11 THE PENSTOCK

11.1 How the penstock works

The penstock is simply a long pipe that fills with water. The weight of the water in the pipe provides the required pressure at the nozzle to drive the turbine. This pipe may run directly from the water source to the turbine or from the end of a canal that brings the water closer, saving on the cost of a longer pipe. A filter is connected at the intake end. At the turbine, there is a valve used for turning the water flow on and off. After the valve is the nozzle which concentrates the water into a high-pressure jet.

11.2 Penstock Selection

The penstock is often the most expensive component of a pico hydro scheme. It is therefore important that the pipe used is carefully chosen.
There are three things to consider when buying pipe for the penstock:

- **the material**
- **the internal diameter** - depends on the length and flow rate.
- **the pressure rating** - depends on the net head.

The Pressure Rating

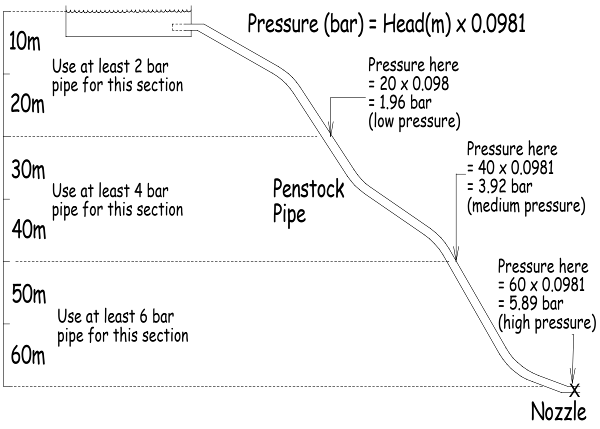

Figure 11-1 Penstock pressure rating

The penstock is designed to convey water under pressure in a safe and efficient manner to the turbine. The higher the pressure, the thicker the pipe walls must be and the more expensive it becomes. The pressure of the water in the penstock depends on the head. If pipe with a pressure rating which is too low is used, then there is risk of a burst. If the pressure rating is too high then money has been wasted. The ideal penstock will be low pressure at the intake and thicker at the nozzle where the pressure is greatest.

Selecting the correct pressure rating

The pressure at any point in the pipe can be easily calculated if the head at that point is known. Refer to Figure 11-1 in order to understand how the pressure in the pipe changes with the head.
Plastic pipe has a built in safety factor of between 1.5 and 2.5 to allow for pressure surges. This means that the pipe can be used up to the manufacturers pressure rating (providing that the joins between the lengths have been correctly made and the pipe is firmly anchored or buried). The flow control valve must be turned slowly on and off to minimise sudden pressure surges. If these guidelines are followed and the pipe is used up to the manufacturers pressure rating then costs will be kept to a minimum without a safety compromise.

The importance of pipe diameter

The diameter is important because it affects the power available to the turbine. The larger the diameter, the more power there will be. Although the pipe may appear smooth, it has some surface roughness that slows down the water. This slowing down is called 'frictional loss'. The frictional loss is expressed in metres of head loss and is greater when the speed of the water is greater. The water speed and therefore the frictional loss increase if either the turbine nozzle is made larger or the penstock diameter is made smaller. Frictional loss also increases in proportion with the penstock length. If a pipe of larger diameter is used then the frictional loss is less but the price increases significantly. Typically, if the diameter of a pipe is doubled, then the price is increased four times. The frictional loss however is about 30 times less!

Selecting the Optimum diameter

First, find out the flow rate required for the turbine. This information should be provided by the manufacturer. If not, use the method based on the nozzle diameter which is described in the complimentary manual for manufacturers of the Pico Power Pack. Also needed, is the total length of pipe required (the distance taken by the pipe from the forebay to the turbine) and the total head available.

Look at Table 11-1. First find the flow rate nearest to the one required in the left-hand column. The recommended compromise between friction loss and cost of pipe is 15%-20% frictional loss. All the head losses given are for 100 metres of pipe. These figures must be multiplied by [required pipe length / 100] in order to give an estimate of frictional loss at the site. This loss should normally be no more than 25% of the total head. If the head loss is 20%, then the net head will be 80% of the gross (total) head:

NET head (available to turbine)
= GROSS head (total head)
– head loss due to friction

Sometimes a head loss different to 20% should be chosen. For example, if the gross head available at the site is scarcely enough to run the turbine, then a penstock only resulting in a 10% frictional loss could be considered. Alternatively, if the distance between the site for the powerhouse and the forebay tank is long and head is more than necessary, a loss of 30% could be tolerated if it meant a significant saving in cost with sufficient power still being provided.

