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# Hydro Power

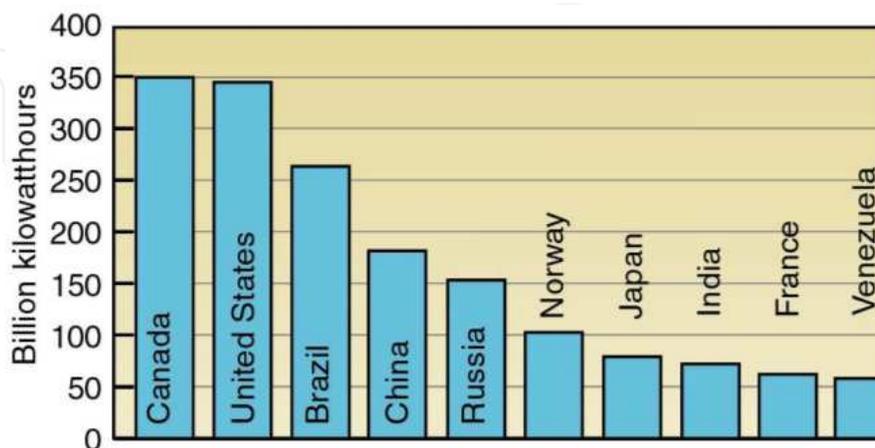
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## 1. Introduction

Humans have used the power of flowing water for thousands of years. Early civilizations used wooden paddle wheels to grind corn and wheat to flour. The word *Hydro* comes from the Greek word for water. *Hydropower* traditionally represents the energy generated by damming a river and using turbine systems to generate electrical power. However, there are several other ways we can generate energy using the power of water. Ocean waves, tidal currents and ocean water temperature differences can all be harnessed to generate energy. More than 70 percent of the earth is covered by water. The United States is one of the worlds top producers of hydropower (see chart). As much as 12 percent of the electrical energy generated in the U.S. is currently derived from hydropower systems. Parts of the Pacific Northwest generate as much as 70 percent of their electricity using hydroelectric sources. More than half the renewable energy generated in the United States comes from hydroelectric dams. Hydroelectric power is currently the least expensive source of electrical power and is much cleaner than power generated using fossil fuels.



Source: EIA, Annual Energy Review 1997, July 1998, Table 11.15

**Figure 1.** The amount of annual hydro electric energy of different countries.

Flowing and falling water have potential energy. Hydropower comes from converting energy in flowing water by means of a water wheel or through a turbine into useful mechanical power. This power is converted into electricity using an electric generator or is used directly to run milling machines. The potential energy of water may be used directly without conversion operation because of different in elevation diverted the water through a pipelines in order to supply the water in the daily usage .

## 2. History of hydro power

In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized. Small-scale hydropower was the most common way of electricity generating in the early 20<sup>th</sup> century. The first commercial use of hydroelectric power to produce electricity was a waterwheel on the Fox River in Wisconsin in 1882 that supplied power for lighting of two paper mills and a house. Within a matter of weeks for this installation, a power plant was also put into commercial service at Minneapolis<sup>1</sup>. India has a century old history of hydropower and the beginning was from small hydro. The first hydro power plant was of 130 kW set up in Darjeeling during 1897, marked the development of hydropower in the country. Similarly, by 1924 Switzerland had nearly 7000 small scale hydropower stations in use. Even today, Small hydro is the largest contributor of electricity from renewable energy sources, both at European and world level. With the advancement of technology, and increasing requirement of electricity, the thrust of electricity generation was shifted to large size hydro and thermal power stations.

However, it is only during the last two decades that there is a renewed interest in the development of small hydro power (SHP) projects mainly due to its benefits particularly concerning environment and ability to produce power in remote areas. Small hydro projects are economically viable and have relatively short gestation period. The major constraints associated with large hydro projects are usually not encountered in small hydro projects. Renewed interest in the technology of small scale hydropower actually started in China which has more than 85,000 small-scale, electricity producing, hydropower plants.

Hydropower will continue to play important role throughout the 21st Century, in world electricity supply. Hydropower development does have some challenges besides the technical, economic and environmental advantages it shares above other power generation technologies.

At the beginning of the new Millennium hydropower provided almost 20% (2600 TWh/year) of the electricity world consumption (12900 TWh/year). It plays a major role in several countries. According to a study of hydropower resources in 175 countries, more than 150 have hydropower resources. For 65 of them, hydro produces more than 50% of electricity; for 24, more than 90% and 10 countries have almost all their electricity requirements met through hydropower.

### 3. Hydro power system classification

A different countries have different criteria to classify hydro power plants, a general classification of hydro power plants is as follows in table 1 :

<i>Type</i>	<i>Capacity in KW</i>
Micro Hydro	<i>Up to 100</i>
Mini Hydro	<i>101 to 2000</i>
Small Hydro	<i>2001 to 25000</i>
Large Hydro	<i>&gt; 25000</i>

**Table 1.** The hydro power types according to output power

The hydro plants are also classified according to the “Head” or the vertical distance through which the water is made to impact the turbines. The usual classifications are given in table 2. below:

<i>Type</i>	<i>Head Range</i>
High head	<i>100 m and above</i>
Medium head	<i>30 – 100 m</i>
Low head	<i>2 – 30 m</i>

**Table 2.** The hydro power types according to head

These ranges are not rigid but are merely means of categorizing sites. Schemes can also be defined as:

- Run-of-river schemes
- Schemes with the powerhouse located at the base of a dam
- Schemes integrated on a canal or in a water supply pipe

Most of small hydro power plants are “run-of-river” schemes, In order to imply that they do not have any water storage capability. The power is generated only when enough water is available from the river/stream. When the stream/river flow reduces below the design flow value, the generation ceases as the water does not flow through the intake structure into the turbines. Small hydro plants may be stand alone systems in isolated areas/sites, but could also be grid connected (either local grids or regional/national grids). The connection to the grid has the advantage of easier control of the electrical system frequency of the electricity, but has the disadvantage of being tripped off the system due to problems outside of the plant operator’s control.

#### 4. The hydro power principles

Power generation from water depends upon a combination of head and flow. Both must be available to produce electricity. Water is diverted from a stream into a pipeline, where it is directed downhill and then through the turbine (flow). The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. The turbine in turn drives the generator where electrical power is produced. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to turbine and system inefficiencies. Water pressure or Head is created by the difference in elevation between the water intake and the turbine. Head can be expressed as vertical distance (feet or meters), or as pressure, such as pounds per square inch (psi). Net head is the pressure available at the turbine when water is flowing, which will always be less than the pressure when the water flow is turned off (static head), due to the friction between the water and the pipe. Pipeline diameter also has an effect on net head. Flow is quantity of water available, and is expressed as 'volume per unit of time', such as gallons per minute (gpm), cubic meters per second (m<sup>3</sup>/s), or liters per minute (lpm). Design flow is the maximum flow for which the hydro system is designed. It will likely be less than the maximum flow of the stream (especially during the rainy season), more than the minimum flow, and a compromise between potential electrical output and system cost. The theoretical power (P) available from a given head of water is in exact proportion to the head and the quantity of water available.

$$P = Q \times H \times e \times 9.81 \text{ (kW)}$$

Where

P Power at the generator terminal, in kilowatts (kW)

H The gross head from the pipeline intake to the tail water in meters (m)

Q Flow in pipeline, in cubic meters per second (m<sup>3</sup>/s)

e The efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator, expressed by a decimal (e.g. 85% efficiency= 0.85)

9.81 is a constant and is the product of the density of water and the acceleration due to gravity (g)

*Example:* A site has a head of 100 m with flow of 0.1 m<sup>3</sup>/s .calculate the output power output if a) e=100% , b) e=50% .

