## 4.11 Classification of water turbine:

Turbines convert available energy in the form of falling water into rotating shaft power. They operate on the principle of either =impulse‘(equal pressure on each side of the runner) or =reaction‘(pressure drops across the runner). A brief description of most common types of turbine is given here.

### 4.11.1. Impulse Turbines:

In impulse turbines pressure energy is converted first in a nozzle into the kinetic energy of a high-speed jet of water, which is then converted to rotation in contact with the runner blades by deflection of water and change of momentum. The runner can operate in air and the water remains at atmospheric pressure before and after making contact with runner blades. It needs casing only to control splashing and to protect against accidents. The three impulse turbines considered here are the (i) Pelton, (ii) Turgo and (ii) cross flow (also known as Banki, Mitchell or Ossberger turbine).

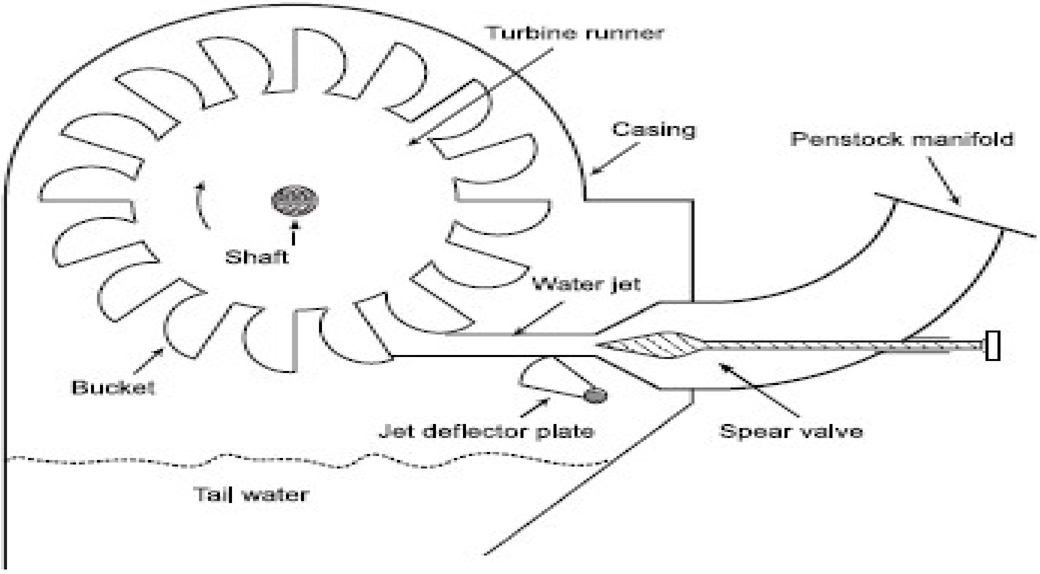
1. **Pelton Turbine:**

The Pelton Turbine consists of a wheel with a series of split buckets set around its rim as shown in figure. A high velocity jet of water is directed tangentially at the wheel. The jet hits each bucket and is split in half, so that each half is turned and deflected back almost through 180°. Nearly all the energy of the water goes into propelling the bucket and the deflected water falls into a discharge channel below. Care must be taken to allow plenty of space on either side of a Pelton runner to allow deflected water to exit without splash interference. For optimum efficiency the jet velocity needs to be about twice the speed of the bucket. The runner of such a turbine is large for the power produced. The use of two or more jets placed symmetrically around the rim will allow a smaller runner for a given flow of water and hence an increased rotational speed. The required power can still be attained.

### Following options are available for control:

- **Replacement of nozzles**: It is possible to divide the yearly flow variation in two, three or more parts and make a nozzle for each flow. The turbine operator can then remove one nozzle and replace it with the desired nozzle. This is very low cost method of controlling the flow.