Example :Selecting penstock diameter

a) Which is the diameter of penstock that will give a head loss of around 20% and be the most cost effective. The following information is known:
The turbine selected requires a flow rate of 6 litres per second
The gross head is 70 meters
The penstock will be 300 meters in length

Answer:
Head loss is required which will be approximately 20% of 70.
70 x 0.20 = 14 metres
The values in the table are for pipes of 100m in length. We require 300 meters therefore the values in the table must be multiplied by
300/100 = 3
Looking along the column for a flow of 6 l/s and calculating the head loss:
300 m of 50mm pipe = 3 x 17.07 = 51.21 metres
300 me of 63mm pipe = 3 x 5.48 = 16.44 metres
300 m of 75 mm pipe = 3 x 2.36 = 7.08 metres

Clearly the best choice is 63mm (2.5") pipe which gives a head loss near to 14 metres

b) If HDPE pipe of only 100mm and 50mm diameter were available, what would be the most cost-effective combination?
Answer:
80 metres of 50mm pipe (for high pressure section)
= 0.8 x 17.07 = 13.6 metres
220metres of 100mm pipe (for low pressure section)
= 2.2 x 0.58 = 1.28 metres
Total head loss = 13.6 +1.28
= 14.9 metres

Penstock Materials

For pico hydro schemes, the penstock pipe is usually made from plastic. HDPE (High Density Polyethylene) is used in many countries. It is particularly suitable because it is both flexible and weather resistant. This type of pipe is usually coloured black. Internal diameters up to 75mm (3") are flexible enough to be coiled up which makes transportation easier. Common internal diameters (or 'nominal bore') used for pico-hydro are 50mm, 63mm, 75mm, 90mm, 100mm and 110mm.

Alternative materials are PVC (Polyvinyl-chloride) and steel. PVC is widely available for use as domestic waste pipe. However, PVC pipe and fittings for domestic use are rated for low pressures only and therefore not suitable for penstocks. Low-pressure PVC pipe is suitable for use in the forebay (flushing pipe and overflow). Steel is commonly used for larger hydro when the flow and pressure in the pipe are higher. The three materials have been compared in Table 11-2.

11.3 Connecting the Nozzle

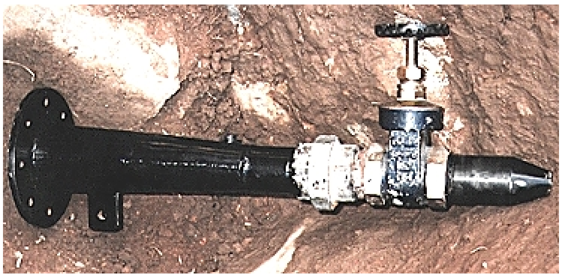

Figure 11-2 Reducer, gate valve and nozzle

A gate valve is recommended to turn on and off the water supply to the turbine. These are widely available and because they take more time to close, they reduce the likelihood of large 'surge pressures' from developing in the penstock that can cause it to burst. This can occur with "butterfly" or "globe" valves that allow the flow to be reduced more rapidly. Grease should regularly be applied to the threaded stem of the valve to prevent corrosion and eventual seizing. The turbine nozzle should be threaded on the outside to allow the valve to be screwed into place. The manufacturer should supply a compatible valve with the turbine. PTFE tape or paste is very useful to help lubricate and waterproof threaded connections and should be applied if available. Similarly on the penstock side, a suitable threaded connector is required. This may be provided on a reducer as illustrated in Figure 11-2 which can then be attached to a larger penstock diameter using a flange coupling (see Figure 11-10).

Table 11-1 Head Loss per 100m length for different diameters of plastic pipe at different rates of flow

Flow (l/s)	Internal Pipe Diameter (Nominal Bore)				
	50mm (2")	63mm (2.5")	75mm (3")	88mm (3.5")	100mm (4")
2.0	2.28m	0.75m	0.33m	0.15m	0.08m
4.0	8.03m	2.62m	1.13m	0.52m	0.28m
6.0	17.07m	5.48m	2.36m	1.09m	0.58m
8.0	29.09m	9.31m	3.97m	1.83m	0.98m
10.0	44.19m	14.05m	5.98m	2.73m	1.48m
12.0	61.9m	19.69m	8.38m	3.82m	2.05m

