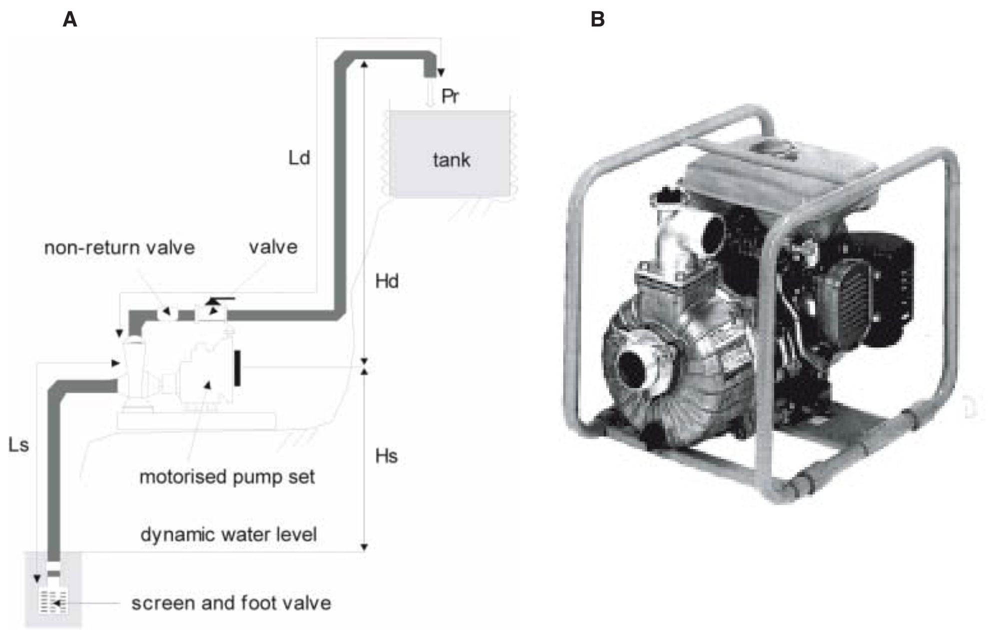


Figure 9.13: Surface-mounted motorised pump.
A: installation diagram. B: photograph.

$$TMH = H_s + H_d + J \text{ linear} + Pr + J \text{ secondary}$$

$$TMH = (5 + 25) + (206\ .\ 5{,}85\%) + 10.33 + 10\% \text{ of } J \text{ linear} = 53 \text{ m}$$

A pressure of 1 bar is equal to 10.33 mWG under normal temperature and pressure conditions; 5.85% represents the head-loss coefficient per m of pipe for the given conditions (DN 50 pipe, flow 2 l/s – see Chapter 11 and Annex 12A). Calculating the TMH allows the TMH-flow pair (53 m, 120 l/min) to be determined in order to choose a suitable pump.

Here, the corresponding pump is the TEF2-50 (Figure 9.12). The manufacturers give the characteristics of the pumps in the form of families of curves (see Figure 9.15). Normally, a technical file (Table 9.VII) is created to avoid errors in dealing with the order (choice of pipes, markings, type of fuel etc.).

Table 9.VII: Technical file for a pump.

DN suction (mm)	50
DN delivery (mm)	1 x 40 + 2 x 25
Maximum flow (l/min)	400
Maximum TMH (m)	75
Working point	
Flow (l/min)	120
TMH (m)	53
Application	Pumping from a stream
Engine	ROBIN EY-20D
Power (hp, rpm)	5.0/4 000
Type / fuel	4 stroke, air-cooled, petrol

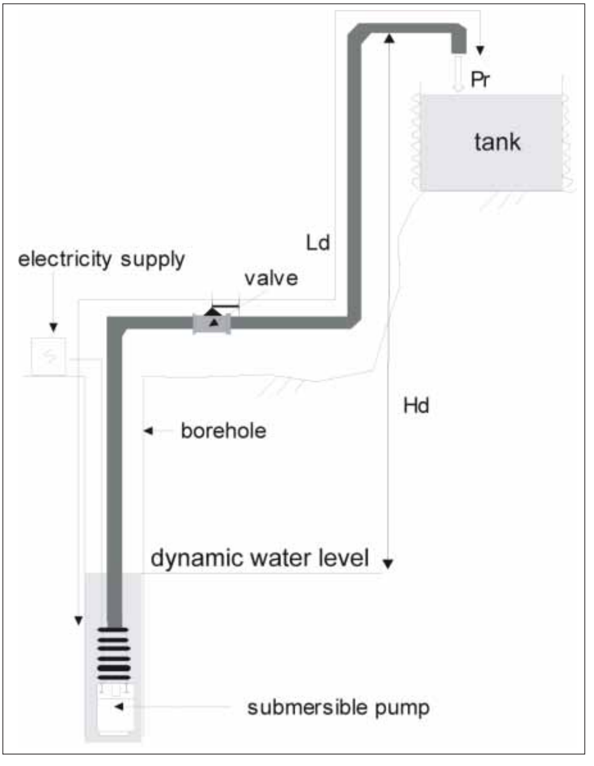


Figure 9.14: Installation plan for a submerged multistage electric pump.

4.2 Submersible electrical pump

To calculate the TMH of an submersible electrical pump (shown in Figure 9.14), the same procedure as that given in paragraph 4.1 is followed:

$$TMH = (60 + 25) + (260\ .\ 5.85\%) + 10.33 + \text{Secondary} \approx 120 \text{ mWG}$$

Strictly speaking, secondary head-losses should be calculated. In the case of a submersible lift pump (no suction head), this term is sometimes neglected or arbitrarily taken as 10%.

The coding of Grundfos pumps is presented in the form SP 5 A 12, for example, where SP stands for submersible pump, 5 the exploitation flow range (5 m^3/h) and 12 the number of stages (multi-stage pump).

For the example given, a pump capable of producing 7.2 m^3/h at 120 mWG is required. It is therefore necessary to choose the SP 8A series (Figure 9.15) and, from that series, the 30-stage pump (Figure 9.5) is the SP 8A 30. Table 9.VIII indicates the external diameters of the pumps for 4" and 6" boreholes.

Table 9.VIII: Diameters of Grundfos submersible pumps.

Pump range	Diameter (mm)	Diameter (mm)	Diameter (mm)
SP1A - 5A	95		
SP8A - 5 to 25		101	
SP8A - 30/50			138
SP 14A		101	
SP 45 A			145 to 192

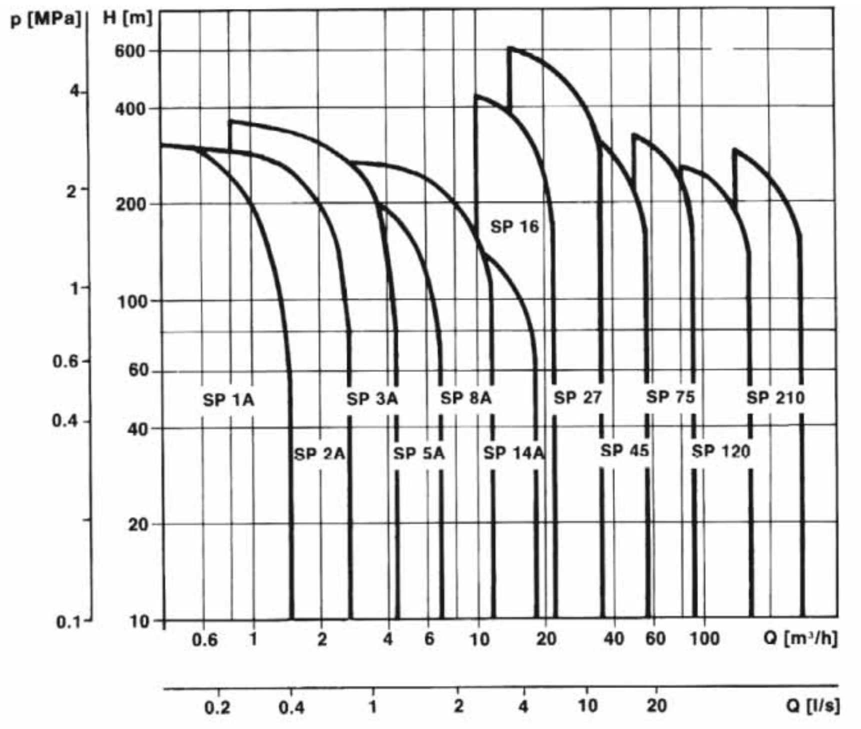


Figure 9.15: Range of Grundfos pumps.