Solution:

a.  $P = 100 * 0.1 * 9.81 * 100\% = 98.1 \text{ KW}$

b.  $P = 100 * 0.1 * 9.81 * 50\% = 49 \text{ KW}$

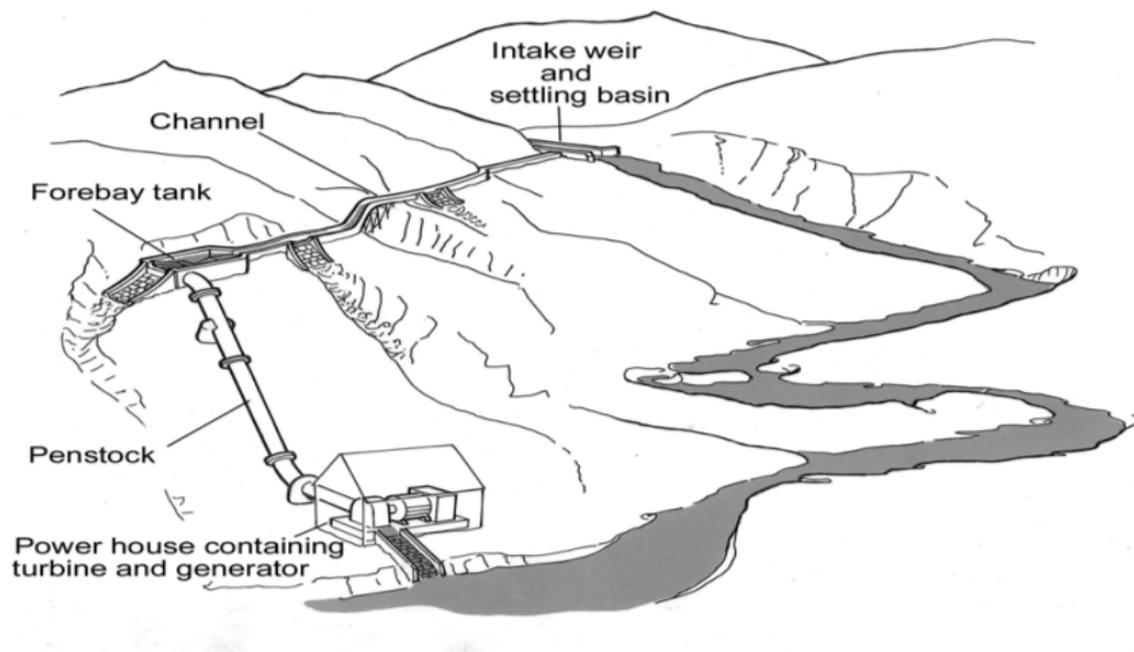
Table 3. below shows the output power (KW) with ( e = 50%) for different heads and flows

Head (m)	Flow Rates ( $m^3/s$ )								
	0.01	0.02	0.04	0.08	0.1	0.2	0.5	1.0	2.0
	Output Power in (KW)								
1	4.9	9.8	19.6	39.2	49	98	245	490	980
2	9.8	19.6	39.2	78.4	98	196	490	980	1960
4	19.6	39.2	78.4	156.8	196	392	980	1960	3920
8	39.2	78.4	156.8	313.6	392	784	1960	3920	7840
10	49	98	196	392	490	980	2450	4900	9800
15	73.5	147	294	588	735	1470	3675	7350	14700
20	98	196	392	784	980	1960	4900	9800	19600
30	147	294	588	1176	1470	2940	7350	14700	29400
40	196	392	784	1568	1960	3920	9800	19600	39200
50	245	490	980	1960	2450	4900	12250	24500	49000
100	490	980	1960	3920	4900	9800	24500	49000	98000
150	735	1470	2940	5880	7350	14700	36750	73500	147000
200	980	1960	3920	7840	9800	19600	49000	98000	196000

**Table 3.** Table 3. the output hydro power with different heads and flow rates

## 5. Basic components of a hydropower system

Figure 2 below shows the major components of a typical hydropower scheme. The water in the river is diverted by the weir through an opening in the river side (the 'intake') into a channel (this could be open or buried depending upon the site conditions). A settling basin is built in to the channel to remove sand and silt from the water. The channel follows the contour of the area so as to preserve the elevation of the diverted water. The channel directs the water into a small reservoir/tank known as the 'forebay' from where it is directed on to the turbines through a closed pipe known as the 'penstock'. The penstock essentially directs the water in a uniform stream on to the turbine at a lower level. The turning shaft of the turbine can be used to rotate a mechanical device (such as a grinding mill, oil expeller, wood lathe, etc.) directly, or to operate an electricity generator. The machinery or appliances which are energized by the turbine are called the 'load'. When electricity is generated, the 'power house' where the generator is located transfers the electricity to a step-up 'transformer' which is then transmitted to the grid sub-station or to the village/area where this electricity is to be used.



**Figure 2.** The hydro power plant components

### 5.1. Civil works

Civil works structures control the water that runs through a hydropower system, and conveyances are a large part of the project work. It is important that civil structures are located in suitable sites and designed for optimum performance and stability. Other factors should be considered in order to reduce cost and ensure a reliable system, including the use of appropriate technology, the best use of local materials and local labour, selection of cost-effective and environmentally friendly structures, landslide-area treatment and drainage-area treatment. Head works consist of the weir (see Figure 2 ), the water intake and protection works at the intake to safely divert water to the headrace canal. At some sites you may be able to install the penstock directly in the intake, with no need for a canal.

A hydropower station essentially needs water to be diverted from the stream and brought to the turbines without losing the elevation/head. Given below are some of the important factors that must be kept in mind while designing a hydropower system: **Available head:** The design of the system has effects on the net head delivered to the turbine. **Flow variations:** The river flow varies during the year but the hydro installation is designed for almost a constant flow. **Sediment:** Flowing water in the river sometimes carry small particles of hard abrasive matter (sediment) which can cause wear to the turbine if they are not removed before the water enters the penstock. **Floods:** Flood water will carry larger suspended particles and will even cause large stones to roll along the stream bed. **Turbulence:** In all parts of the water supply line, including the weir, the intake and the channel, sudden alterations to the flow direction will create turbulence which erodes structures and causes energy losses. Most common civil structures used in a hydro power scheme are:

### 5.1.1. Weir and intake

A hydro power system necessitates that water from the river to be diverted and extracted in a reliable and controllable manner. The water flowing in the channel must be regulated during high river flow and low flow conditions. A weir can be used to raise the water level and ensure a constant supply to the intake. Sometimes it is possible to avoid building a weir by using natural features of the river. A permanent pool in river could also act as a weir.

Another condition in site selection of the weir is to protect it from damage. Sometimes, in remote hilly regions, where annual flooding is common it may be prudent to build temporary weir using local resources and manpower. The temporary weir is a simple structure at low cost using local labour, skills and materials. It is expected to be destroyed by annual or bi-annual flooding. However, advanced planning has to be done for rebuilding of the weir.

The intake of a hydro power is designed to divert only a portion of the stream flow or the complete flow depending upon the flow conditions and the requirement. Hydro power schemes use different types of intakes distinguished by the method used to divert the water into the intake. For hydro power schemes, intake systems are smaller and simpler. The following three types of intakes have been described here: side intake with and without a weir and the bottom intake. The advantages and disadvantages associated with each of these are given in the table below:

Attributes	Side intake without weir	Side intake with weir	Bottom intake
Advantages	<ol style="list-style-type: none"> <li>1. Relatively cheap</li> <li>2. No complex machinery required for construction</li> </ol>	<ol style="list-style-type: none"> <li>1. Control over water level</li> <li>2. Little maintenance necessary (if well designed)</li> </ol>	<ol style="list-style-type: none"> <li>1. Very useful at fluctuating flows. Even the lowest flow can be diverted.</li> <li>2. No maintenance required (if well designed)</li> </ol>
Dis-advantages	<ol style="list-style-type: none"> <li>1. Regular maintenance and repairs required.</li> <li>2. At low flows very little water will be diverted and therefore this type of intake is not suitable for rivers with great fluctuations in flow.</li> </ol>	<ol style="list-style-type: none"> <li>1. Low flow cannot be diverted properly</li> <li>2. Modern materials like concrete necessary.</li> </ol>	<ol style="list-style-type: none"> <li>1. Expensive.</li> <li>2. Local materials not suitable.</li> <li>3. Good design required to prevent blockage by sediment.</li> </ol>

**Table 4.** The advantages and disadvantages of the intake types

### 5.1.2. Power channels

The power channel or simply a channel conducts the water from the intake to the forebay tank. The length of a channel depends upon the topography of the region and the distance of powerhouse from the intake. Also the designing of the MHP systems states the length of the channel sometimes a long channel combined with a short penstock can be cheaper or required, while in other cases a combination of short channel with long penstock would be more suitable.