Penstock Material	Transport to site	Installation	Joining sections	Lifetime	Roughness
HDPE	Dia. 75mm or less can be coiled	Easy because flexible	Requires skill to fusion weld	Very weather resistant and tough	Low so not much head loss.
PVC	6m lengths only	More difficult because quite rigid	Easy with pipe connectors and PVC cement but high cost	Degrades in sunlight unless painted	Low so not much head loss
Steel	Difficult in remote areas because of weight	Rigid and heavy therefore difficult	Welding or bolting flanged sections together. Not cost-effective for pico hydro	Corrodes gradually and requires maintenance	Medium for new pipe becoming worse with corrosion

Table 11-2 Comparison of penstock materials

11.4 Penstock Installation

STEP 1 LAYING OUT

Figure 11-3 Delivering pipe sections to the site.

Check that the pipe that has been delivered is the correct type and length. The route for the penstock from the intake to the generator should have been marked out and vegetation cleared where necessary. Lay out the pipe sections along the proposed route, making an initial check that the quantity ordered is sufficient

STEP 2 PREPARING THE ROUTE

Figure 11-4 The penstock can be laid in a trench and then buried when the installation is complete to secure it

The pipe can be laid on the surface of the ground providing that obstructions such as rock and branches have been cleared. Care should be taken to prevent mud, stones and debris from entering the pipe sections. The penstock should follow a downhill course where ever possible and must at no point be higher than the penstock entrance in the forebay. In some situations it will be necessary to lay the pipe in a trench to maintain the correct gradient. In other areas the pipe will require supporting above ground level. How this is achieved will depend on the size of pipe and the height above ground. This is when the advantages of HDPE pipe become apparent. Its flexibility means that it is considerably easier to install than either PVC or steel.

Figure 11-5 Pipe sections that span gaps must be supported at the correct height.

Pipe above 75mm in diameter requires more support than smaller sizes. Initially, sticks can be used to help bridge difficult areas.

Figure 11-6 The supports must be suitably reinforced before filling the pipe.

Before the pipe is filled with water, more secure foundations, using stones and mud for example, must be constructed.

STEP 3 JOINING THE PIPE

HDPE pipe sections can be joined at the site using hot fusion. The tools required are a steel plate with diameter slightly larger than the pipe being joined and a jig to support the two sections.

Figure 11-7 The metal plate is heated in a small fire

First the plate is heated over the embers of a small fire

Figure 11-8 Both sides of the pipe are held against the hot plate.

The two ends of pipe are inserted into either side of the jig with the heated plate in between. The plastic is allowed to soften evenly at the end of both sections by holding the lengths firmly in place.

Figure 11-9 The plate is removed and the two sections are brought together forming a neat bead around the pipe.

When a bead has formed all the way around on both pipe sections, the plate is removed and the two lengths are forced together. An even weld 'bead' around the whole circumference indicates a successful join. The pipe must not be moved until the joint is completely cool. Teflon is a heat proof, non-stick material which is available in fabric form. A Teflon bag can be used to cover the hot plate and prevent the plastic pipe from sticking during the initial softening. The plate should be at 220°C for softening HDPE. Heat temperature indicating crayon ('Thermochoc' in Nepal) are available which change colour when the correct temperature has been reached. A small amount is applied to the plate during heating. The correct plate temperature is often learned by experience however, as the crayons are not always readily available.

STEP 4 CONNECTING TO THE TURBINE NOZZLE

Figure 11-10 Penstock connection using flanges

The connection between the penstock and the turbine is important because it is here that the water is at its highest pressure. Sometimes the penstock is connected directly to the gate valve that controls the flow. A reducer is usually required as the penstock diameter is generally larger than the valve. A suitable method of connecting a plastic penstock to a steel reducer is illustrated in Figure 11-10. An HDPE pipe flange fitted with a steel ring has been fused to the end of the penstock. This can then be securely bolted to the reducer after inserting a gasket.

An 'Excel' software program has been developed to help design the penstock and calculate the head loss in different pipe sections. For a copy of the program, please contact the editorial address.

12 The POWERHOUSE

12.1 Construction

Figure 12-1 Typical stone powerhouse in Nepal

A good design of powerhouse will protect the turbine, generator and other equipment over its lifetime, which should be a minimum of 15 years. The construction of the powerhouse will vary depending on local availability of materials, local preferences and the local climate. However, cutting costs by building an insubstantial powerhouse is false economy. Constant maintenance and repair work will be required otherwise the life of the generating equipment will be considerably reduced. Equally, an over-built powerhouse will be more expensive than necessary. The following guidelines will help to construct a building that will be a suitable compromise between cost and quality for most locations.

