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"Hydropower and Thermal Energy": A Theoretical Perspective

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Abstract—*Today's modern world is dependent on various types of advanced technological breakthroughs that are making our life more productive as well as comfortable. In simple terms, inexpensive and reliable electricity is critical to the sustained economic growth and security of any nation. Today's world is dependent on reliable, low cost and abundant energy.*

It is the power plant which provides this critical energy source. As an amazing fact, in the United Nations around 90% of the electricity is produced from the power plants that use steam as an energy source; with just 10% of the electricity produced from hydroelectric power plants. In other parts of the world as well, similar proportions are common for their electric production.

The power plant may be defined as a facility which transforms various types of energy into electricity or heat for some useful purpose. Based on the input mode to the power plant, the plant design will be drastically different for each energy source.

The forms of the input energy can be categorized as follows –

1. *The potential energy of an elevated body of water. In simple technical terms, it may be referred to as the hydroelectric power plant.*
2. *The chemical energy that is relatively from the hydrocarbons which are contained in the fossil fuels such as coal, oil or natural gas, which can be referred to as a fossil fuel fired power plant.*
3. *Now, comes the most amazing technology which is called as the Nuclear power plant. The energy developed is predominantly due to the separation or attraction of atomic particles.*

The present study is a humble effort towards the review of Hydropower as well as Thermal energy and the detailed theoretical investigation of the generation of these energies.

Keywords*:* *Energy, Rankine's Cycle, Carnot Vapour Cycle, Hydropower, Thermal Efficiency.*

1. INTRODUCTION

The growing concern for energy security is gradually becoming a major threat for a developing nation like INDIA. One of the most significant contributor to this has been the question of becoming self sufficient in power generation to meet the expontential demand of a growing nation.One of the most astonishing fact is that INDIA has been the 2nd best growing nation,even in the economic downslide of 2008-2009.Inspite of the current trend, one cannot overlook this fact that a regular supply of electricity is essential for a strong economic growth.An estimate shows that for every 1% economic growth,power generation capacity for INDIA needs to grow by 5-6 times to sustain the levels of growth for decades to come.

Nowadays most of the electricity produced throughout the world is from steam power plants. However electricity is being produced by some other power generation sources such as for example Hydropower,biogas power, solar cells etc. One newly developed method of electricity generation is the Magneto Hydro Dynamic Power Plant.

History Of Hydropower Development:

Wind and running water were the only available sources of mechanical power from ancient times.In the past decades water wheels were used for milling, pumping and lifting water from a lower to a higher elevation for irrigation. Water wheels of various types are still being used in many countries. An attempt to improve the efficiency of the water wheel contributedto the development of hydroelectric plants.Aiming at the improvement of the turbine efficiency,which went up to 60-70% in the mid of 1850's, extensive theoretical work was done by mathematician and engineers between 1750-1850.

However the utilization of water turbines in the production of electricity became extremely popular after the invention of Dynamo or Generator in 1880's.The new birth of the electric power supply was marked by the opening of 12.5 kW plant on the Fox river near New York, USA.

The supply of electricity to a number of consumer in parallel had been mastered. Improved design of generator & motor were presented in rapid succession and multi phase motor proposed by Tesla in 1888,opened the practical use in the industry.

Nonetheless the use of Arc Lamps for lighting dates back to 1822 in USA, 1876 in Germany & 1879 in Switzerland.

2. STEAM AND ITS IMPORTANCE

Steam is one of the most important critical resource in todays industrial world. It is essential for the production of paper and other wood products,for the preparation and serving of foods for cooling and heating of large buildings,for driving equipments such as pumps and compressors and for powering ships.However the most important priority remains as the primary source of powerfor the production of electricity.

Steam is extremely valuable because it can be produced anywhere in the world by utilizing the heat that comes from the fuels that are available in the nearby area. Steam also has some unique properties that are extremely important in the production of energy. Steam is basically recycled,from steam to water and subsequently back to steam again in a manner which is non toxic in nature. The modern steam plants of today are a combination of some complex engineered system that work to produce steam in the most efficient manner that is economically feasible. In any kind of situation however the steam power plant must obtain the required amount of heat. This heat must come from an energysource which varies significantly based on the plant’s location in the world. The sources of heat could be the following:

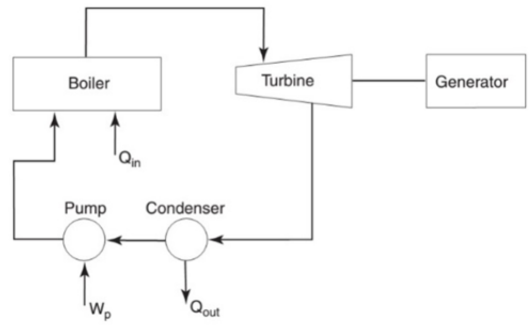
- A fossil fuel-coal, oil or natural gas.
- A nuclear fuel such as uranium.
- Other forms of energy which includes waste heat from exhaust gases of the gas turbines by product fuels such as Carbon Monoxide(CO),blast furnance gas(BFG) or methane,geo thermal energy and solar energy.

Each of the fuels contain potential energy in the forms of a heating value and this is measured by terms of british thermal units(B tus) per each pound or cubic feet of the fuel.Depending on whether the fuel is a solid or a gas.A British thermal unit is about equal to the quantity of heat required to raise one pound of water by one degree Fahrenheit.As the water is heated,it eventually changes its form by turning into steam.As the heat is continuously added, the steam reaches the desired temperature and pressure for the particular application.

3. DETAILED INVESTIGATION ON GENERATION OF THERMAL ENERGY-

The steam plant cycle:

The simplest steam cycle of practical significance is referral to as the Rankine’s cycle.Thesteam cycle is important because it connects processes that allow heat to be converted to work on a continuous basis.This simple cycle was based on dry saturated steam being supplied by a boiler to a power unit such as a turbine that drives an electric generator.Dry saturatedsteam is at the temperature that corresponds to the boiler pressure, is not super heated and does not contain moisture. The steam from the turbine exhausts to a condenser, from which the condensed steam is pumped back into the boiler. It is also called a condensing cycle and a simple schematic of the system is shown in the figure:



The schematic diagram also shows heat(Q_{in}) being supplied to the boiler and generator connected to the turbine for the production of electricity. Heat (Q_{out}) is removed by the condenser and the pump supplies energy (Wp) to the feed-water in the form of a pressure increment to allow it to flow through the boiler.

A higher plant efficiency is obtained if the steam is initially superheated which subsequently means that less steam and less fuel are required for a specific output. (Superheated steam has a temperature that is above that of dry saturated steam at the same pressure and thus contains more heat content called “enthalpy”. If the steam is reheated and passed through a second turbine, cycle efficiency also improves and moisture in the steam is reduced as it passes through the turbine.Due to this phenomena, the erosion of the turbine blades is subsequently reduced.

With the addition of superheat,the turbine transforms the additional energyinto work without forming moisture and thus, energy is basically recoverable in the turbine.

By the addition of regenerative feed water heating, the original Rankine cycle was improved significantly.This is done by extracting steam from various stages of the turbine to heat the feed water as it is pumped from the condenser back to the boiler to complete the cycle. It is this cycle concept that is using in modern power plants.

4. APPLICATION OF THERMODYNAMICS

Two important area of the application of thermodynamics are power generaton and refrigeration. Both power generation and refrigeration are usually accomplished by a system that operates on a thermo-dynamic cycle.

Thermodynamic cycle can be categorized as follows-

a) Power cycles
b) Refrigeration cycles.

5. BASIC CONSIDERATION IN THE ANALYSIS OF POWER CYCLES

Actual cycle:
The cycles encountered in actual devices are difficult to analyze because of the presence of complicating effects, such as friction and the absence of sufficient time for establishment of the equilibrium conditions during the cycle.

Ideal cycle:

When the actual cycle is stripped of all the internal irreversibilities and complexities,a new cycle is formed that resembles the actual cycle closely but it is made of totally internally reversible process. Such a cycle is referred to as the ideal cycle.

Carnot Cycle:

The Carnot cycle is composed of four totally reversible processes

a) Isothermal heat addition at high temperature. (T_H).

b) Isentropic Expansion from high temperature to low temperature.

c) Isothermal heat rejection at low temperature.

d) Isentropic compression from low temperature to high temperature.

