Power Generation with Simultaneous Aeration using a Gravity Vortex Turbine

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ABSTRACT

The primary aim of this paper is to determine and prove the possibility of using a gravitational vortex turbine for free flowing drainage water. Departing from the principles that normally govern hydraulic machines, this new turbine utilizes energy transformation taking place in a free vortex flow. An idea of a power plant that houses these turbines is outlined in this paper. Aeration of drainage water is an added advantage in vortex flow. Such a power plant is a new idea that combines hydraulics, environmental engineering and mechanical engineering. The central drain of Delhi is considered for study and the potential of Delhi's Najafgarh drain is also calculated. To the best of author's knowledge such a system of aeration cum power generation from low head drainage water is absent anywhere else. The suitability of Delhi's drainage system for hydraulic power generation is amplified in this paper. The paper outlines drain water as a source of renewable energy, that can be tapped year long especially in metropolitan cities of India. An economic analysis was carried out to study the efficiency of using a vortex turbine in power plant for power generation from drainage water.

Key Words: gravitational vortex turbine, hydro power plant, drainage water, aeration.

1. INTRODUCTION

Sustainable energy production is gaining importance day by day. At the same time rapid urbanisation and industrialization combined with improper town planning has led to the destruction and death of nearby water bodies. Discharge of drainage water without aeration or any other treatment in metropolitan Indian cities such as Delhi, Mumbai and all others have led to the blackening of water sources [1].

Indian city drains handle sheer volumes of water every day. A new method of aerating water combined with power generation could go a long way in solving the problem of water treatment as well as power generation. Even under low head this much amount of water if efficiently utilized can generate sufficient power not only for the plant but also for the grid. By using the power of water in vortex flow under gravity, an attempt is made to make power from Indian drains.

2. GRAVITATIONAL VORTEX PLANT

Gravitational vortex power plant (GVPP) is a type of micro hydro power plant. The plant is capable of producing energy from a low hydraulic head of 0.7 – 3m with low flow rate of 50 L/s. It was invented by Austrian engineer Franz Zotloterer. Zotloterer came across this idea while he was attempting to find a way to aerate water without external power.

2.1 Working

Water vortex turbine consists of a circular basin with a central drain. Water enters tangentially inside the basin and forms a stable vortex at the central drain. Symmetrical eddies are formed inside the circular basin. In gravitational vortex flow turbine free vortex flow (irotational) occurs. The equation of such flow is:

$$V_t = k/2\pi r$$

V_t - tangential velocity- strength of vortex, r- radial distance from centre.

Vortex strength is a constant, so shorter streamlines have high values of V_t. From Bernoulli's equation, we have:

$$\frac{P}{\rho} + \frac{V^2}{2} + gZ = constant$$

Assuming that all streamlines are of straight height, we get:

$$\frac{P}{\rho} + \frac{V^2}{2} + = constant$$

As velocity (V) increases, pressure (P) decreases.

The radial velocity increases due to gravity. The tangential velocity of water increases continuously in the direction of the vortex centre. The vortex tube is squeezed by the inward water flow which presses it from all sides. As radius decreases, rotation increases. At a certain rotational speed, centrifugal force comes into play and pushes water radially away from the drain. This causes a depression to be developed and a funnel shape is formed. Gravity pulls water down the drain, water pressure pushes inward and centrifugal force pushes outward. These forces balance to form a beautiful vortex. A turbine is placed coaxial with the drain. The curved turbine blades are turned by the swirling water in the vortex. The runner is simple and consists of inclined curved blades usually 4 or 6 in number. Thus rotational energy of water flow is converted to electrical energy.

The turbine rotates at about 20 rotations per minute .Its coupled to a generator by means of a gearbox. Energy conversion efficiency of 84% has been reported in test installations. Another installation reported 73% test efficiency.

Figure.1 A gravitational vortex turbine

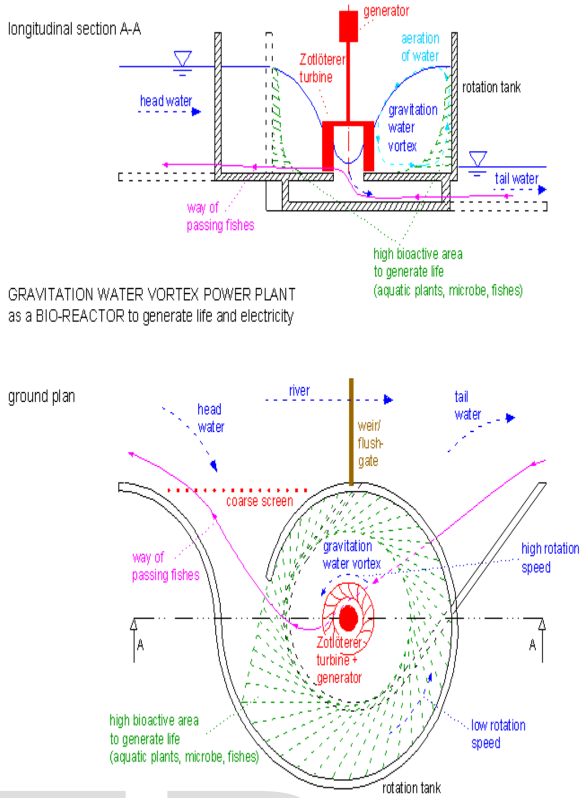

Figure. 2 Gravitational Water Vortex Power Plant as a BIO REACTOR to generate electricity

2.2 Past works & findings:[5]

1. The water surface profile of the vertex can be modelled mathematically and predicted accurately
2. Optimum vortex strength occurs within the range of orifice diameter to tank diameter ratios (d/D) of 14% - 18 % for low and high head sites respectively.
3. Vortex height varies linearly with discharge.