In the Himalayan region, the hydro power channels are sometimes as long as a few kilometers to create a head of 10 to 60 meters or more. Generally power channels are excavated and to reduce friction and prevent leakages these are often lined with cement, clay or polythene sheet. Size and shape of a channel and material used for lining are often dictated by cost and head considerations. During the process of flowing past the walls and bed material, the water loses energy. The rougher material have greater friction loss and higher elevation difference needed between channel entry and exit.

In hilly regions it is common that the power channel would have to cross small streams. In such situations it is often prudent to build a complete crossing over the channel, during rainy season and flash floods, rocks/mud may block the channel or wash away sections of the channel. Sometimes just the provision of a drain running under the channel (in case of very small streams along stable slopes) is usually adequate. The power channel has some important parts which are described in the sub-sections below:

### 5.1.3. Settling basin

The water diverted from the stream and carried by the channel usually carries a suspension of small particles such as sand that are hard and abrasive and can cause expensive damage and rapid wear to turbine runners. To get rid of such particles and sediments, the water flow is allowed to slow down in 'settling basins' so that the sand and silt particles settle on the basin floor. The deposits are then periodically flushed. The design of settling basin depends upon the flow quantity, speed of flow and the tolerance level of the turbine (smallest particle that can be allowed). The maximum speed of the water in the settling basin can thus be calculated as slower the flow, lower is the carrying capacity of the water. The flow speed in the settling basin can be lowered by increasing the cross section area.

### 5.1.4. Spillways

Spillways along the power channel are designed to permit overflow at certain points along the channel. The spillway acts as a flow regulator for the channel. During floods the water flow through the intake can be twice the normal channel flow, so the spillway must be large enough to divert this excess flow. The spillway can also be designed with control gates to empty the channel. The spillway should be designed in such a manner that the excess flow is fed back without damaging the foundations of the channel.



**Figure 3.** Spillway of Darbandikhan dam

#### *5.1.5. Forebay tank*

The forebay tank serves the purpose of providing steady and continuous flow into the turbine through the penstocks. Forebay also acts as the last settling basin and allows the last particles to settle down before the water enters the penstock. Forebay can also be a reservoir to store water depending on its size (large dams or reservoirs in large hydropower schemes are technically forebay).

A sluice will make it possible to close the entrance to the penstock. In front of the penstock a trashrack need to be installed to prevent large particles to enter the penstock. A spillway completes the forebay tank.



**Figure 4.** Forebay tank

## 5.2. Penstock

The penstock pipe transports water under pressure from the forebay tank to the turbine, where the potential energy of water is converted into kinetic energy in order to rotate the turbine. The penstock is often the most expensive item in the project budget – as much as 40 percent is not uncommon in high-head installations. It is therefore worthwhile to optimize its design in order to minimize its cost. The choice of size and type of penstock depends on several factors that are explained briefly in this section. Basically, the trade-off is between head loss and capital cost.

Head loss due to friction in the penstock pipe depends principally on the velocity of water, the roughness of pipe wall and the length and diameter of pipe. The losses decrease substantially with increased pipe diameter. Conversely, pipe costs increase steeply with the increase of diameter. Therefore, a compromise between cost and the required performance. The design philosophy is first identify available pipe options, select a target head loss of 5 to 10 percent or less of the gross head, and keep the length as short as possible. Several options for sizes and types of materials may need to be calculated and evaluated in order to find a suitable penstock pipe. A smaller penstock may save on capital costs, but the extra head loss may account for lost energy and revenue from generated electricity (if you are selling the power). In smaller systems, the allowable head loss can be as much as 33 percent. This is particularly relevant to developers who combine domestic water supply and penstock in the same pipe.

Several factors should be considered when deciding which material will be used in a particular penstock: design pressure, the roughness of the pipe's interior surface, method of joining, weight and ease of installation, accessibility to the site, design life and maintenance, weather conditions, availability, relative cost and likelihood of structural damage.

The pressure rating of the penstock is critical because the pipe wall must be thick enough to withstand the maximum water pressure; otherwise there will be a risk of bursting. The pressure of the water in the penstock depends on the head; the higher head is higher pressure. Pressure ratings are normally given in bar units or PSI; 10.2 m of head will exert a pressure of 1 bar, or 14.5 PSI. The penstock becomes more expensive as the pressure rating increases.

The most commonly used materials for a penstock are HDPE, uPVC and mild steel because of their suitability, availability and affordability. Layout of the penstock pipelines depends on their material, the nature of terrain and environmental considerations; they are generally surface-mounted or buried underground. Special attention is necessary where a penstock is installed in a very cold environment; protection from ice and frost must be considered. In severe frost areas, penstocks should always be buried below the frost line. Where freezing is not a concern, the penstock may be left above ground. However, it is generally preferable to bury the penstock to provide protection from expansion, animals and falling trees. Because of changes in the ambient temperature, the length of the penstock pipe may be subjected to expansion and contraction. Expansion joints are used to compensate for maximum possible changes in length.

<i>Material</i>	<i>Friction</i>	<i>Weight</i>	<i>Corrosion</i>	<i>Cost</i>	<i>Jointing</i>	<i>Pressure</i>
<i>Mild Steel</i>	XXX	XXX	XXX	XXXX	XXXX	XXXXX
<i>HDPE<sup>2</sup></i>	XXXXX	XXXXX	XXXXX	XX	XX	XXXXX
<i>uPVC<sup>3</sup></i>	XXXXX	XXXXX	XXXX	XXXX	XXXX	XXXXX

<sup>1</sup>Adapted from Frankel, Peter, et al. *Micro-Hydro Power : A Guide for development Workers*. London, U.K: Intermediate Technology Publications in association with the Stockholm Environment Institute, 1991.

X = Poor ----- XXXXX = Excellent

<sup>2</sup>HDPE = High density polyethylene

<sup>3</sup>uPVC = Unplastified polyvinyl chloride

**Table 5.** Comparison of Penstock Materials<sup>1</sup>

The hydrostatic pressure created from the head must be determined so that a suitable wall thickness can be determined. This pressure is given by Equation (1).

$$\text{Pressure} = \rho * g * H \quad (1)$$

$\rho$  density of water

$g$  acceleration due to gravity

$H$  head

With the pressure calculated, the minimal wall thickness can then be calculated from Equation (2).

$$t = P * D / 2 * s \quad (2)$$

$t$  wall thickness

$P$  hydrostatic pressure

$D$  diameter

$s$  allowable tensile stress

Friction is always present, even in fluids, it is the force that resists the movement of objects. When you move a solid on a hard surface, there is friction between the object and the surface. If you put wheels on it, there will be less friction. In the case of moving fluids such as water, there is even less friction but it can become significant for long pipes. Friction can be also be high for short pipes which have a high flow rate and small diameter as in the syringe example. In fluids, friction occurs between fluid layers that are traveling at different velocities within the pipe (see Figure 5). There is a natural tendency for the fluid velocity to be higher in the center of the pipe than near the wall of the pipe. Friction will also be high for viscous fluids and fluids with suspended particles.