The pump can work from electric mains or a generator, with connections consisting of:
– a waterproof cable to connect the pump to the control board;
– a control board linking up with the generator or mains.

5 Electricity supply

Depending on the situation in the field, the electrical supply may come from:
– the mains (mainly in an urban environment);
– a generator (where there is no suitable mains supply);
– a solar energy system.

Each system has its own constraints (technical level required, equipment and running costs, payback period, equipment maintenance), which must be evaluated (Table 9.IX). All things being

Table 9.IX: Various electricity supplies for pumps.

Supply	Aspects to be evaluated or verified
Mains	Reliability of the mains: phases, power cuts, voltage drops Installation of a transformer; supply cable (length and diameter), power losses
Generator	Generator capacity; supply cable (length and diameter); phases
Solar	Power needed; number of photovoltaic panels Inverter – supply cable (length and diameter)

equal, a solar installation is better in terms of running costs, but will be much more expensive than installing a standard generator.

5.1 Power and current

Whatever the type of electricity supply, it is fundamental to estimate the power consumed by the electric motor of the pump. Section 3.1 explains in detail how to calculate the power depending on the TMH and flow. The power consumed by the pump motor can now be determined.

5.1.1 PERFORMANCE

Depending on the type of transmission between the pump and motor, the efficiency, or ratio between the effective hydraulic power and the mechanical power provided by the motor is:
– 85% to 90% in the case of a direct shaft drive;
– 70% in the case of a belt drive.

$$P_{motor} = \frac{P_{ef}}{0.7}$$

5.1.2 ELECTRICAL POWER

Nominal power: $P = VI$ (kVA), is the power used to designate generators.

Actual power: $P = VI \cos \phi$(kW), is the power used to calculate the consumption of motors. It takes into account the reactive power factor $\cos \phi$, equal to 0.8.

5.1.3 CURRENT AND VOLTAGE

On the motor specification plates, two values of current are given:
– nominal current I_n, drawn during normal running;
– starting current I_s, drawn when the motor starts, greater than I_n.

5.1.3.1 Nominal current absorbed by the motor

– for dc: $I_n = (Pn \times 1{,}000)/(V\rho)$
– for single-phase ac: $I_n = (Pn \times 1{,}000)/(V\rho\cos \phi)$
– for three-phase ac: $I_n = (Pn \times 1{,}000)/(\sqrt{3}V\rho\cos\phi)$

where I_n is the nominal current (A), Pn the nominal power of the pump motor (kW), V the voltage (V) and ρ the motor efficiency.

The more powerful the motor, the higher its efficiency. For 50 kW motors, the efficiency is 0.85; for 1 kW motors it is lower, about 0.70. The higher the hydraulic head-losses, the lower the efficiency. A full-load current C can then be defined for minimum head-losses and optimum performance. Choking (increase of head-losses) causes a decrease in motor efficiency, and therefore a higher power consumption than the normal regime (see Section 3.5.2).

Motors of 1 to10 kW AC running at 3 000 rpm draw the following currents:
– single-phase 220 V: 5.0 A per kW;
– three-phase 220 V: 3.8 A per kW;
– three-phase 380 V: 2.2 A per kW.

5.1.3.2 Starting current and power required

When the motor starts, the power absorbed (for running up the electric motor and hydraulic gear from 0 to 3 000 rpm) is very much higher than the nominal power. As the voltage is fixed, the current increases. Manufacturers generally give the ratio Is/In, which gives the voltage absorbed when the pump is started directly. The actual value (around 6) is noted on the pump motor plate.

The power of the generator or the mains to which the pump is connected must be sufficient for the starting current I_s. This therefore is the term used for calculating the generator power necessary to drive the pump, using the following formula:

$$P\ (kVA) = VI_s$$

Since this current is absorbed in a very short time, an empirical calculation for generator design is suggested (see Section 5.2.2).

5.1.3.3 Voltage drop

The motor works optimally at a certain voltage. The size of the supply cables must be calculated so as not to cause a voltage drop of more than 5% at the motor terminals (Table 9.X). The size of the cables is given by the following formula:

$$A = \frac{L\rho IC}{V\Delta v}$$

where A is the cable cross-sectional area (mm^2), L its length (m), ρ its resistance ($\approx 0.02\ \Omega.mm^2/m$), I the current (A), C a coefficient depending on supply, V the nominal voltage (V), and Δv the maximum voltage drop (5%).

$C = 2\cos\phi \times 10$ in case of direct single-phase start.

$C = \sqrt{3}\cos\phi \times 100$ in case of direct three-phase start.

Table 9.X: Number and cross-sectional area of cables depending on motor power and supply (power lines of 100 m or more).
Standard cross-sectional areas: 1.5, 2.5, 4, 6, 10 mm².

Motor power (kW)	Single-phase 220 V	Three-phase 220 V	Three-phase 380 V
0.55	3 / 1.5 mm²	4 / 1.5 mm²	4 / 1.5 mm²
1.1	3 / 2.5 mm²	4 / 1.5 mm²	4 / 1.5 mm²
2.2	–	4 / 2.5 mm²	4 / 1.5 mm²
3.7	–	4 / 2.5 mm²	4 / 1.5 mm²
5.5	–	4 / 4 mm²	4 / 1.5 mm²
11	–	4 / 6 mm²	4 / 2.5 mm²

5.2 Generator choice

The generator is chosen on the basis of the characteristics of the pump motor. A three-phase pump is always supplied by a generator providing three-phase current. A single-phase pump can be supplied by a single-phase generator, or preferably by a three-phase one, in order to reduce starting-current problems. A starter box is necessary for single-phase motors.

Theoretical calculations are not sufficient to choose a generator correctly, since they do not take into account their characteristics, which vary depending on the power-generation technology. For relatively low power ranges (< 10 kVA), an empirical calculation is recommended. For much higher power levels, progressive starting is normally the most suitable solution to solve starting-current problems.

5.2.1 THEORETICAL POWER CALCULATION (MOTOR AND GENERATOR)

The characteristics of the SP8A-25 pump motor are given by the manufacturer:

– $I_{nominal} = 8.9$ A
– $I_s/I_n = 4.4$ (< 6)
– $\cos \phi = 0.87$
– $I_s = 8.9 \times 4.4 = 39.2$ A
– power consumed by the pump motor:
  P = VI Cos ϕ = 380 X 8.9 X 0.87 = 2.9 KW
– power required from the generator:
  P(VA) = VI = 380 x 8.9 = 3.4 kVA
– starting power required from the generator:
  P (VA) = VI_s = 380 x 39.2 = 14.8 kVA

The power required from the generator that supplies this pump should, according to the calculations, be 14 kVA. In fact, two additional factors are taken into account in the final choice: the starting frequency and the fact that the motor is three-phase, which has a lower starting torque than a single-phase motor.

5.2.2 EMPIRICAL CALCULATION

Making an approximation for generators of less than 10 kVA, the power of the generator is twice the nominal pump motor power, plus 25%:

$$P_{gen} = (P_{pump} \times 2) + 25\%$$

So, in this example: $P_{gen} = (2.9 \times 2) + 25\% = 7.25$ kVA.

6 Dewatering pumps

6.1 Principle and material

In contrast with standard submersible pumps, these lift pumps are capable of pumping turbid water (containing mud or sand). They are used, for example, for pumping out excavation sites.

This type of equipment is used for pumping out wells, and they are more appropriate for this than motorised surface pumps, which are limited by their maximum suction lift, which is 10 m, and also, for obvious safety reasons, it is absolutely out of the question to lower a motorised pump into a well while diggers are working in it (it would be impossible to evacuate the exhaust gas).

These pumps can also be used for any kind of pumping from a stream, to supply a water-treatment station (emergency water-supply system) or for irrigation.

Experience has led to the development of both electric and pneumatic water pumps.

For well digging, pneumatic pumps, despite their cost, (pumps plus compressor) seem to be the most suitable (robust, safe, no electricity at the bottom of the well). They work with a small compressor, providing a minimum of 6 bars and 35 l/s, and can also be very useful on other jobs on the site (e.g. pneumatic hammers).