- **Spear valves**: A needle valve or spear valve, which is so called because streamlined spearhead, is arranged to move within the nozzle, allowing variation in effective orifice cross section area without introducing energy loss.
- **Varying the number of jets**: If multi-jet turbine has shut off valves fitted on each of its jets, it can be run at different flow rates by simply altering the number of jets playing on the runner
- **Deflector plate**: The water jet can be deflected away from the buckets of the runner if a jet deflector plate is rotated into its path. This is very quick and does not require the shutdown of the flow in the penstock, with consequent pressure surge danger.
- **Shut-off valves**: It is usual to place a valve, either a gate valve or a butterfly valve, in the turbine manifold. However, certain precautions are to be observed on its use. Pelton wheels are often driven by long penstocks in which surge pressure effects, due to valve closure, can be very dangerous and lead to damage caused by bursting of the penstock. The valve must always be closed slowly, particularly during the last phase just before shutoff. Gate valves are sometimes used mistakenly to regulate flow, by partially closing them. This causes damage on the valve plate due to **cavitation** effects.



Pelton turbine

Figure 4.11.1

*[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 313]*

## 2. Turgo Turbine:

- The Turgo turbine is similar to the Pelton but the jet is designed to strike the plane of the runner at an angle (typically 20°) so that the water enters the runner on one side and exits on the other. Therefore, the flow rate is not limited by the spent fluid interfering with the incoming jet (as is the case with Pelton turbines).
- As a consequence, a Turgo turbine can have a smaller diameter runner than a Pelton for an equivalent power. It, therefore, runs at a higher speed. It shares the general characteristics of impulse turbines listed for Pelton. Turgo does have certain disadvantages also. Firstly it is more difficult to fabricate it as compared to a Pelton wheel, since the buckets (or vanes) are complex in shape, overlapping and more fragile than Pelton buckets.
- Secondly, the Turgo experiences a substantial axial load on its runner which must be met by providing a suitable bearing on the end of the shaft.