Another cause of friction is the interaction of the fluid with the pipe wall, the rougher pipe has higher friction. Friction depends on:

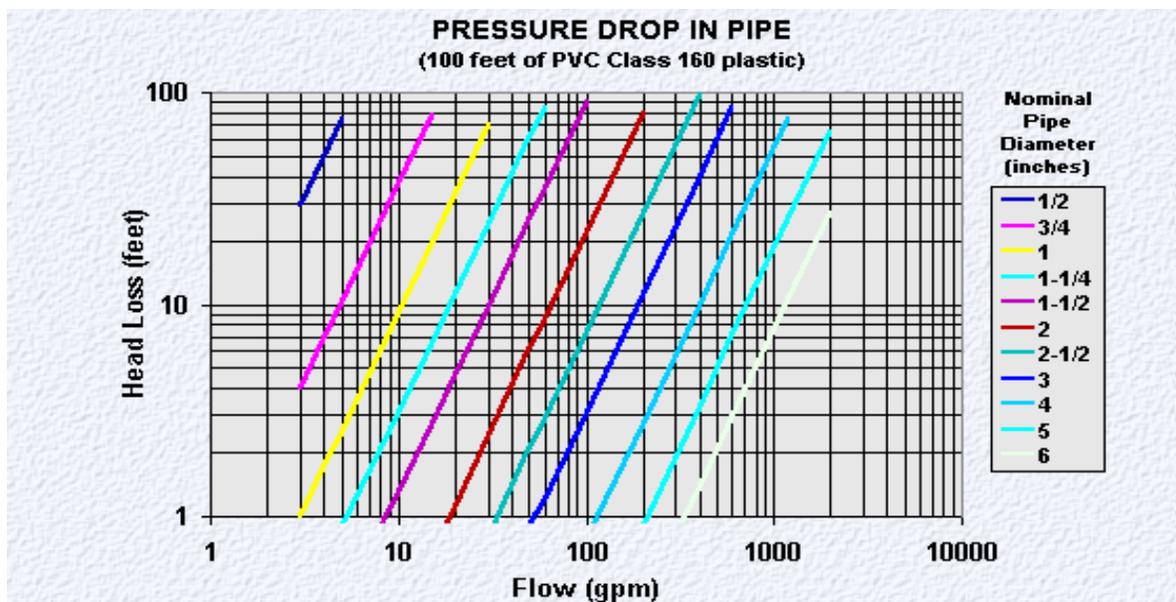
- average velocity of the fluid within the pipe
- viscosity
- pipe surface roughness

the increase in any one of these parameters will increase friction. The amount of energy required to overcome the total friction loss within the system has to be supplied by the pump if you want to achieve the required flow rate. In industrial systems, friction is not normally a large part of a pump's energy output. For typical systems, it is around 25% of the total. If it becomes much higher then you should examine the system to see if the pipes are too small. However all pump systems are different, in some systems the friction energy may represent 100% of the pump's energy, this is what makes pump systems interesting, there is a million and one applications for them. In household systems, friction can be a greater proportion of the pump energy output, maybe up to 50% of the total, this is because small pipes produce higher friction than larger pipes for the same average fluid velocity in the pipe. Another cause of friction are the fittings (elbows, tees, y's, etc) required to get the fluid from point to point. Each one has a particular effect on the fluid streamlines. For example in the case of the elbow, the fluid streamlines that are closest to the tight inner radius of the elbow lift off from the pipe surface forming small vortices that consume energy. This energy loss is small for one elbow but if you have several elbows and other fittings it can become significant. Generally, they rarely represent more than 30% of the total friction due to the overall pipe length.

To sum up, head losses in a penstock depend on:

- Its shape: singularities as elbows or forks tend to increase head losses
- Its internal diameter
- Its wall roughness and its evolution due to its degradation or/ and to wall deposits.

It may be recalled here that energy loss due to friction in a penstock can be estimated as being inversely proportional to its diameter to the power of five. For instance, a diameter increase of 20% leads to a head losses decrease of 60%. Figure 5. shows the relation between the head loss (feet) with the flow rate (gpm) for a 100 feet PVC class 160 plastic pipe.



**Figure 5.** The relation of head loss with the flow

### 5.3. Turbines

Turbine is the main piece of equipment in the hydro power scheme that converts energy of the falling water into the rotating shaft power. The selection of the most suitable turbine for any particular hydro site depends mainly on two of the site characteristics – head and flow available. All turbines have a power-speed characteristic. This means they will operate most efficiently at a particular speed, head and flow combination. Thus the desired running speed of the generator or the devices being connected/ loading on to the turbine also influence selection. Other important consideration is whether the turbine is expected to generate power at part-flow conditions. The design speed of a turbine is largely determined by the head under which it operates. Turbines can be classified as high head, medium head or low head machines. They are also typified by the operating principle and can be either impulse or reaction turbines. The basic turbine classification is given in the table below:

<i>Turbine Runner</i>	<i>High Head</i>	<i>Medium Head</i>	<i>Low Head</i>	<i>Ultra- Low Head</i>
<i>Impulse</i>	<b>Pelton Turgo</b>	<b>Cross- flow Turgo Muti-jet Pelton</b>	<b>Cross- flow Multi – jet – Turgo</b>	<b>Water wheel</b>
<b>Reaction</b>	-	<b>Francis Pump- as – turbine</b>	<b>Propeller Kaplan</b>	<b>Propeller Kaplan</b>

**Table 6.** Groups of water Turbines

The rotating part (called ‘runner’) of a reaction turbine is completely submerged in water and is enclosed in a pressure casing. The runner blades are designed in a manner such that the pressure difference across their surface imposes lift forces (similar to the principle used for airplane wings) which cause the runner to turn/rotate.

The impulse turbine (as the name suggests) on the other hand is never immersed in water but operates in air, driven by a jet (or jets) of water striking its blades. The nozzle of the penstock converts the head of the water (from forebay tank) into a high speed jet that hits the turbine runner blades that deflect the jet so as to utilize the change of momentum of the water and converting this as the force on the blades – enabling it to rotate.

Impulse turbines are usually cheaper than reaction turbines because there is no need for a pressure casing nor for carefully engineered clearances, but they are also only suitable for relatively higher heads.

#### 5.3.1. Impulse turbines

Impulse turbines are more widely used for micro-hydro applications as compared to reaction turbines because they have several advantages such as simple design (no pressure seals around the shaft and better access to working parts - easier to fabricate and maintain), greater tolerance towards sand and other particles in the water, and better part-flow efficiencies. The impulse turbines are not suitable for low head sites as they have lower

specific speeds and to couple it to a standard alternator, the speed would have to be increased to a great extent. The multi-jet Pelton, crossflow and Turgo turbines are suitable for medium heads.

#### 5.3.1.1. Pelton turbine

A Pelton turbine consists of a set of specially shaped buckets mounted on a periphery of a circular disc. It is turned by forced jets of water which are discharged from one or more nozzles and impinge on the buckets. The resulting impulse spins the turbine runner, imparting energy to the turbine shaft. The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet.



**Figure 6.** Pelton Turbine

The cutaway on the lower lip allows the following bucket to move further before cutting off the jet propelling the bucket ahead of it and also permits a smoother entrance of the bucket into the jet. The Pelton bucket is designed to deflect the jet through 165 degrees which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet. They are used only for sites with high heads ranging from 60 m to more than 1000 m.

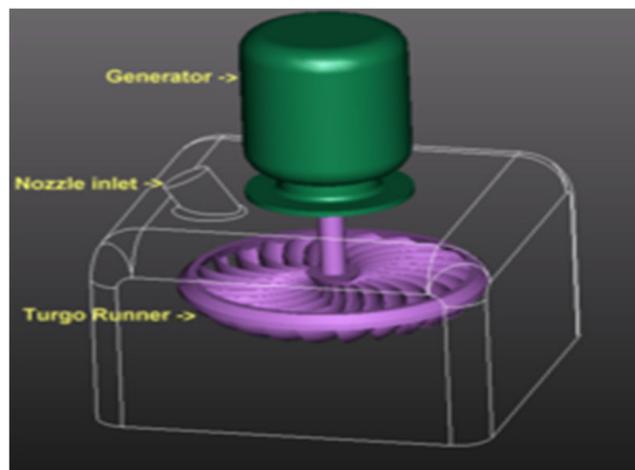
#### 5.3.1.2. Turgo impulse turbines

The Turgo turbine is an impulse turbine designed for medium head applications. These turbines achieve operational efficiencies of up to 87%. Developed in 1919 by Gilkes as a modification of the Pelton wheel, the Turgo has certain advantages over Francis and Pelton designs for some applications. Firstly, the runner is less expensive to make than a Pelton wheel while it does not need an airtight housing like the Francis turbines. Finally the Turgo has higher specific speeds and at the same time can handle greater quantum of flows than a Pelton wheel of the similar diameter, leading to reduced generator and installation cost. Turgo turbines operate in a head range where the Francis and Pelton overlap. Turgo installations are usually preferred for small hydro schemes where low cost is very important.