On the other hand, for any kind of pumping from a stream or river (drinking or irrigation water), electric water pumps are more suitable due to their low bulk, their hydraulic efficiency (TMH-flow) and their lower purchase and running costs (generator consumption is low compared to that of a compressor).

6.2 Electric dewatering pumps

The characteristics of the model quoted (Figures 9.16 and 9.17) provide a multi-purpose pump for everyday situations. There are obviously other ranges of pumps depending on specific applications.

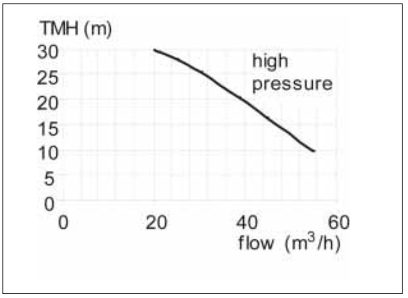


Figure 9.16: Characteristic curve for an electric dewatering pump.

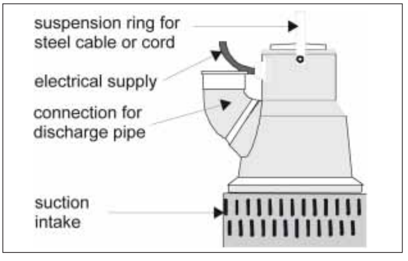


Figure 9.17: Electric dewatering pump. Model 2102 HT 234; weight: 50 kg; height and diameter: 660 x 470 mm; discharge diameter: 2"; nominal power: 4.6 kW; supply voltage: 380 V, 50 Hz three-phase or 220 V, 50 Hz three-phase

6.3 Pneumatic water pumps

Using a pneumatic pump and pneumatic hammer for well digging (Figure 9.18) requires an alternation of pumping phases (pump valve open) and digging phases (hammer valve open). Air containing oil vapour is toxic (masks are needed for workers), and it is advisable to keep lubrication to a minimum. Simple daily lubrication of the equipment will solve this problem.

The model selected by ACF is a membrane pump with characteristics as given in Figure 9.19.

7 Renewable energy pumps

Nowadays, solar pumping technology is widely available from various manufacturers. It can be useful for water supply to a medium-size village. However, flows and TMH remain limited (a maximum of 100 m^3/day/100 m). Also, the area of the solar panels to be installed quickly becomes significant, with consequent increases in cost. Maintenance of these installations must be considered under the same terms as that of a conventional installation, even if the running cost is very low: it is necessary to ensure the availability of spares and the training of technicians for this method. Turning to solar energy must not lead to false ideas about the cost of the water and maintenance of the installation.

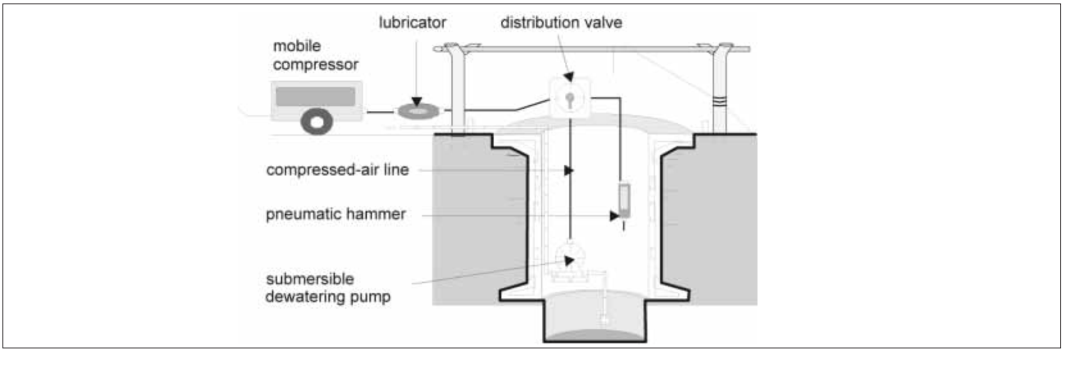


Figure 9.18: Using a pneumatic pump and a pneumatic hammer in well digging.

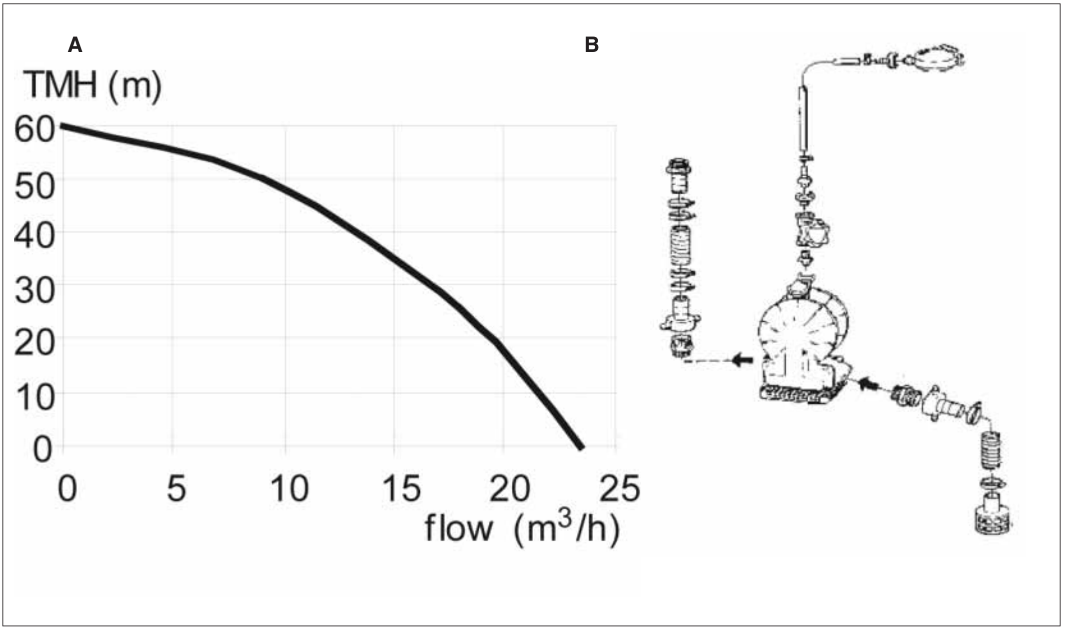


Figure 9.19: Membrane dewatering pump.
A: characteristic curve. B: exploded view. Weight: 31 kg; H x W x L: 60 x 40 x 35. Discharge: DN 2.5"; compressed-air pressure 6 bar, flow 34 l/s, air inlet: DN 0.75".

ACF's experience with pumps using the Nile current at Juba (Sudan) is an alternative which deserves to be presented in this section about pumping with renewable energy.

7.1 Solar pumping

7.1.1 SOLAR ENERGY

Solar panels convert solar energy (excitation of photons) into electrical energy (excitation of electrons). This energy can be stored in batteries (accumulators) to allow continuous running, or be transmitted directly to the electrical equipment.

There are thus two possible approaches:

– direct solar pumping (Figure 9.20) ;

– battery storage (refrigerator, lighting, radio etc.).

Solar pumping is always carried out directly to avoid the need for accumulators (e.g. batteries), which are costly and have to be changed every two or three years. In a water system, the elevated tank takes on the role of the accumulator:

– the solar panels provide the power needed to drive the pump. Mounting them in series provides the voltage necessary for the converter (the voltages of the modules are added to each other);

– the converter supplies the pump with 220 V a.c. from the direct current provided by the solar panels. The rotor speed and therefore the flow of the pump vary depending on the hours of sunshine, with maximum flow occurring in the middle of the day (strong sunshine).

The electricity produced by the panels is several amps d.c., at a voltage of 12 to 18 V, and, depending on the model, providing power of 60 to 90 Wc (4.86 A, 18.5 V and 90 Wc for the BP Solar 590).

The performance of solar panels depends on the hours of sunshine, angle of incidence, and cell temperature. These parameters depend on latitude as well as on the local climatic and geographic characteristics. A study is always necessary to determine the panel area required.