Foundations:

- A foundation trench should be dug down to solid rock or otherwise to a depth of one metre below each wall. It should be twice as wide as the intended wall. Any soft areas at the bottom of the trench should be dug out and filled with stone or concrete. The trenches should be levelled as far as possible in a similar way. Soil dug out of the trench should not be used for this purpose.
- A footing is then required on which the walls will stand. This should be twice the width of the walls and stepped up at the top as shown in Figure 12-2. Suitable materials for the footing are concrete, brick and stone depending on what material is used for the walls.

Floor:

- Raised above ground level to prevent flooding during heavy rainfall.
- Lined with concrete to ensure secure foundations for the turbine and generating equipment.
- Sloped towards the tailrace so that any spillage drains away.
- Large enough area to allow for all round access to turbine, generator and control equipment. If any mechanically-driven machinery such as grain mills are also housed or likely to be in the future, then the floor area should be increased accordingly.

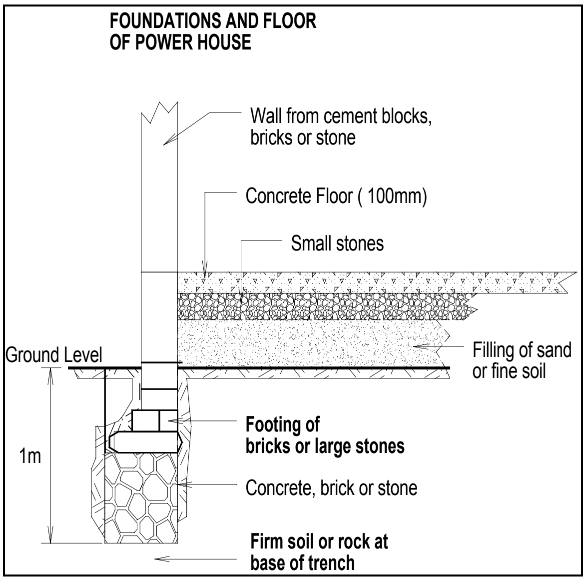

Figure 12-2 Recommended construction of foundations and floor

Walls:

- Should be at least 2m high at the lowest point and constructed to allow roof to be pitched.
- Should be thick enough to allow adequate protection from storms. Provision should be made for mounting control box, ballast equipment, capacitor box etc. Suitable methods are the use of wooden panels and built in shelving.

Windows:

- Essential to provide light and ventilation.
- Not facing the prevailing wind direction.
- Should be secured with wire mesh or wooden shutters to prevent unauthorised entry (not necessarily with glass.)
- Window area should be $1m^2$ for every $10m^2$ of floor space.

Door:

- The door to the powerhouse should open outwards for safety and should be lockable.
- It must be large enough to allow access for all equipment including possible future acquisitions.
- It should prevent entry of rainwater.

Tailrace:

- The tailrace should be lined with concrete to a depth of 100mm inside the powerhouse.
- The concrete lining should extend a minimum of 1m outside the powerhouse and must be leak proof in order to protect the powerhouse foundations.

Figure 12-3 Power house under construction, Nepal

Roof:

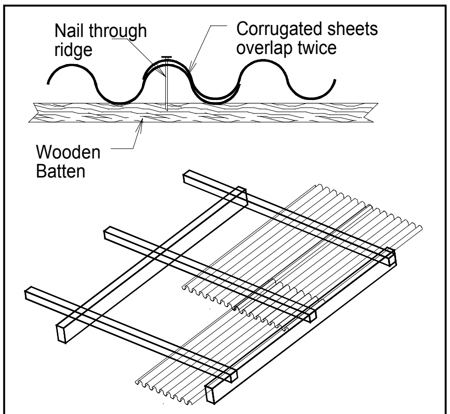

Figure 12-4 Suggested techniques for assembly of corrugated steel roof

- The roof must be watertight and pitched to improve drainage.
- It should preferably be made of a fire-proof material such as clay tile or corrugated steel and definitely be waterproof.
- It should extended beyond the walls to prevent water from entering the window spaces.
- Ventilation spaces should also be left under the eaves to allow circulation of air if the windows are closed.