Turgo turbine is an impulse turbine where water does not change pressure but changes direction as it moves through the turbine blades. The water's potential energy is converted to kinetic energy with a penstock and nozzle. The high speed water jet is then directed on

the turbine blades which deflect and reverse the flow and the water exits with very little energy. Like all turbines with nozzles, blockage by debris must be prevented for effective operation. A Turgo runner looks like a Pelton runner split in half. For the same power, the Turgo runner is one half the diameter of Pelton runner, and so twice the specific speed. e Turgo can handle a greater water flow than Pelton because exiting water doesn't interfere with adjacent buckets.

The specific speed of Turgo runners is between the Francis and Pelton. Single or multiple nozzles can be used. Increasing the number of jets increases the specific speed of the runner by the square root of the number of jets i.e., four jets yield twice the specific speed of one jet on the same turbine.

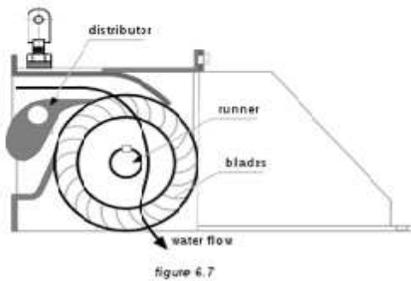


**Figure 7.** Turgo Turbine

### 5.3.1.3. Crossflow turbine

Also called a Michell-Banki turbine a crossflow turbine has a drum-shaped runner consisting of two parallel discs connected together near their rims by a series of curved blades. A crossflow turbine always has its runner shaft horizontal (unlike Pelton and Turgo turbines which can have either horizontal or vertical shaft orientation). Unlike most water turbines, which have axial or radial flows, in a crossflow turbine the water passes through the turbine transversely, or across the turbine blades. As with a waterwheel, water enters at the turbine's edge. After passing the runner, it leaves on the opposite side. Going through the runner twice provides additional efficiency. When the water leaves the runner, it also helps clean the runner of small debris and pollution. The cross-flow turbines generally operate at low speeds. Crossflow turbines are also often constructed as two turbines of different capacity that share the same shaft. The turbine wheels are the same diameter, but different lengths to handle different volumes at the same pressure. The subdivided wheels are usually built with volumes in ratios of 1:2. The subdivided regulating unit (the guide vane system in the turbine's upstream section) provides flexible operation, with  $\frac{1}{3}$ ,  $\frac{2}{3}$  or 100% output, depending on the flow. Low operating costs are obtained with the turbine's relatively simple construction. The water flows through the blade channels in two directions: outside to inside, and inside to outside. Most turbines are run with two jets,

arranged so that the two water jets in the runner will not affect each other. It is, however, essential that the turbine, head and turbine speed are harmonized. The turbine consists of a cylindrical water wheel or runner with a horizontal shaft, composed of numerous blades (up to 37), arranged radially and tangentially. The edge of the blades are sharpened to reduce resistance to the flow of water. A blade is made in a part-circular cross section (pipe cut over its whole length). The ends of the blades are welded to disks to form a cage like a hamster cage and are sometimes called "squirrel cage turbines"; instead of the bars, the turbine has trough-shaped steel blades.



**Figure 8.** Crossflow Turbine

The water flows first from the outside of the turbine to its inside. The regulating unit, shaped like a vane or tongue, varies the cross-section of the flow. These divide and direct the flow so that the water enters the runner smoothly for any width of opening. The guide vanes should seal to the edges of the turbine casing so that when the water is low, they can shut off the water supply. The guide vanes therefore act as the valves between the penstock and turbine. The water jet is directed towards the cylindrical runner by a fixed nozzle. The water enters the runner at an angle of about 45 degrees, transmitting some of the water's kinetic energy to the active cylindrical blades. The turbine geometry (nozzle-runner-shaft) assures that the water jet is effective. The water acts on the runner twice, but most of the power is transferred on the first pass, when the water enters the runner. Only  $\frac{1}{3}$  of the power is transferred to the runner when the water is leaving the turbine.

The crossflow turbine is of the impulse type, so the pressure remains constant at the runner. The peak efficiency of a crossflow turbine is somewhat less than a Kaplan, Francis or Pelton turbine. However, the crossflow turbine has a flat efficiency curve under varying load. With a split runner and turbine chamber, the turbine maintains its efficiency while the flow and load vary from  $\frac{1}{6}$ <sup>th</sup> to the maximum. The crossflow turbines are mostly used in mini and micro hydropower units less than 2 MW and with heads less than 200 m, since it has a low price and good regulation. Particularly with small run-of-the-river schemes, the flat efficiency curve yields better performance than other turbine systems, as flow in small streams varies seasonally. The efficiency of a turbine is determined whether electricity is produced during the periods when rivers have low heads. Due to its better performance even at partial loads, the crossflow turbine is well-suited to stand-alone electricity generation. It is simple in construction and that makes it easier to repair and maintain than other turbine types. Another advantage is that the crossflow turbines get cleaned as the water leaves the runner (small sand particles, grass, leaves, etc. get washed away),

preventing losses. So although the turbine's efficiency is somewhat lower, it is more reliable than other types. Other turbine types get clogged easily, and consequently face power losses despite higher nominal efficiencies.

### 5.3.2. Reaction turbines

The more popular reaction turbines are the Francis turbine and the propeller turbine. Kaplan turbine is a unique design of the propeller turbine. Given the same head and flow conditions, reaction turbines rotate faster than impulse turbines. This high specific speed makes it possible for a reaction turbine to be coupled directly to an alternator without requiring a speed-increasing drive system. This specific feature enables simplicity (less maintenance) and cost savings in the hydro scheme. The Francis turbine is suitable for medium heads, while the propeller is more suitable for low heads.

The reaction turbines require more sophisticated fabrication than impulse turbines because they involve the use of larger and more intricately profiled blades together with carefully profiled casings. The higher costs are often offset by high efficiency and the advantages of high running speeds at low heads from relatively compact machines. Expertise and precision required during fabrication make these turbines less attractive for use in micro-hydro in developing countries. Most reaction turbines tend to have poor part-flow efficiency characteristics

#### 5.3.2.1. Francis turbine

The Francis turbine is a reaction turbine where water changes pressure as it moves through the turbine, transferring its energy. A watertight casement is needed to contain the water flow. Generally such turbines are suitable for sites such as dams where they are located between the high pressure water source and the low pressure water exit. The inlet of a Francis turbine is spiral shaped. Guide vanes direct the water tangentially to the turbine runner. This radial flow acts on the runner's vanes, causing the runner to spin. The guide vanes (or wicket gate) are adjustable to allow efficient turbine operation for a wide range of flow conditions. As the water moves through the runner, its spinning radius decreases, further delivering pressure acting on the runner. This, in addition to the pressure within the water, is the basic principle on which the Francis turbine operates. While exiting the turbine, water acts on cup shaped runner buckets leaving without any turbulence or swirl and hence almost all of the kinetic or potential energy is transferred. The turbine's exit tube is shaped to help decelerate the water flow and recover the pressure. Francis Turbine and generator Guide vanes at minimum flow setting (cut-away view) Guide vanes at full flow setting (cut-away view) Francis turbines can be designed for a wide range of heads and flows and along with their high efficiency makes them one of the most widely used turbines in the world. Large Francis turbines are usually designed specifically for each site so as to gain highest levels of efficiencies (these are typically in the range of over 90%). Francis turbines cover a wide range of head – from 20 meters to 700 meters, and can be designed for outputs power ranging from just a few kilowatts to one Gigawatt.