7.1.2 SOLAR PUMPING STATION DESIGN

7.1.2.1 Principle

To define the solar panel power necessary for pumping, the geographical situation must be known in order to determine the hours of sunshine and the total solar radiation (HSP: hour sun peak), as well as flow and TMH. The following procedure must be followed:

– definition of the HSP (kWh/m^2/day), depending on the maximum number of hours of sunshine and length of day. The HSP is therefore defined in relation to the latitude of the site;
– choice of pump depending on flow and TMH (Table 9.XI);
– use of the efficiency charts of the pumps provided by the manufacturer to obtain, depending on the HSP, the necessary power developed by the panels (Wp) to operate the pump in this range of flow and TMH (see Figure 9.21);
– determination of the number of panels: Wp/Pn (nominal power of each panel);
– verification of the nominal voltage to operate the inverter (depending on model);
– calculation of instantaneous flow at maximum hours of sunshine, using the chart providing flow depending on power Wcc = 0.8 x Wp.

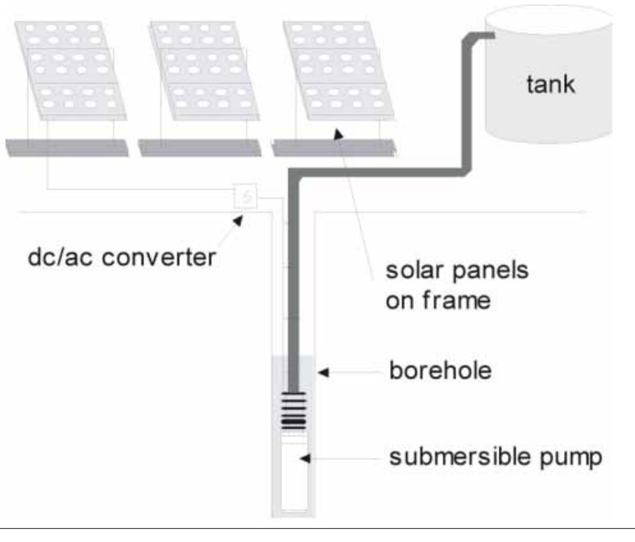


Figure 9.20: Supplying a pump using solar panels.

Table 9.XI: Main Grundfos solar pumps with mean daily flows (HSP 5.7; temp 30°C; 20° N latitude; inclination 20°).

Pump	TMH (m)	Mean daily flow (m^3/day)
SP1.5A-21	80-120	10
SP2A-15	50-120	15
SP3A-10	30-70	20
SP5A-7	2-50	35
SP8A-5	2-28	60
SP14A-3	2-15	>100

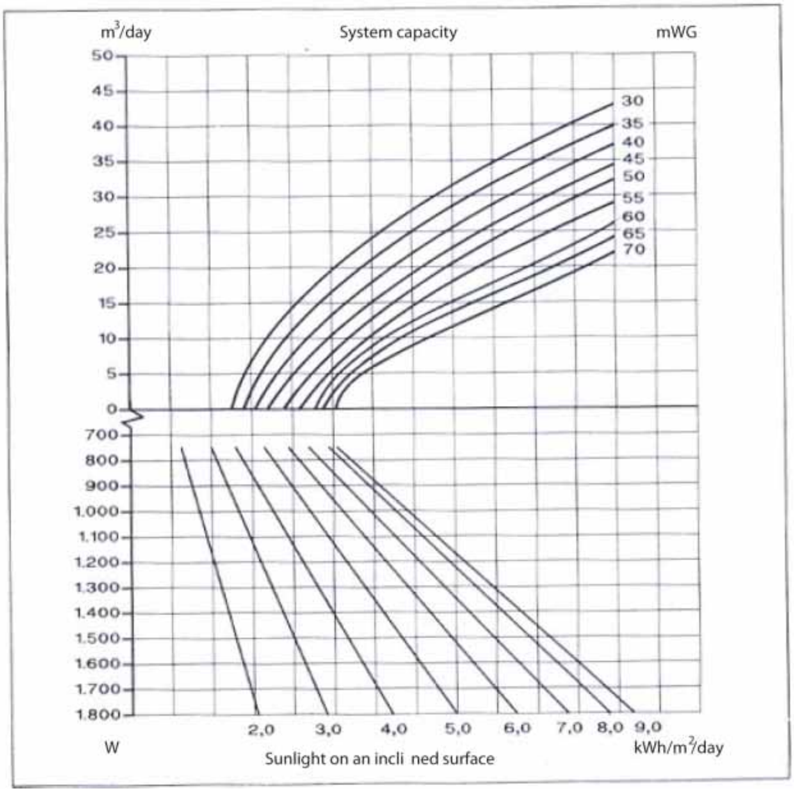


Figure 9.21: Design chart for SP3A-10 pump for 11 hours of sunshine per day and average temperature of 30°C.

7.1.2.2 Example of a pumping station

Basic data:

– TMH 65 m, Q = 10 m^3/day;

– station in Mali, HSP = 5.7 kWh/m^2/day.

In the case of an SP3A-10 pump, the chart in Figure 9.21 gives a useful motor power (Wp) of 1 400 W.

To equip the installation with BP Solar 590 panels to provide 90 Wc requires: Wp/Pn = 1 400/90 = 15.5 panels.

Therefore, with the inverter working under a nominal voltage of 110 V, seven 18-V panels mounted in series are necessary.

The station will therefore be composed of 21 panels, 3 modules (in parallel) of 7 panels each (in series).

Instantaneous flow is Wcc = 1 890 (90 x 21) x 0.8 = 1512 W; according to the chart, the pump will provide 3.5 m^3/h.

7.2 Hydraulic energy

Garman pumps, made under licence in England and Khartoum (Sudan), are centrifugal surface pumps that use the motive force of the current of a river or stream on a turbine to drive the pump shaft.

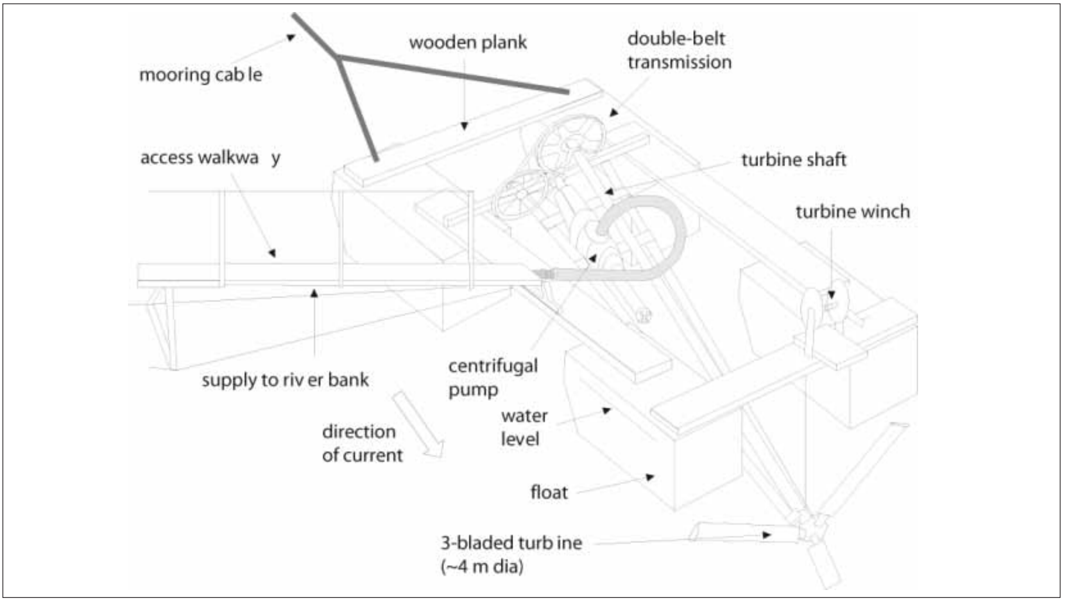


Figure 9.22: Garman pump installed on a raft.

These pumps can work continuously (24 h/24) provided that the watercourse has a minimum speed of 0.85 m/s, and a depth of about 3 m (Figures 9.22 and 9.23). They can be used to provide drinking water, but are especially useful for irrigation water, bearing in mind their low lift height, low running cost reduced to the simple maintenance of the pumps and turbine (blades), and finally the absence of fuel.

The choice of turbine blades depends on the speed of the current and the depth of the watercourse (Table 9.XII).