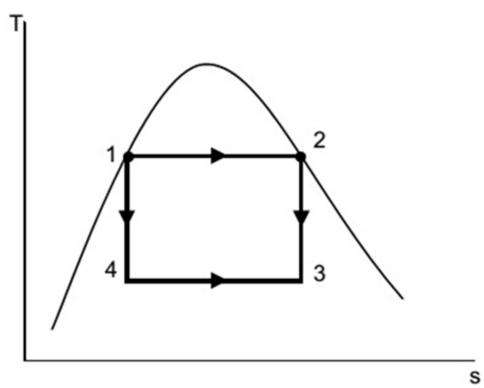
Thermal Efficiency of Carnot Cycle may be given by:

$\mathbf{n_{th}}$ **,carnot = 1-(T_L/T_H)**

The carnot vapour cycle:

a) A steady flow carnot cycle executed with the saturation dome of a pure substance is shown in the figure:

The fluid is heated reversibly and isothermally in a boiler (Process 1-2) expanded isentropically in a turbine (Process 2-3), condensed reversibly and isothermally in a condenser (Process 3-4) and compressed isentropically by a compressor to the initial state (Process 4-1).

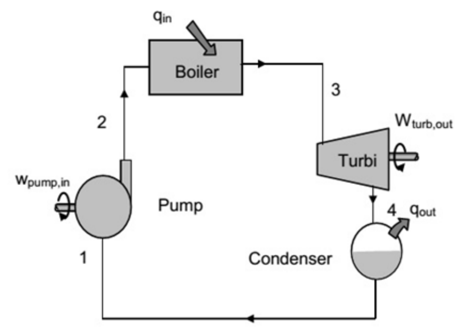


b)The carnot cycle is not a suitable model for vapour power cycle because it cannot be approximated in practice.

Rankine cycle: The ideal cycle for vapour power cycle:

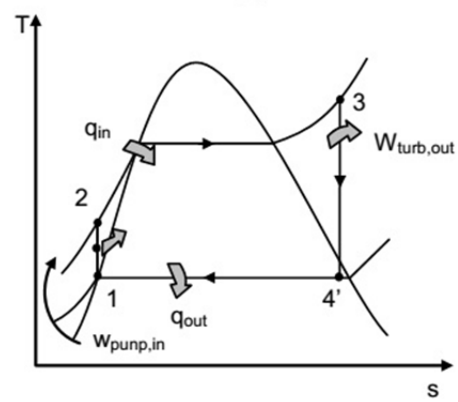
a) The impracticalities associated with carnot cycle can be eliminated by super heating the steam in the boiler and condensing it completely in the condenser.The resulting cycle is the rankine cycle which is the ideal cycle for vapour power plants.

The construction of power plant and Ts diagram is shown in the figure:



b) The ideal rankine cycle does not involve any internal irreversibilites.

c) The rankine cycle consists of the following four processes



1-2 → Isentropic compression in pump

2-3 → Constant pressure heat addition in boiler

3-4 → Isentropic expansion in turbine

4-1 → Constant pressure heat rejection in a condenser

How can we increase the efficiency of the Rankine cycle?

The rankine cycle efficiency can be increased by increasing average temperature at which heat is transferred to the working fluid in the boiler or decreasing the average temperature at which heat is rejected from the working fluid in the condenser. That is the average fluid temperature should be as high as possible during heat addition and as low as possible during heat rejection.

The 3 ways by which the efficiency of the rankine cycle can be increased are:

a) Lowering the condenser pressure.

b) Superheating the steam to high temperature.

c) Increasing the boiler temperature.

Detailed investigation on the generation of hydro power:

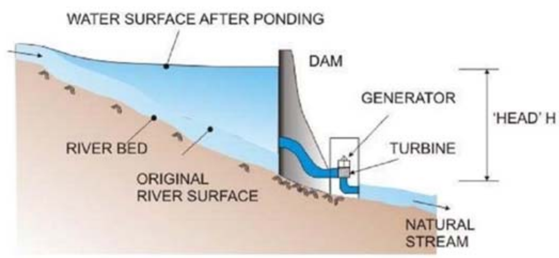
Principle of Hydropower engineering:

The water of the oceans and water bodies on land are evaporated by the energy of the sun's heat and gets transported as clouds to different parts of the earth. The clouds travelling over land and falling as rain on earth produces flows in the rivers which returns back to the sea. The water of rivers and streams, while flowing down from places of higher elevations to those with lower elevations, loose their potential energy and gain kinetic energy. The energy is quite high in many rivers which have caused them to etch their own path on the earth's surface through millions of years of continuous erosion. In almost every river, the energy still continues to deepen the channels and migrate by cutting the banks, though the extent of morphological changes vary from river to river. Much of the energy of a river's flowing water gets dissipated due to friction encountered with its banks or through loss of energy through internal turbulence. Nevertheless, the energy of water always gets replenished by the solar energy which is responsible for the eternal circulation of the Hydrologic Cycle.