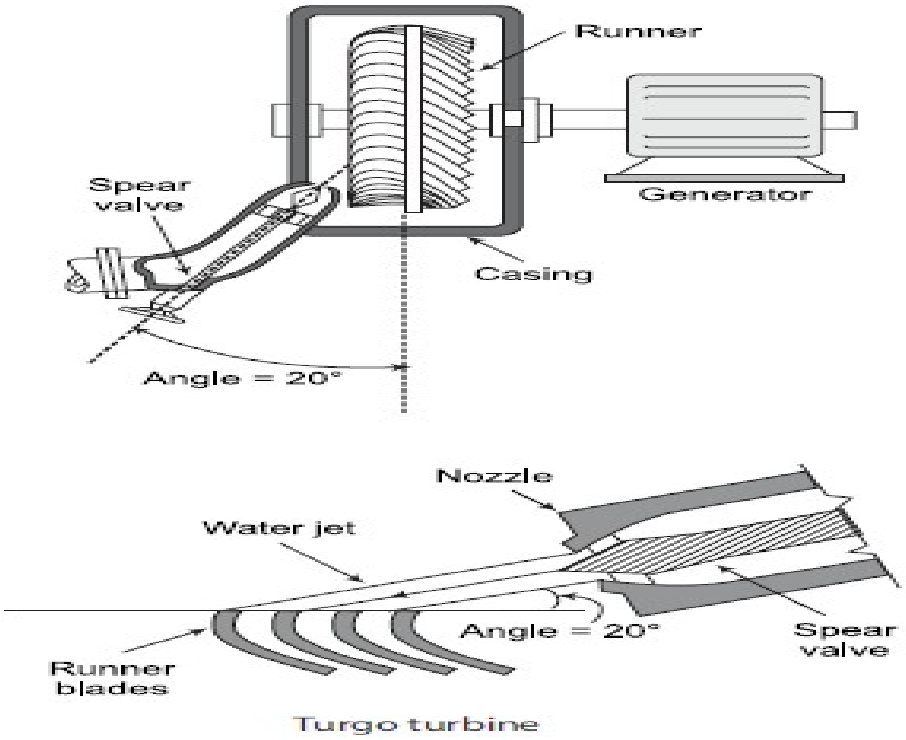


Figure 4.11.2

*[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 315]*

## 3. CrosslowTurbine:

- Crossflow turbines are also called Banki, Mitchell or Ossberger turbines. A Crossflow turbine, has a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. The shaft of the runner is always kept horizontal in all cases (unlike Pelton and Turgo turbines which can have horizontal as well as vertical orientations). In operation a rectangular nozzle directs the jet to the full length of the runner. The water enters the top of the runner through the curved blades imparting most of its kinetic energy. It then passes through the runner and strikes the blades again on exit, imparting a smaller amount of energy before falling away with little residual energy.
- The effective head driving the cross flow runner can be increased by inducement of a partial vacuum inside the casing. This is done by fitting a draught tube below the runner which remains full of tail water at all times. Careful design of valve and casing is necessary to avoid conditions where water might back up and submerge the runner.
- Because of symmetry of a crossflow turbine the runner length can theoretically be increased to any value without changing the hydraulic characteristics of the turbine. Hence, doubling runner length merely doubles the power output at the same speed. The lower the head, the longer the runner becomes, and conversely on high heads the crossflow runner tends to be compact. There are, however, practical limits to length in both cases. If the blades are too long they will flex, leading quickly to fatigue failure at the junction of blade and disc. In case of short runner operating on high head, efficiency losses at the edges become considerable.

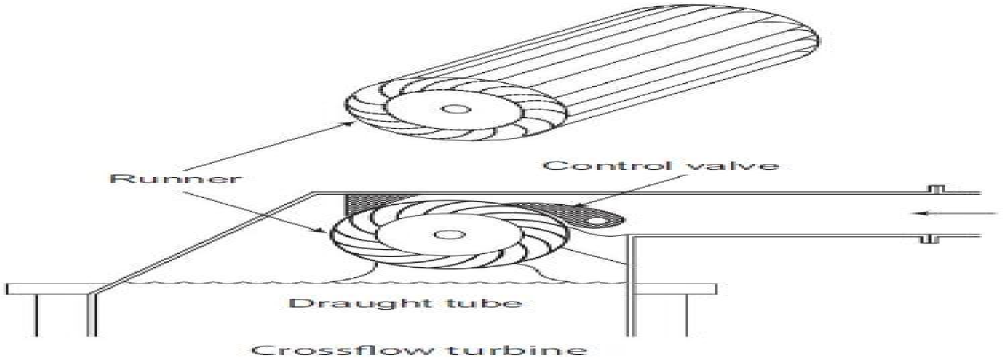


Figure 4.11.3

*[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 317]*

- ➔ Two major attractions in the cross flow have led to a considerable interest in this turbine. Firstly, it is a design suitable for a wide range of heads and power ratings. Secondly, it lends itself easily to simple fabrication techniques, a feature which is of interest in developing countries. The runner blades, for instance, can be fabricated by cutting a pipe lengthwise in strips.

## 4.11.2 Reaction Turbines

- ★ Reaction turbines exploit the oncoming flow of water to generate hydrodynamic lift forces to propel the runner blades. They are distinguished from the impulse type by having a runner that always functions within a completely water-filled casing. All reaction turbines have a diffuser known as a =draft tube‘ below the runner through which the water discharges. The draft tube slows the discharged water and reduces the static pressure below the runner and thereby ncreases the effective head. The two main types of reaction turbine are:

(a) Francis turbine and (b) the propeller turbine (with Kaplan variant)

- ★ In general, reaction turbines will rotate faster than impulse types given the same head and flow conditions. The propeller type will rotate even faster than Francis. These high speeds have the very important implication that the reaction turbines can often be directly couple to a generator without any speed-increasing drive system. Significant cost savings are made in eliminating the drive and the maintenance of the hydro unit becomes very much simpler.
- ★ On the whole, reaction turbines need more sophisticated fabrication than impulse types, because they involve the use of large, more intricately profiled blades. The extra expense involved is offset by high efficiencies and the advantage of high running speeds at low heads from relatively compact machines. However, for use in micro-hydro in developing countries, these turbines are less attractive due to fabrication constraints. All reaction turbines are subject to the danger of cavitation, and tend to have poor part flow efficiency characteristics.

### 1. Francis Turbine

- ★ Figure below illustrates the construction of Francis turbine. The inlet has a spiral shape. Casing is scrolled to distribute water around the entire perimeter of the runner. The guide vanes, direct the water tangentially to the runner.