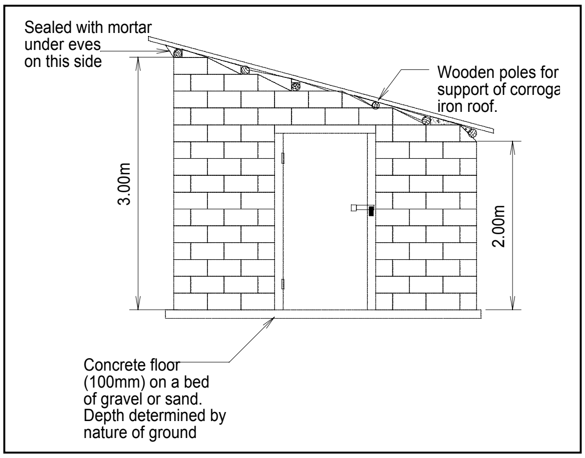

Figure 12-5 Recommended powerhouse construction methods

12.2 Layout

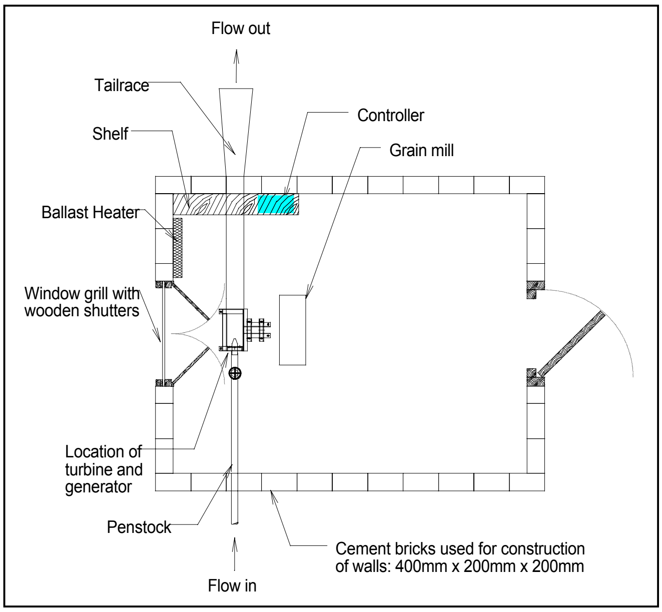

Figure 12-6 Suggested layout for powerhouse components

12.3 Planning the Installation.

1. Planning	2. Preparation	3. Construction and Assembly	4. Connection	5. Testing	6. Commissioning
Finalise the design particularly concerning the locations of the powerhouse, forebay or reservoir and intake	Order deliver and store materials and equipment at the site taking into account any late modifications	Lay the penstock pipe in position negotiating any difficult ground such as rocky outcrops or sunken areas	Connect penstock sections and join to flow control valve		
Make minor adjustments to design, and mark out positions of powerhouse, penstock and forebay or reservoir	Clear a path through the vegetation for the penstock digging a shallow channel if necessary	Position intake and dig canal if necessary. Otherwise lay pipe to forebay area which has been marked if forebay is required	Support penstock where necessary and cover particularly if made of PVC.		
Ensure that sufficient gradient exists for water to flow into forebay or reservoir from intake pipe or canal	Clear the site and construct the foundations for the powerhouse, allowing correct positioning of turbine and generator. Consider if earth connection is in base.	Assemble turbine and generator base frame on support structure and built supports for mechanically driven machinery	Line the forebay or reservoir as necessary with concrete or stone and cement and complete any building work at the intake	Check penstock and fittings for leaks	
	Make any final adjustments to positioning of forebay or reservoir and excavate	Construct the walls and roof of the powerhouse	Connect excitation capacitors, load controller, ballast and protection devices to generators	Test run turbine and generator to check for correct operation	Cover penstock with turf or soil
	Identify a suitable location for an earth connection near the powerhouse. (Unless earth is buried in the foundations)	Excavate and position the earth electrode. Attach a cable to powerhouse		Check correct operation of controller and ballast.	Train operators and managers
				Check operation of mechanical loads	Resolve any electrical problems with domestic connections.
Distribution System					
Check site plan including length and size of distribution cable required before delivery	Connect distribution cables together, erecting poles where necessary	Position domestic loads and load-limiters. Connect service cables to main distribution system.	Connect protection devices such as RCD(s) and lightning arrestors	Connect the distribution system to the load controller	Check operation of distribution system

Table 12-1 The installation has been divided into six phases to help the developer plan the order of activities. Work down the columns and then across the table, some activities can be carried out in parallel with others which will save time.