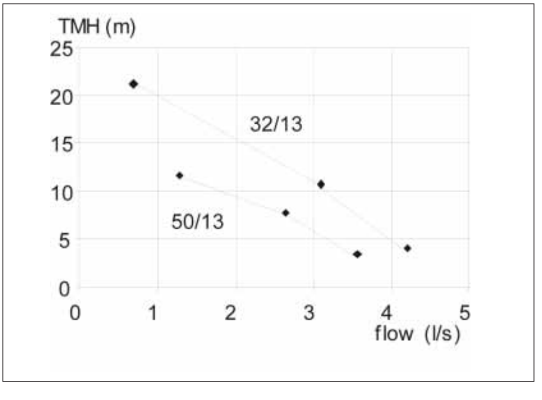


Figure 9.23: Characteristic curves for Garman 32/13 and 50/13 pumps.
Current speed: 0.85 – 0.9 m/s; large blades (ACF, Sudan, 1996).
These two pumps mounted in series on the Nile at Juba produced around 2 l/s for a TMH of 25 m.

Table 9.XII: Lengths of turbine blades as a function of the characteristics of the watercourse.

	Speed of the current (m/s)		
Depth	0.7-1	1-1.2	1.2-1.4
2.5 to 3 m	—	—	80 cm
3 to 3.5 m	—	100 cm	80 cm
3.5 to 4 m	120 cm	100 cm	80 cm

7.2.1 ROTARY SPEED OF THE PUMP

Here, the rotary speed of the pump depends on the speed of the current, and also on the diameter of the pulleys which transmit that rotation to the pump shaft:

$$\omega_{pump} = (\phi_1 / \phi_2)\ (\phi_3 / \phi_4)\omega_{screw}$$

where ϕ is the diameter of the pulleys and ω the rotational speed of the shafts (rpm). For example, if the turbines turns at 21 rpm, the pump shaft will turn at 2 320 rpm with the pulley configurations shown in Figure 9.24.

Table 9.XIII: Adjustment of rotary speed of a Garman pump.

Ratio	Modification to be carried out
r < 1.45	Reduction of pump pulley diameter
1.45 < r <1.55	Acceptable working range; a 1.55 ratio is the best setting
r > 1.65	Increase in turbine blade size and pump pulley diameter

7.2.2 PERFORMANCE TEST

Empirically, the speed of the turbine shaft is measured in revolutions per minute (rpm) light or under load (pump connected by the set of belts to the turbine shaft). The ratio $r = \omega_{light}/\omega_{load}$ gives the efficiency of the installed pump (Table 9.XIII).

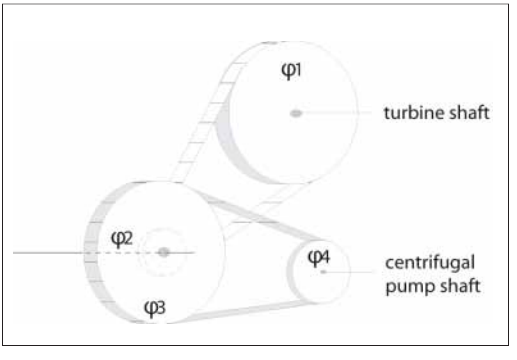


Figure 9.24: Mounting plan for pulleys.

Pulley	Diameter (mm)
ϕ_1	49.5
ϕ_2	5.6
ϕ_3	50
ϕ_4	4

Table 9.XIV: Components necessary to mount a Garman pump.

Denomination	Quantity
Type 32/13, 40/13 or 50/13 centrifugal pump	1
Turbine transmission shaft (3” galvanised tube)	1
Long, medium or short blades (80, 100 or 120 cm)	3
Turbine shaft ball bearing	2
Turbine shaft drive belt	1 + spare
Pump transmission belt	1 + spare
Intermediate shaft roller bearings	2
Large pulley	2
Stainless steel winch cable	1
Intake non-return valve with screen	1
Pump pressure gauge	1
Raft for pump installation	1
Steel mooring cable	1
Access walkway	1

7.2.3 COMPONENTS OF A GARMAN PUMP

The list of components is given in Table 9.XIV. The price of a Garman pump, made in Khartoum, is about USD 2 000.

8 Handpumps

Handpumps are normally used for boreholes and wells. They allow wells to be sealed against contamination and, in many cases, may increase the amount of water lifted.

Most handpumps are volumetric pumps with a submerged piston, controlled by a mechanical linkage or a hydraulic one (system developed by A. Vergnet). Some of them can pump water to a height of more than 60 m.

Several types of durable handpump have been developed to meet field conditions, especially intensive use. The choice is carried out on the basis of technical and socio-economic criteria (Table 9.XV).

Table 9.XV: Selection criteria for pump installation.

Technical criteria	Socio-economic criteria
Pumping depth and desired flow	Existence of a spares distribution network
Pump diameter	Pump tested and accepted by the population
Ease of installation and maintenance	Pumps already installed in the zone
Durability and reliability of the pump	State or inter-agency directives
Type of pumping:	Cost
– lift to reservoir	
– drive by motor + belt possible	

Type of pump	Diameter of pipes (borehole)	
Suction pump type VN6	2”	DN 50 (52 mm interior)
Vergnet 3C	3”	DN 75 (82 mm interior)
Other pumps	4”	DN 100 (103 mm interior)
Kardia K65	$4"^{1/2}$	DN 115 (113 mm interior)

8.1 Main types of handpump

Handpumps are classified according to their installation depth (Table 9.XVI): suction pumps for dynamic levels less than 7 m; lift pumps for dynamic levels greater than 7 m; pumps adapted to

Table 9.XVI: Usual working range of handpumps.

10 m	20 m	30 m	40 m	50 m	60 m	70 m	80 m	90 m	100 m

.... Tara ....
.... Vergnet HPV 30 ....
.... India Mark 2 ....
.... Aqua/Afridev ....
.... Kardia ....
.... Vergnet HPV 60 ....
.... Volonta ....
.... Monolift ....
.... Vergnet HPV 100 (*) ....

* 2 persons pumping.

great pumping depths (> than 35 m). Vergnet and Monolift pumps also have the capacity of delivering water to elevated tanks (this requires pump-head sealing).

The working flows of handpumps vary depending on the installation depth and the type of pump. For example:

– Aquadev pump installed at 15 m: 1.4 to 1.8 m^3/h;
– VN6 suction pump at 6 m: 1.5 to 1.8 m^3/h;
– HPV 60 Vergnet pump at 35 m: 1 m^3/h.

Mean flows, depending on pumping rate (strokes per minute), are given by the manufacturers.

8.2 Piston pumps

8.2.1 SUBMERGED PUMPS

The working principle of these pumps is described in Figure 9.25. The various submerged elements are presented in Figure 9.27.

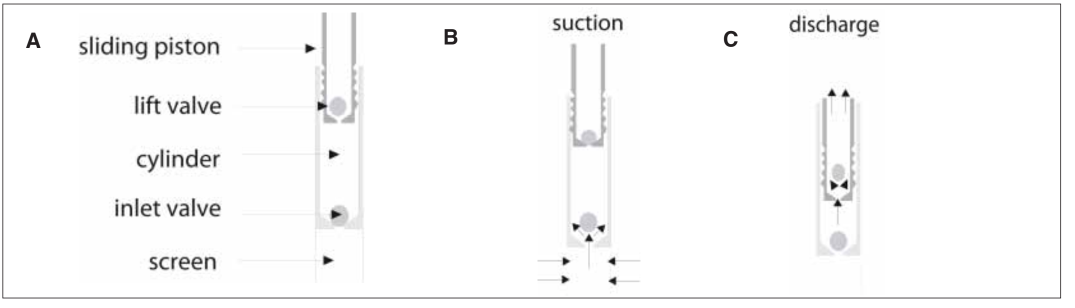


Figure 9.25: Working principle of a piston pump.
A: outline principle. B: piston rises, inlet-valve opens, lift-valve closes, chamber fills with water. C: piston falls, lift-valve opens while inlet-valve closes, chamber empties.

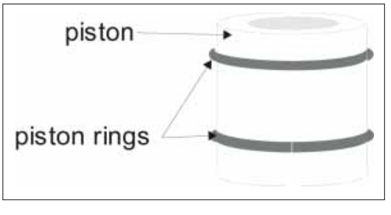


Figure 9.26: Piston sealing – piston rings.