- The runner blades are profiled in a complex manner. In operation, water enters around the periphery of the runner through guide vanes, passes through the runner blades before exiting axially from the centre of the runner.
- This radial flow acts on the runner vanes (blades), causing the runner to spin. The guide vanes (or wicket gate) may be adjustable to allow efficient turbine operation for a range of water flow conditions. As the water moves through the runner its spinning radius decreases, further acting on the runner.
- The water imparts most of it's =pressure'energy to the runner and leaves the turbine via a draught tube. The Guide vanes regulate the water flow as it enters the runner, and usually are linked to a governor system which matches the flow to turbine loading.

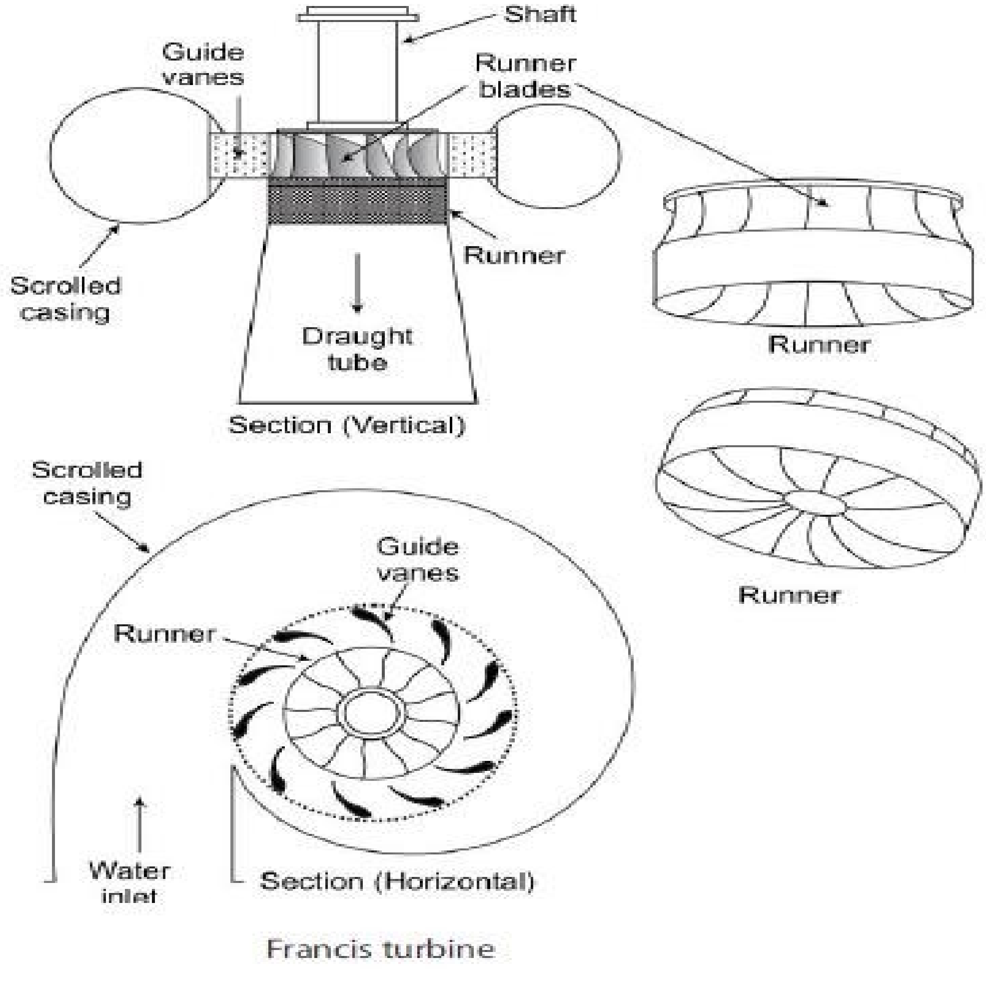


Figure: 4.11.4

*[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 318]*

**2. The Propeller Turbine and Kaplan:**

- ★ Propeller type turbines are similar in principle to the propeller of a ship, but operating in reversed mode. Typical construction is shown figure. It is often fitted inside a continuation of the penstock tube. Water flow is regulated by use of swivelling gates (wicket gates) just upstream of the runner (propeller). The part flow efficiency characteristic tends to be poor. This kind of propeller turbine is known as a _fixed blade axial-flow‘ turbine, since the geometry of the turbine does not change. Although traditionally the propeller is profiled to optimize the effect of pressure lift force acting on it, designs have been produced with flat section blades which offer less efficiency but are more easily fabricated. This kind of design can be considered seriously for micro hydro applications where low cost and ease of fabrication are priorities. It is also possible to consider casting the propeller casing in concrete.