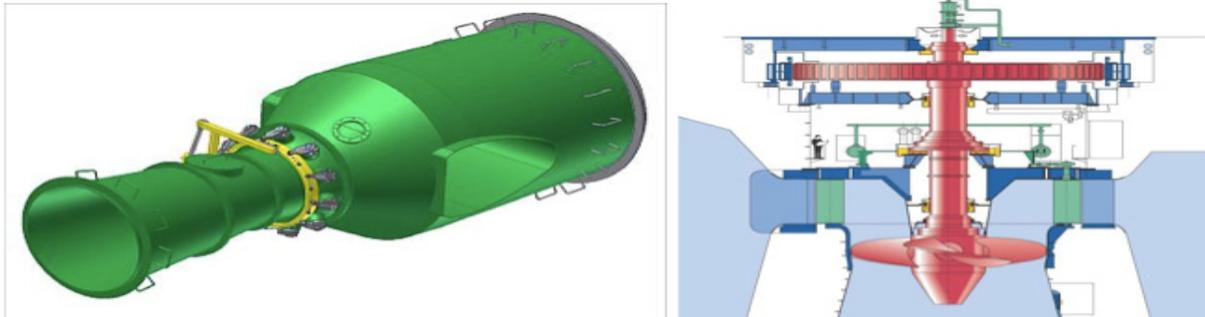
**Figure 9.** Francis Turbine

#### 5.3.2.2. Kaplan turbine

The Kaplan turbine has adjustable blades and was developed on the basic platform (design principles) of the Francis turbine by the Viktor Kaplan in 1913. The main advantage of Kaplan turbines is its ability to work in low head sites which was not possible with Francis turbines. Kaplan turbines are widely used in high-flow, low-head power production.

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the wicket gate and spirals on to a propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy.

The turbine does not need to be at the lowest point of water flow, as long as the draft tube remains full of water. A higher turbine location, however, increases the suction that is imparted on the turbine blades by the draft tube that may lead to cavitations due to the pressure drop. Typically the efficiencies achieved for Kaplan turbine are over 90%, mainly due to the variable geometry of wicket gate and turbine blades. This efficiency however may be lower for very low head applications. Since the propeller blades are rotated by high-pressure hydraulic oil, a critical design element of Kaplan turbine is to maintain a positive seal to prevent leakage of oil into the waterway. Kaplan turbines are widely used throughout the world for electrical power production. They are especially suited for the low head hydro and high flow conditions – mostly in canal based hydro power sites. Inexpensive micro turbines can be manufactured for specific site conditions (e.g. for head as low one meter). Large Kaplan turbines are individually designed for each site to operate at the highest possible efficiency, typically over 90%. They are very expensive to design, manufacture and install, but operate for decades.



**Figure 10.** Kaplan Turbine

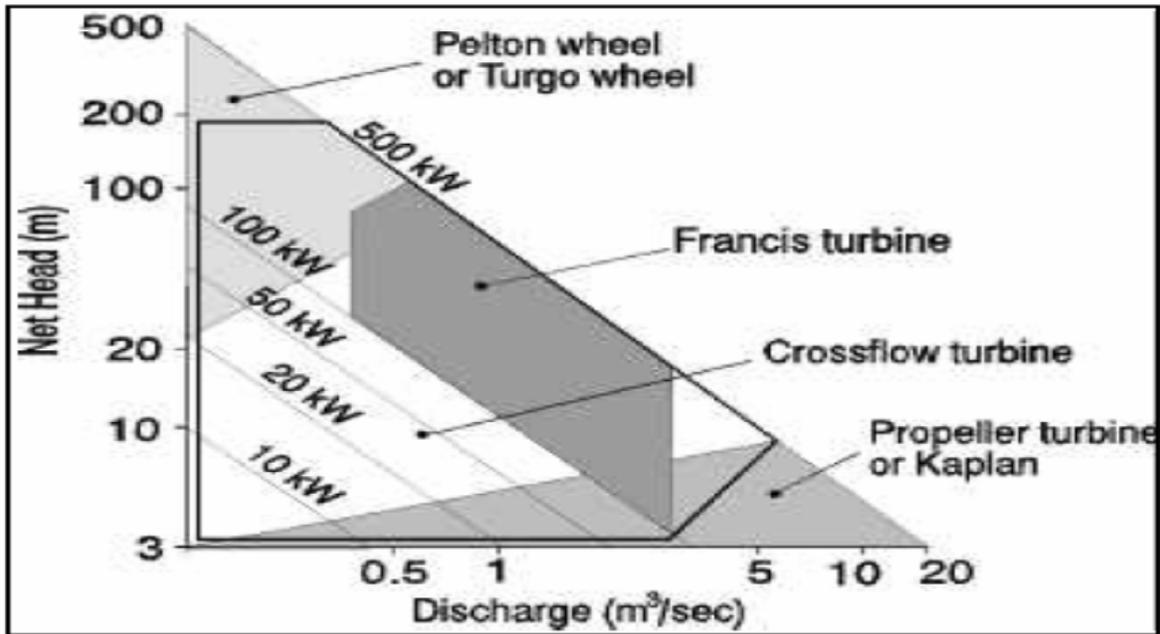
### 5.3.3. Turbine selection

Selection of an appropriate turbine to a large extent is dependent upon the available water head and to a lesser extent on the available flow rate. In general, impulse turbines are used for high head sites, and reaction turbines are used for low head sites. Kaplan turbines with adjustable blade pitch are suitable for wide ranges of flow or head conditions, since their peak efficiency can be achieved over a wide range of flow conditions. Small turbines (less than 10 MW) may have horizontal shafts, and even fairly large bulb-type turbines up to 100 MW or so may be horizontal. Very large Francis and Kaplan machines usually have vertical shafts because this makes best use of the available head, and makes installation of a generator more economical. Pelton turbines may be installed either vertically or horizontally.

Some impulse turbines use multiple water jets per runner to increase specific speed and balance shaft thrust. Turbine type, dimensions and design are basically governed by the following criteria:

- Net head
- Variation of flow discharge through the turbine
- Rotational speed
- Cavitation problems (quality of water available from penstock)
- Cost

The main criterion considered in turbine selection is the net head. The figure given above (Turbine Application Chart) specifies the range of operating heads for each turbine type. The figure above and the table below show some overlapping, so that for a given head several types of turbines can be used. The selection is particularly critical in low-head schemes, where large discharges need to be handled to be economically viable.



**Figure 11.** Turbine Application Chart based on Head and Discharge

Turbine Type	Typical range of heads (H = head in m)
Hydraulic wheel turbine	$0.2 < H < 4$
Archimedes' screw turbine	$1 < H < 10$
Kaplan & Propeller	$2 < H < 40$
Francis	$10 < H < 350$
Pelton	$50 < H < 1300$
Michell-Banki	$3 < H < 250$
Turgo	$50 < H < 250$

**Table 7.** The selection of turbine according to the head

#### 5.3.4. Turbine efficiency

A significant factor in the comparison of different turbine types is their relative efficiencies both at their design point and at reduced flows. Typical efficiency curves are shown in the figure below. An important point to note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Crossflow and Francis turbines falls away more sharply if run at below half their normal flow. Most fixed-pitch propeller turbines perform poorly except above 80% of full flow.

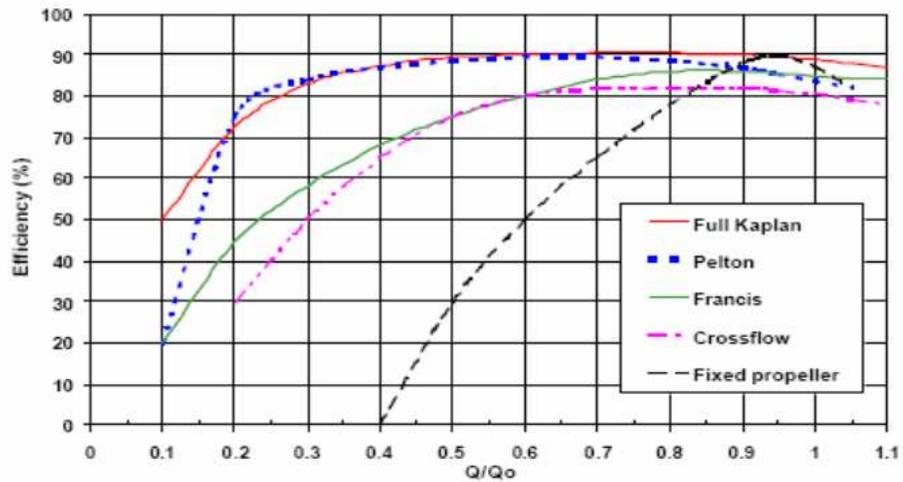


Figure 12. Efficiency of Various Turbines based on Discharge rate

### 6. Hydro power in Iraq

In Iraq there are two big rivers (Tigris & Euphrates) where a many dams are built, that gives the ability to establish a hydro electric power plants on these dams such as ( mousal , hadeetha , samara , diala ,dokhan.....etc ), which are distributed on the map below.