The rings which ensure piston/cylinder sealing (Figure 9.26) are subject to continuous friction, and are therefore wear components. Some manufacturers have eliminated them (hydraulic seals).

There are all sorts of valves used in handpump cylinders (Figure 9.27). Any valve malfunction can mean a drop in pump

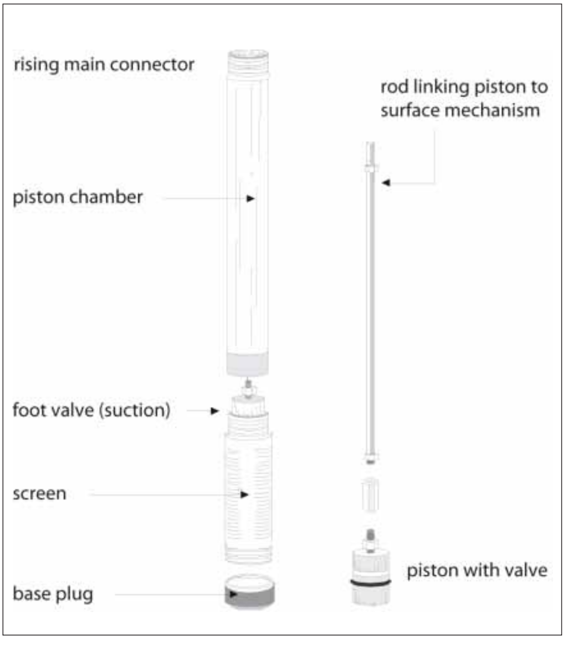


Figure 9.27: Kardia pump cylinder.

Examples of piston lift pumps are given in Figures 9.28 to 9.31.

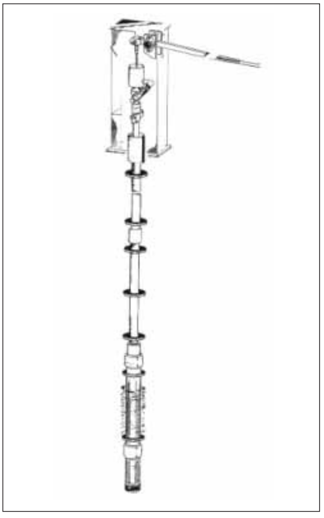


Figure 9.28: Kardia K65 and K50 pumps (for very large depths).

Manufacturer	Preussag AG
Pump head and handle	Galvanised steel
Pump rods, rising main	Screwed stainless steel and PVC tubes
Pump body	Stainless steel
Piston, cylinder	PVC
External diameter	K 65: 70 mm; K 50: 50 mm
Total weight (25 m)	110 kg
Price	2400 euros ex-works (45 m)
Performance (40 strokes/min)	K 65: 1 m^3/h at 30 m; K 50: 672 l/h at 45 m
Advantages	Excellent corrosion resistance Ease of installation (screwed PVC) Good manufacturing quality
Disadvantages	Frequent loosening of the handle ball-bearing Fixing screws (use a product such as Frenbloc) High purchase cost

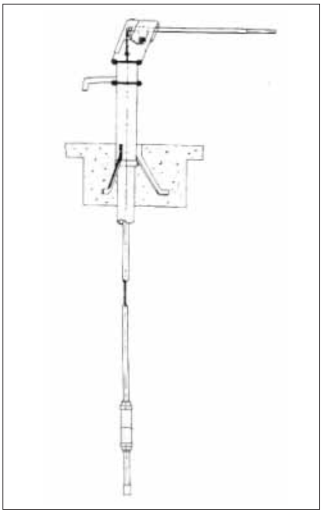


Figure 9.29: India Mark II pumps.

Manufacturers	Local, or French (Soverna)
Pump head	Galvanised steel
Pump rods, rising main	Galvanised steel
Pump body	Varies with manufacturer: stainless steel (Mali) or galvanised steel (India)
Total weight	120 kg for 25 m
Price	600 – 750 euros (25 m)
Performance (40 strokes/min)	700 l/h at 25 m
Advantages	Subsidised by UNICEF, low purchase cost
Disadvantages	Problems with transmission chain Tripod recommended for installation (heavy pump) Mark III version too heavy (pipes in 3" G.I.)

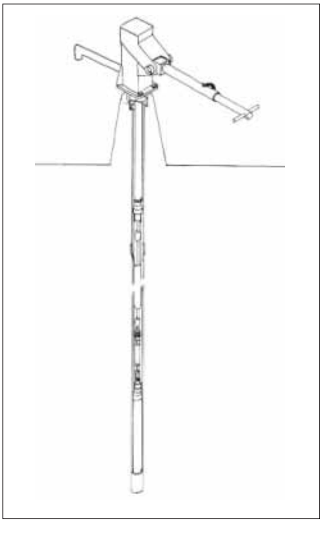


Figure 9.30: Aquadev and Afridev pumps.

Manufacturers	Aquadev-Mono pumps (England), or local (Kenya, Mozambique)
Pump head	Microwelded stainless steel
Pump rods, rising main	Steel and PVC
Pump body	PVC
Piston	Synthetic
Total weight	100 kg for 25 m
Approximate price	750 euros ex-works (25 m)
Performance (40 strokes/min)	1.3 m^3/h
Advantages	Good manufacturing quality with Aquadev Piston and foot valve completely demountable without removing PVC outlet pipe
Disadvantages	PVC column fixed with adhesive thus difficult to remove PVC quality poor, depending on manufacturer (Afridev) Afridev rod-fixing brackets unreliable

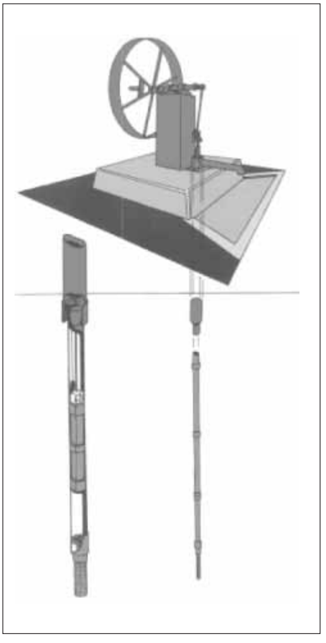


Figure 9.31: Volanta handpump.

Manufacturer	Jensen Venneboer (Netherlands)
Pump stand	Mild steel painted
Flywheel	Mild steel painted
Rising main	PVC
Pump cylinder	Reinforced epoxy resin
Plunger / pump rods	Stainless steel
Valves	Rubber
Total weight	700 kg
Approximate price	3 500 euros (without pipes)
Discharge at 75 watts	20 m head: 1.5 m^3/h, 50 m head: 1 m^3/h, 80 m head: 0.5 m^3/h
Pumping lift	10 – 80 m
Advantages	Good quality materials, durability, strength It allows water to be lifted to elevated places and to be pumped to a safe distance from the well (decreasing the risk of contamination of the water point, useful for cattle watering) Can be coupled with a windmill or motor
Disadvantages	High cost Difficult local manufacture Difficult to handle by children Requires very clean water or the piston can block

Examples of piston lift pumps are given in Figures 9.28 to 9.31.

8.2.2 SUCTION PUMPS

The VN6-type suction piston pump is made locally in South-East Asia (Figure 9.32). Its simplicity in design and manufacture make it a pump which is very cheap (USD 30), but it suffers frequent pump-body fractures (poor quality). Manufacturing quality varies depending on country (Bangladesh, Vietnam, Myanmar). Its use is possible up to dynamic levels of 8 to 9 m, with the installation of a supplementary foot valve, because the valve in the cylinder is usually of poor quality. A steel pedestal, to which the shoulder bolts are screwed, is necessary, to avoid embedding the bolts in the baseplate.