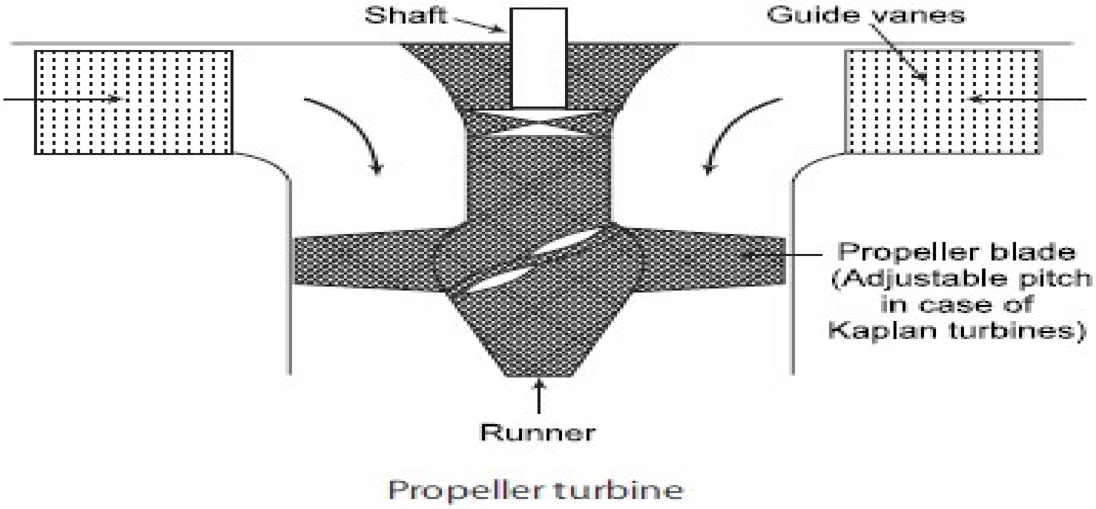
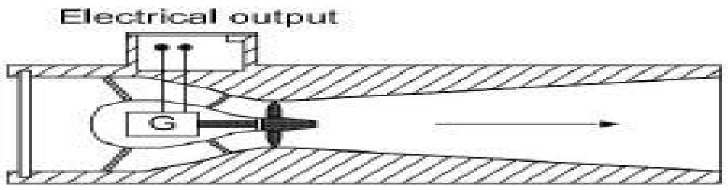


Figure: 4.11.5

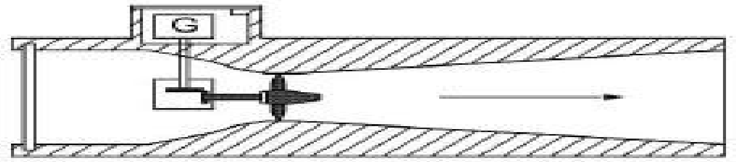
*[Source: “Renewable Energy Sources and Emerging Technologies” by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 319]*

- ★ Large-scale hydro sites make use of more sophisticated versions of propeller turbine. Varying the pitch of propeller blades simultaneously with wicket gates adjustment has the effect of maintaining high efficiency under part flow conditions. Such turbines are known as _variable pitch‘propeller types or Kaplan turbines. Wicket gates are carefully profiled to induce tangential velocity or _whirl‘in the water. Water enters radially or axially through these guide vanes. Variable pitch designs involve complex linkages and are usually not cost effective in any except the largest of micro hydro applications.