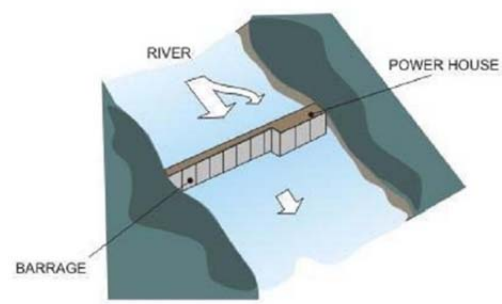
Hydropower engineering tries to tap this vast amount of energy available in the flowing water on the earth's surface and convert that to electricity. There is another form of water energy that is used for hydropower development: the variation of the ocean water with time due to the moon's pull, which is termed as the tide. Hence, hydropower engineering deals with mostly two forms of energy and suggest methods for converting the energy of water into electric energy. In nature, a flowing stream of water dissipates throughout the length of the watercourse and is of little use for power generation. To make the flowing water do work usefully for some purpose like power generation (it has been used to drive water wheels to grind grains at many hilly regions for years), it is necessary to create a head at a point of the stream and to convey the water through the head to the turbines which will transform the energy of the water into mechanical energy to be further converted to electrical energy by generators. The necessary head can be created in different ways of which two have been practically accepted.

These are:

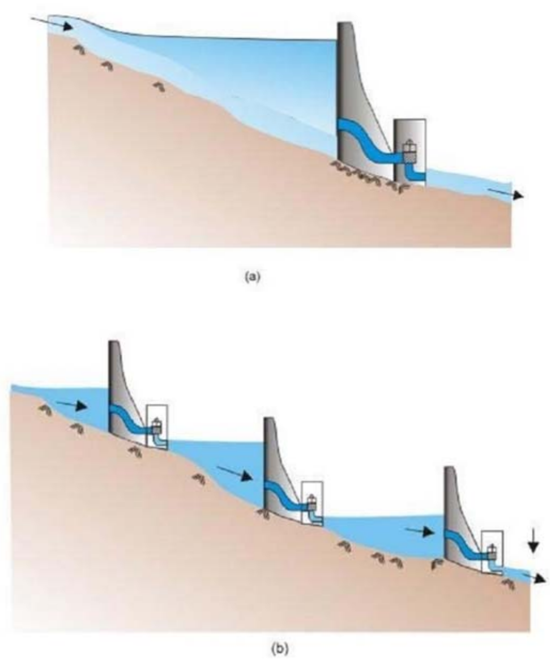
1. Building a dam across a stream to hold back water and release it through a channel, conduit or a tunnel (Figure)



2. Divert a part of the stream by creating a low-head diversion structure like barrage.



A series of integrated power developments along the same watercourse form what may be called a multistage hydroelectric system in which each portion of the river with a power plant of its own is referred to as a stage (Figure). The head created by a dam put across a lowland river usually ranges from 30 to 40m. In mountainous terrain, it may run over 200m.



6. HYDROPOWER POTENTIAL

Electricity from water is usually referred to as Hydro-Power, where the term 'hydro' is the Greek word for water and hydropower is the energy contained in water. It can be converted in the form of electricity through hydroelectric power plants. All that is required is a continuous inflow of water and a difference of height between the water level of the upstream intake of the power plant and its downstream outlet.

In order to evaluate the power of flowing water, we may assume a uniform steady flow between two cross-sections of a river, with **H** (metres) of difference in water surface elevation between two sections for a flow of **Q** (m^3/s), the power (**P**) can be expressed as

$$P = \gamma Q\left(H + \frac{v_1^2 - v_2^2}{2g}\right) \quad \text{[Nm/s]}$$

Where $\mathbf{v_1}$ and $\mathbf{v_2}$ are the mean velocities in the two sections. Neglecting the usually slight difference in the kinetic energy and assuming a value of γ as $9810 N/m^2$, one obtains the expression of power as

P= 9810*QH* [Nm/s]

Since an energy of 1000Nm/s can be represented as 1kW (1kilo-Watt), one may write the following:

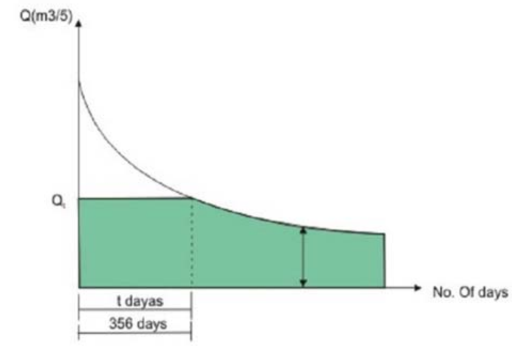
***P=981QH* [kW]**

The above expression gives the theoretical power of the selected river stretch at a specified discharge.