Figure 13. The distribution map of Dams in Iraq

Most of these dams have been used in the generation of electricity by building a hydro electric power plants on it and the output power of these plant in Iraq are shown in table 6 below. The total generated power in Iraq is about **10171.5 MW** as we see from this table the hydro power generated is about **2489 Mw** which represent a (25%) the amount of hydroelectric power generated in Iraq varies according to the incoming quantity of water that enter from these rivers.

<i>Name of hydro power plant</i>	<i>Generated power output ( Mw )</i>
<i>Mosul</i>	1050
<i>Hadeetha</i>	60
<i>Hindia</i>	15
<i>Dukhan</i>	400
<i>Al- Kufa</i>	5
<i>Hmreen Dam</i>	50
<i>Samaraa</i>	84
<i>Al- Qadssia</i>	660
Darbandikhan	240

**Table 8.** Hydro power plants in Iraq

### 6.1. Hydropower transportation and power conservation

In order to achieve the maximum (optimum) utilization of water and hydropower of the rivers in Iraq we study and calculate the elevation of water at the dams in the whole country such as (Hadeetha, Samara, Diala, Hindia, Kufa and Abasia ....etc) and the elevation of the middle and south province center (Baghdad, Basra, Babylon, Kut, Nasria, Missan, and Samawa), by using the Google Earth program and then calculate the difference in elevation. Figure (14) shows the map of the region of study.

Since the incoming water to Iraq was decrease last years and the high demand on the water and electricity, the concentration of study was on the water supply and the amount of electricity that can be generated from this quantity of water. In addition to the lack of fresh water that suitable for the everyday using because the high ratio of salts in the water that arrive to some cities through Tigris& Euphrates rivers, the problem that the other will be faced with the continuous reduction in the arrived quantity of water to Iraq, and the increasing in pollution levels of these rivers in the future. Where the expected pollution levels will cross over the permission level at which the processing of water become more difficult that the traditional water station can reach it.



**Figure 14.** The map of the region of study

static (at no flow ) head loss = 80 ft				dynamic(at design flow) head loss =100 ft		
Q	D	Po/p	EPM	D	Po/p	EPM
1000	30	28.8	20736	28	36	25920
2000	39	57.6	41472	37	72	51840
3000	45	86.4	62208	43	107	77760
4000	50	115.2	82944	48	144	103680
5000	55	144	103680	52	180	129600
6000	59	172.8	124416	56	216	155520
7000	62	201.6	145152	59	252	181440
8000	65	230.4	165888	62	288	207360
9000	68	259.2	186624	65	324	233280
10000	71	288	207360	68	360	259200

Head = 400ft , Distance = 466 mile, Sys. Efficiency =50%, Q = flow rate(in gpm), D = pipe line diameter(in inch), Po/p = power output(in KW), EPM = Energy per month(in KWH)

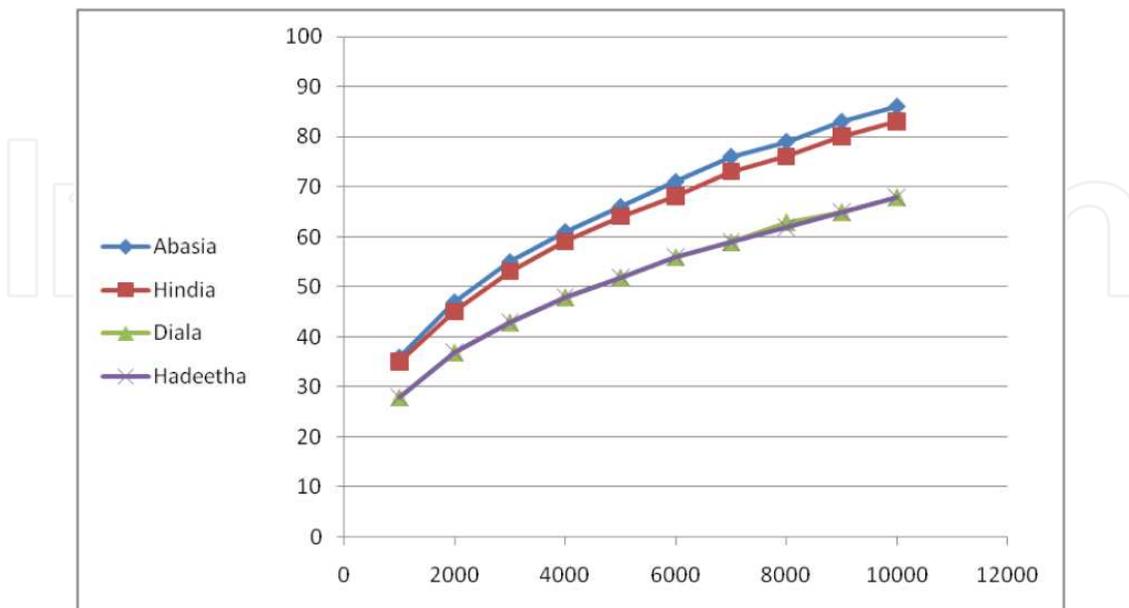
**Table 9.** Shows the Relation Between The Q (flow rate) and the o/p Power and Pipeline Diameter and The Other Parameters are Constant.

From the results shown in the above tables we see that. The difference in elevation(head) between Basra city and Hadeetha dam is 400 ft and the distance is 466 mile approximately. To supply the city by 1000 gpm we need a pipeline with 28 inch diameter or more, and to supply the city by 10000 gpm the pipeline of 68 inch diameter or more can be used. These pipeline can produce a hydroelectric power from 36 KW to 360 KW which can save an energy from 25920 KWH to 259200 KWH per month, in addition to the power saving, through the way of supplying water with high pressure by using a pipeline, which will consumed in the case of lifting that quantities of water from the river ( low lift ) at the destination point to the water station or for any other using of water.

The difference in elevation(head) between Basra city and Diala (Hemrin) dam is 290 ft and the distance is 341 mile approximately. To supply the city by 1000 gpm we need a pipeline with 28 inch diameter or more, and to supply the city by 10000 gpm the pipeline of 68 inch diameter or more can be used. These pipelines can produce a hydroelectric power from 26.1 KW to 261 KW , which can save an energy from 18792 KWH to 187920 KWH per month in.

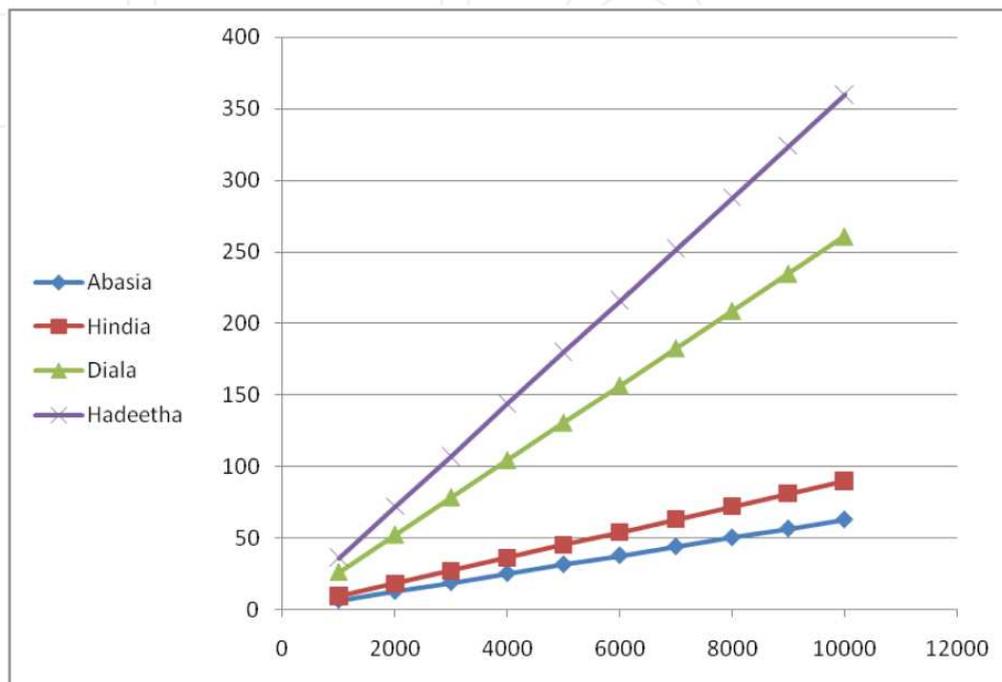
The difference in elevation(head) between Basra city and Abasia dam is 70 ft and the distance is 260 mile approximately. To supply the city by 1000 gpm we need a pipeline with 36 inch diameter or more, and to supply the city by 10000 gpm the pipeline of 86 inch diameter or more can be used. These pipelines can produce a hydroelectric power from 6.3 KW to 63 KW , which can save an energy from 4536 KWH to 45360 KWH per month