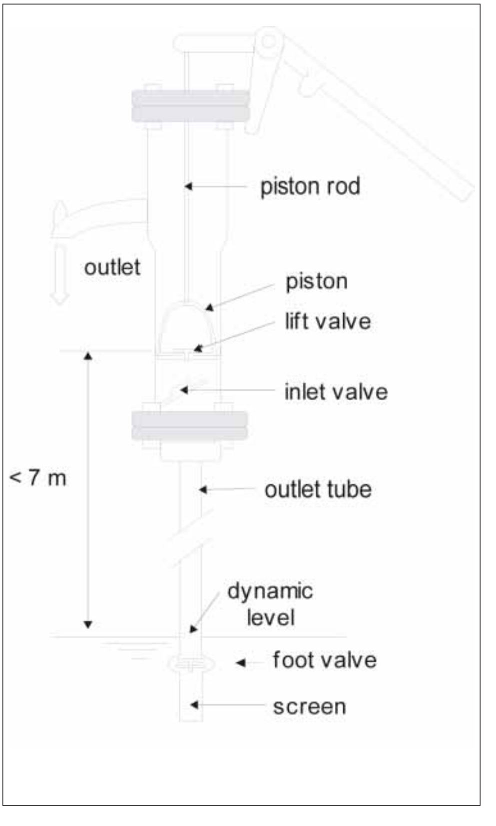


Figure 9.32: VN6-type suction pump.

8.3 Hydraulic pumps

Hydraulic pumps, developed principally by Vergnet SA, are lift pumps which work with a hydraulic transmission between the submerged cylinder and the pump head, which reduces the number of moving parts (Figure 9.33). There are

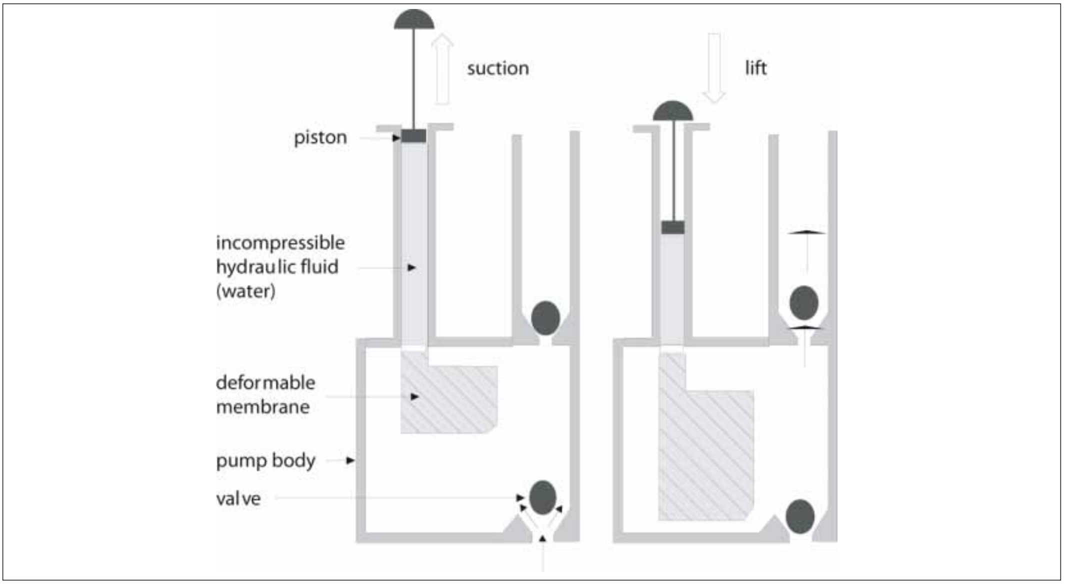
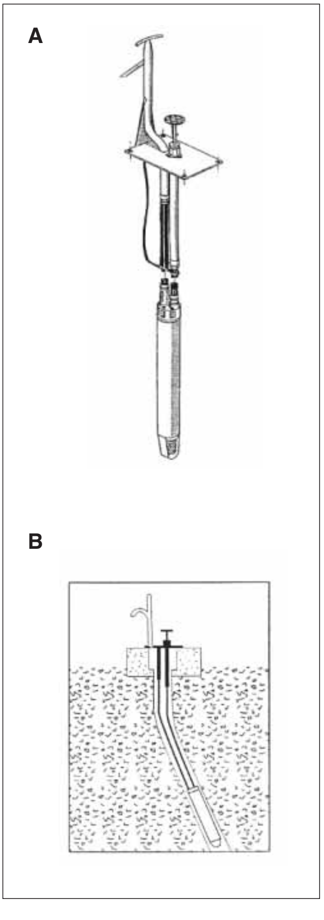


Figure 9.33: Working principle of Vergnet hydropump.



three models: HPV 30 - 60 - 100.

The balloon, a deformable rubber cylinder, varies in volume inside a sealed pump body (Figure 9.34 A). The controls are hydraulic, since the balloon is deformed by the water pressurised from the surface by the piston (pedal).

The HN30 and the Hydro India work on the same principle but are

Figure 9.34: Vergnet hydropump.
A: HPV 60. B: Hydro India 60.

Pump head	Galvanised steel
Pedal cylinder	Stainless steel
Control tube	High-density polythene
Rising main	High-density polythene
Pump body	Stainless steel
Cylinder	Stainless steel
Balloon	Rubber
Valves	Ball type
Total weight	45 kg for 25 m
Prices	950 euros (HPV 30), 1 300 euros (HPV 60) 2 500 euros (HPV 100)
Performance	1.3 m^3/h at 30 m, 0.8 m^3/h at 70 m, 0.7 m^3/h at 90 m
Advantages	Working in boreholes that are out of alignment (see Figure 3.34 B), excellent corrosion resistance, ease of installation and repair Few wear components, simple assembly and disassembly, very low weight pumps, good quality/price ratio
Disadvantages	Auto-cut-off on recent models; frequent power loss on hydraulic control On older models, balloon expensive but guaranteed 3 years Pedal action sometimes poorly regarded by certain communities

worked with a handle (hand) and not a pedal (foot), Figure 9.34 B.

8.4 Helical rotary pump

This pump, also known as a progressive cavity pump, works on the principle of volumetric variation. The pumping element (hydraulic part) incorporates a helical rotor in iron alloy, which turns inside an elastic stator with

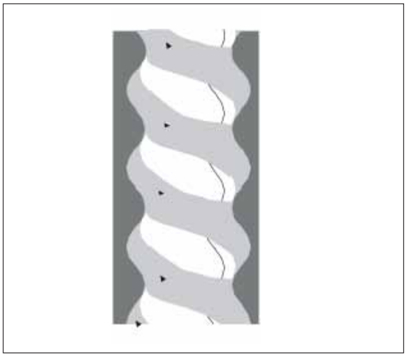


Figure 9.35: Helical rotor of the Monolift pump.

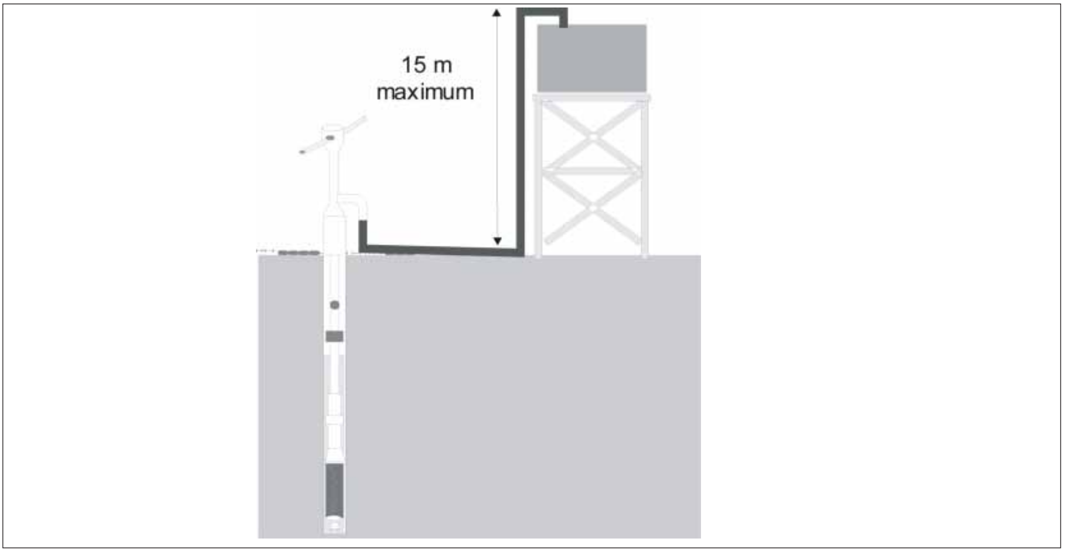


Figure 9.36: Pumping to a tank using a Monolift pump.