In order to evaluate the potential of power that may be generated by harnessing the drop in water levels in a river between two points, it is necessary to have knowledge of the hydrology or stream flow of the site, since that would be varying everyday. Even the average monthly discharges over a year would vary. Similarly, these monthly averages would not be the same for consecutive years. Hence, in order to evaluate the hydropower potential of a site, the following criteria are considered:

- Minimum potential power is based on the smallest runoff available in the stream at all times, days, months and years having duration of 100 percent. This value is usually of small interest.
- Small potential power is calculated from the 95 percent duration discharge.
- Medium or average potential power is gained from the 50 percent duration discharge.
- Mean potential power results by evaluating the annual mean runoff.

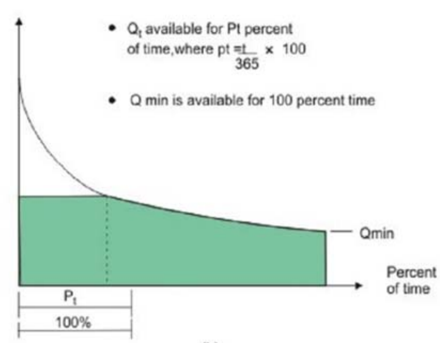
Since it is not economically feasible to harness the entire runoff of a river during flood (as that would require a huge storage), there is no reason for including the entire magnitude of peak flows while calculating potential power or potential annual energy. Hence, a discharge-duration curve may be prepared (Figure) which plots the daily discharges at a location in the decreasing order of magnitude starting from the largest daily discharge observed during the year and going upto the minimum daily discharge at a location in the decreasing order of magnitude starting from the largest daily discharge observed during the year and going upto the minimum daily discharge.



(a)

From this annual discharge curve, a truncation is made at a discharge Q_t which is the discharge corresponding to a time of 't' days, where t can be the median (say, 182 days or 50 percent duration, denoted by (Q_{182} or $Q_{50\%}$), or a higher Q_t (t less than

182 days) can beselected by specialists who are familiar with the local conditions and future plans for power supply.



(b)

Accordingly, the annual magnitude of potential (theoretical) energy can be computed in KWh as below and referring to the Figure:

$$E_p = 24 \times 9.81 H\left(Q_t + \sum_i^{365} Q_i\right)$$

$$\approx 235 H \cdot A \qquad \text{(in kWh)}$$

Where Q_i denotes the daily mean flow during the period 365-t days and A, the hatched area cut by Q_t where the area under the curve has a unit **m^3 ×day/s.**

The massive influx of water in the hydrologic cycle has an estimated potential for generating, on a continuous basis, 40,000 billion units (TWh) of power annually for the whole world (CBIP, 1992). Hydropower potential is commonly divided into three categories:

a) ***Theoretical***: 40,000 TWh

b) ***Technical***: 20,000 TWh

c) ***Economical***: 9,800 TWh

7. CONCLUSION

- In terms of initial cost of thermal power generating plants are much cheaper, but their maintenance costs are high and need more labor. Thus it is costly. But in Hydel Power, the initial cost of generating hydro-electric power is more costly but their maintenance costs are low and need much less labor. Thus it is comparatively much cheaper.
- The generation of thermal power produces air pollution and dust pollution. Waste materials are detrimental to land and environment. But Hydro-electric power is a clean source of energy. It creates almost no pollution or waste materials which are detrimental to the environment.
- The sources of thermal power are non-renewable resources. So, they are completely exhausted after use and cannot be renewed. But Hydel power is a flow resource. It is not exhausted after uses.
- Nearly 80 per cent of the world's total production of power comes from thermal electricity. But the world's total power production, less than 20 per cent of our requirements come from hydro-electricity.
- The involvement of technical skill and knowledge are comparatively less in generating thermal power plant. The installations of hydel power plants require supreme technical skills and knowledge.

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