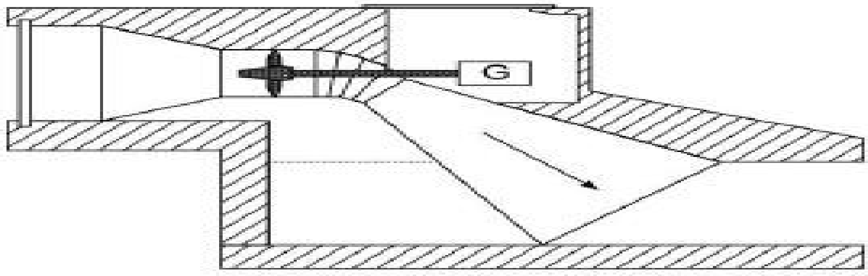
★ Propeller (Kaplan) turbine can be installed in vertical, horizontal or inclined positions. A number of installation designs and arrangement of drives are possible. Three typical designs for horizontal and inclined installation of the turbine. In _bulb type‘design the generator (and gear box if any) is contained in a waterproof bulb, submerged in the flow. Only electric cable duly protected leaves the bulb. The _cross‘design requires a complex right angle drive to transmit power to the generator, which is placed in a separate chamber. _S‘design requires the bend in the water passage to link the turbine with the generator. A typical design for vertical installation of the turbine is shown in figure below.



(a) 'Bulb' design



(b) 'Cross' design

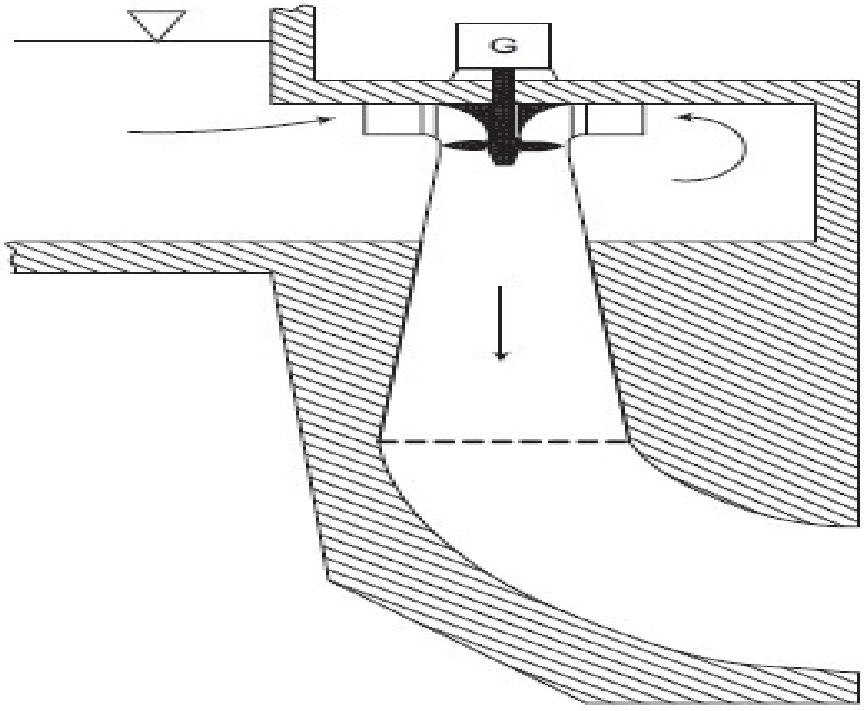


(c) 'S' design

Horizontal and inclined installations of a propeller turbine

Figure 4.11.6

*[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 320]*



Vertical installation of propeller turbine

Figure 4.11.7

*[Source: "Renewable Energy Sources and Emerging Technologies" by D.P.Kothari, K.C Singal, Rakesh Ranjan, Page: 321]*

**3. Reverse Pumps or Pumps-as-Turbines (PATs):**

- ★ Centrifugal pumps can also be used as turbines. Potential advantages are: low cost owing to mass production, availability of spare parts and wider dealer/support networks. Because of high speed they can be directly coupled to generator without requiring coupling drive. A PAT closely coupled to an induction motor sometimes referred to as _monobloc' pump, is commercially available. The motor runs as an induction generator.
- ★ The disadvantages of PATs are: as yet poorly understood characteristics, no direct correlation between pump characteristics and turbine characteristics, lower typical efficiencies, unknown wear characteristics and poor part flow efficiency. In general, PATs are most appropriate for medium head sites. In many countries pumps are manufactured in large quantities for water supply and irrigation purposes, whereas there may be no local manufacturer for water turbines. In these countries PATs may be economical for a wide range of heads and flows.