Figure (15) below shows the relations between the flow rate in gpm with pipeline diameter in inch that represent the quantity of water supplied to the Basra city from the dams (Hadeetha, Diala, Hindia, Abasia). The one who see this relations utilize that the graph of Hadeetha dam and Diala is complying in spite of the difference in the dams head, because the difference in the distances, where long distance causes high friction loss ,so that to decrease this friction loss the pipeline diameter must be large, and the same thing shown for Abasia and Hindia dams.



**Figure 15.** The Relation Between Flow Rate (Q) in gpm and Pipeline Diameter in inch For Supplying Water to Basra City from Dams

Figure (16) below shows the relations between the flow rate in gpm that represent the quantity of water supplied to the Basra city from the dams (Hadeetha, Diala, Hindia, Abasia) with the hydroelectric generated power in KW. The idea behind this graph is that the slopes of the lines increase with the increasing of head at the dams, so that the hydro generated power from Hadeetha dam is the higher and the lower power from Abasia dam for the same quantity of the flow rate (Q) gpm.



**Figure 16.** The Relation Between Flow Rate (Q) in gpm and The Hydroelectric Generated power in KW From Supplying Water to Basra City from Dams

From all the above, if the one need to adopted this study to execute or establishing a project of water pipelines and a micro & mini hydroelectric generators, which need to a further studying about cost calculations and the obstacles or difficulties that may be faced him, because this is a theoretical study and the practical project will require a solution to a practical problems that the pipe lines intersect it, like mount, river, villages, ...etc.

## 6.2. Hydro power transportation

The use of pipeline in water transportation guarantee three type of power conservation the first is hydroelectric generation by installing a turbine in the way of this pipeline, the second type of power conservation when it (pipeline) may also being used instead of low lift pumping station for the water treatment plant in this operation the power can be conserved approximately 30% -40% of the whole total power consumed in the water treatment plants in Babylon province when the difference in elevation between the river and the reservoir tank is about 5-10 m (head). The using of pipeline in the supply of water directly conserved power because it doesn't need to convert the hydropower (head & flow rate) into mechanical power and then into electrical power that used in the low lift part of water treatment plant that need

to convert the electrical power into mechanical power to lift the water from the river to the reservoir tank, because of the efficiency of conversion is always less than 100% ( turbine and generator efficiency), this operation leads to conserve the power approximately with 50% or more of the hydropower, which may be consider the third type of power conservation. This type of power conservation is very clear in the water treatment plant at Bekal waterfall figure (17) when the intake established on it, but penstock(pipeline) length is tenths meter to the reservoir tank the length that may extended to kilometer or handered of kilometer in the other place, which represent the low lift in the traditional water treatment plant. Also figure 18 shows the water pump used for pumping water in the water treatment station.



**Figure 17.** Shows the intake and the penstock (pipeline) of Bekal water treatment plant



**Figure 18.** Shows the high head pump station

## 7. Summary

Water is one of our most valuable resources, and hydropower makes use of this renewable treasure. *Hydropower* traditionally represents the energy generated by damming a river and using turbine systems to generate electrical power. In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized. Small-scale hydropower was the most common way of electricity generating in the early 20<sup>th</sup> century. Hydropower will continue playing an important role throughout the 21st Century, in the world of electricity supply. Hydropower development does have some challenges besides the technical, economic and environmental advantages, which shares with the other power generation technologies. At the beginning of the new Millennium hydropower provided almost 20% (2600 TWh/year) of the electricity world consumption (12900 TWh/year).

The countries have different criteria in the classification of hydro power plants, the hydro plants may be also classified according to the “Head” or the vertical distance through which the water is made to impact the turbines.

Power generation from water depends upon a combination of head and flow. Both must be available to produce electricity. Water is diverted from a stream into a pipeline, where it is directed downhill and through the turbine (flow). The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. The turbine in turn drives the generator where electrical power is produced. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to turbine and system inefficiencies. Water pressure or Head is created by the difference in elevation between the water intake and the turbine.

The theoretical power (P) available from a given head of water is in exact proportion to the head and the quantity of water available.

$$P = Q \times H \times e \times 9.81 \text{ (kW)}$$

Where

P Power at the generator terminal, in kilowatts (kW)

H The gross head from the pipeline intake to the tail water in meters (m)

Q Flow in pipeline, in cubic meters per second (m<sup>3</sup>/s)

e The efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator, expressed by a decimal (e.g. 85% efficiency= 0.85)

9.81 is a constant and is the product of the density of water and the acceleration due to gravity (g)

The penstock pipe (pipeline) transports water under pressure from the forebay tank to the turbine, where the potential energy of the water is converted into kinetic energy in order to rotate the turbine. The penstock is often the most expensive item in the project budget – as much as 40 percent is not uncommon in high-head installations. It is therefore worthwhile to optimize its design in order to minimize its cost. Head loss due to friction in the penstock pipe depends principally on the velocity of the water, the roughness of the pipe wall and the length and diameter of the pipe. The losses decrease substantially with increased pipe diameter. Conversely, pipe costs increase steeply with diameter. Therefore, a compromise between cost and performance is required. Several factors should be considered when deciding which material to use for a particular penstock: design pressure, the roughness of the pipe's interior surface, method of joining, weight and ease of installation, accessibility to the site, design life and maintenance, weather conditions, availability, relative cost and likelihood of structural damage. The pressure rating of the penstock is critical because the pipe wall must be thick enough to withstand the maximum water pressure; otherwise there will be a risk of bursting. The penstock becomes more expensive as the pressure rating increases. The most commonly used materials for a penstock are HDPE, uPVC and mild steel because of their suitability, availability and affordability. Layout of the penstock pipelines depends on their material, the nature of the terrain and environmental considerations; they are generally surface-mounted or buried underground.

The hydrostatic pressure created from the head must be determined so that a suitable wall thickness can be determined. This pressure is given by Equation, **Pressure =  $\rho \cdot g \cdot H$**

Turbine is the main piece of equipment in the hydro power scheme that converts energy of the falling water into the rotating shaft power. The selection of the most suitable turbine for any particular hydro site depends mainly on two of the site characteristics – head and flow available. All turbines have a power-speed characteristic. This means they will operate most efficiently at a particular speed, head and flow combination. Thus the desired running speed of the generator or the devices being connected/ loading on to the turbine also influence selection. Other important consideration is whether the turbine is expected to generate power at part-flow conditions. The design speed of a turbine is largely determined by the head under which it operates. Turbines can be classified as high head, medium head or low head machines. They are also typified by the operating principle and can be either impulse or reaction turbines.

In order to achieve the maximum (optimum) utilization of water and hydropower. The use of pipeline in water transportation guarantee three type of power conservation the first is hydroelectric generation by installing a turbine in the way of this pipeline, the second type of power conservation when it (pipeline) may also being used instead of low lift pumping station for the water treatment plant and the using of pipeline in the supply of water directly conserved power because it doesn't need to convert the hydropower

(head & flow rate) into mechanical power and then into electrical power which used in the low lift part of water treatment plant that need to convert the electrical power into mechanical power to lift the water from the river to the reservoir tank, because of the efficiency of conversion.

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