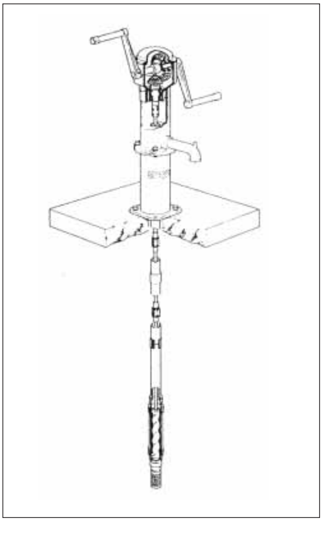


Figure 9.37: Characteristics of the Monolift pump.

Manufacturer	Mono Pumps (England) or Euroflo Pumps (S Africa)
Superstructure	Cast iron
Main shaft	Stainless or galvanised steel
Rising main	Galvanised steel
Pump body, rotor	Chrome-plated brass
Stator	Steel and rubber
Foot valve	Polythene
Total weight	420 kg for 60 m
Approximate price	1 950 euros ex-works (60 m)
Advantages	Robust and very suitable for large depths Simple drive Possibility of lifting water to 15m above the pump
Disadvantages	Fragile angle-gear drive (gear breakage) Handle difficult to turn (sometimes impossible for children), liable to corrosion

a double helix (Figure 9.35). The rotor is operated from the surface by a shaft guided by a bearing.

8.5 Rope-and-washer pump

The rope-and-washer pump is a low-cost technology used at the community and family level. Bombas Mecate S.A. converted this traditional water-pump technology into an inexpensive, durable, and highly efficient water-raising system, taking advantage of the availability of PVC pipe and injection-moulded plastics.

It is usually installed in dug wells and boreholes (100 mm diameter minimum) but it is also possible to install it in riversides. Other advantages are the possibility of installation in non-vertical wells (there is no need to install the pumping pipe vertically) and the adaptation of the system to fill elevated tanks. Designs also can be adapted for irrigation purposes (increasing the size of the washers to increase the yield).

This simple technology has been widely applied in rural Nicaragua and it was disseminated in a very short time over the whole country and other parts of Central America. ACF, as well as other organisations, is already introducing this pump to other countries and it is also supporting local manufacture, adapting the design through small modifications. ACF has promoted the rope-and-washer pump in Nicaragua, Guatemala, Honduras, El Salvador, Colombia, Angola, Guinea Conakry (in process), Mali (in process) and Myanmar (in process), and is studying the possibilities in other countries.

The rope-and-washer pump features a design in which small plastic washers are lined up on a rope (Figure 9.38). The rope is pulled through a plastic rising pipe over a crank-operated drive wheel. The pump stand is of painted mild steel and the drive wheel consists of cut old tires. A ceramic guide box leads the rope with the pistons into the rising pipe (in some places this part is made with part of a glass bottle). This pump is reasonably corrosion resistant. There also exists an adapted design to install in boreholes.

This pump can be powered by hand, animal traction, a stationary bike, wind, or a petrol engine. It can be operated by the whole family for their daily needs, for small agricultural production or for cattle watering.

The rope-and-washer pump requires simple maintenance and has an excellent potential for local manufacturing.

The manufacture requires:

– a plastic injection machine for the washer production - (high density polyethylene is used as

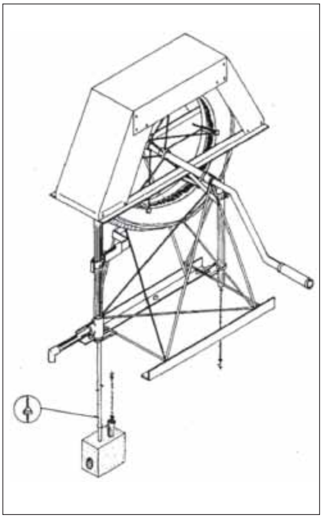


Figure 9.38: Rope pump.

Manufacturers	Rope Technology Transfer Division, Bombas Mecate SA, local manufacturers
Pump stand	Painted steel
Crank	Painted steel pipe
Drive pulley	Rubber and mild steel
Washers	Polyethlylene
Guide box	Ceramic and PVC
Rising main	PVC pipe
Approximate price	Around 100 euros
Approx. discharge at 75 watts	10 m head: 1.4 m3/h 15 m head: 1.1 m3/h 30 m head: 0.7 m3/h
Maximum depth	40 metres standard. 60 metres with double crank.
Advantages	Easy operation and maintenance by communities. Low cost and possibility of local manufacture.
Disadvantages	Sometimes it is difficult to convince authorities that it is appropriate

raw material);
– the purchase of ropes (manufacture is more complicated);
– a guide box made with an entrance pipe, a pumping pipe, a ceramic fitting (the first ceramic fitting is made manually in order to prepare a mould for production pieces), a base and concrete casing;
– the construction of the wheel, pulley and structure with metallic materials.

Note. – Low-cost technology facilitates long-term maintenance, but does not guarantee effective maintenance on its own. Often, cost is not the only factor that blocks repairs, community mobilisation remaining the main constraint.

8.6 Treadle pump

Treadle pumps are a very efficient solution for irrigated agriculture. Their low cost makes them accessible to even poor farmers. The development of treadle pumps started in Bangladesh, and since a few years they have spread to several countries in Africa (ACF exported these pumps from South

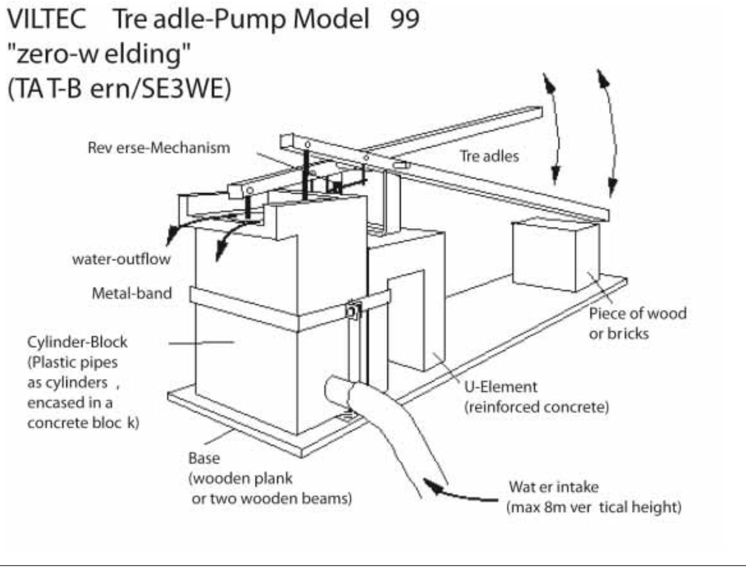


Figure 9.39: Treadle pump (Viltec treadle-pump model 99 "zero welding").

Manufacturer	Diverse (South Africa, Ethiopia)
Cylinders	Metal
Pistons	Rubber
Treadles	Wood (other material is possible)
Support structure	Metal (other material is possible)
Suction pipe diameter	75 mm
Price (2003)	20 – 150 euros
Discharge	3 to 10 m^3/h depending on cylinder diameter and pumping depth
Area irrigated	0.4 hectares
Maximum suction lift	Approximately 6 m
Maximum discharge lift (for pressure model)	10 – 15 m
Advantages	Low cost
	Discharge
	Easy operation and maintenance
	Good manufacturing quality
Disadvantages	Limitation of suction lift (6 m)
	Need of standard replacement parts

Africa to Angola in a irrigation project with small farmers in Matala).

The treadle pump is a suction pump that consists of two metal cylinders with pistons that are operated by a natural walking motion on two treadles (Figure 9.39). The treadles and support structure are made of bamboo or other inexpensive locally-available material. Metallic materials can also be replaced by others (plastic etc.) to prevent corrosion. The efficient step-action operation makes it possible to pump the large volumes of water necessary for irrigation. There are also discharge treadle pumps that allows water to be lifted above the level of the pump. Water can be lifted to elevated places and can be pumped through pipes over long distances (up to 500 m).

All household members are able to operate the pump, and it is strong and easily maintained with standard replacement parts available in local markets at a low cost. The pump can be manufactured locally in simple metalworking shops.

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