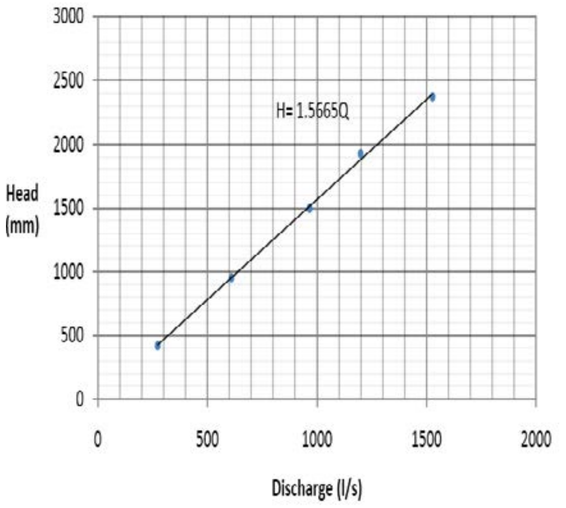

Figure. 3 variation of head v/s discharge.

4. Using Froude's law linear correlations for H v/s Q to prototype can be scaled.
5. Maximum ideal theoretical o/p power = $\rho g Q H_v$ (H_v – height of vortex).
6. Maximum hydraulic efficiency occurs when impeller velocity is half that of fluid velocity.

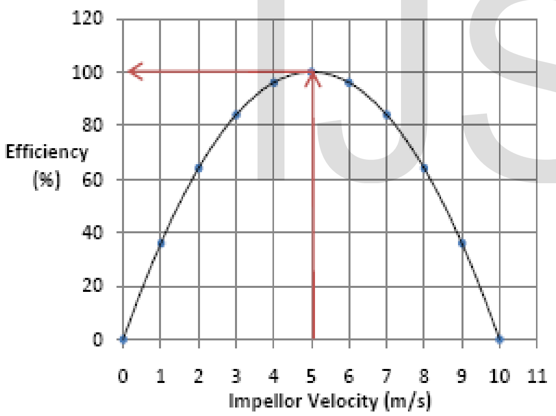

Figure. 4 Expected efficiency curve(V=10m/s)

3. DRAINAGE WATER TREATMENT IN INDIA AND ITS ASSOCIATED PROBLEMS

In India metro cities such as Mumbai, Chennai, Kolkata, drainage water treatment remains one of the major problems. Besides, in India proper drainage water treatment are not done and it is simply discharged into nearby streams and rivers. As drainage water is low in oxygen, addition of this water to nearby rivers and streams without any proper treatment has resulted in the river ecosystem's destruction, death and decrease of indigenous fish species.

Drainage water treatment usually involves straining away large garbage matter as well as floating items. Then aeration of water is done along with suspended impurity removal. This should be followed by a suitable chemical treatment before discharging into rivers.

4. POWER EXTRACTION FROM INDIAN DRAINAGE SYSTEM

The simple theory of gravitational vortex turbine (GVT) makes it suitable for Indian drainage systems. In our country large flow rate, small head drain water is the most unlikely tapped renewable energy source. At all times of the year, Indian city drains are flooded with large quantity of water, not to mention the flooding during rainy seasons. The table shown below gives an idea about the amount of waste water generated in Indian cities and towns.[3]

The idea is to channelize all of this drain water to a single treatment cum power generation plant.

Table. 1 Waste Water generation in India

Parameters	Class I Cities	Class II Towns	Total
Number (as per 2001 census)	423	498	921
Population (millions)	187	37.5	224.5
Water Supply (MLD)	29782	3035	32817
Water Supply (lpcd)	160	81	146
Wastewater generated (MLD)	23826	2428	26054
Wastewater generation (lpcd)	127	65	116
Wastewater treated (MLD)	6955 (29%)	89 (3.67%)	7044 (27%)
Wastewater untreated (MLD)	16871 (71%)	2339 (96.33%)	19210 (73%)

5. CONSTRUCTIONAL DETAILS OF POWER PLANT

In a typical Indian metro city such as Delhi, each building drains water into a local drain which is usually located along roadside. These drains join bigger drains and finally enter the central drain that carries the entire city's drain water. Power plant / treatment plants are setup on the low lying outskirts of city near by the river to which drain water is usually discharged. The central drain carries huge quantity of water usually in the order of many million litres per day (MLD). This makes the central drains potential sources for hydropower exploitation. These central drains usually have their ending at a river.

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So the power house is required to be set up between the central drain and the river. A naturally sloping region along the river bank can be selected as suitable site for construction of turbine units. The natural drainage flow will directly give the direction of slope in most of the cases.

Since gravitational vortex turbines show best efficiency for very low head flows best ranging from 0.5 to 3 m, power generation is done in various stages. Each turbine stage will have the same head of water as that of its preceding stage. This ensures equal power generation from all the turbine units. More number of turbine units also ensures higher percentages of aeration since in each stage vortex flow leads to increased air-water contact. As shown in figure reveal turbine units are set up along the path.

Water from the central drain is passed through a strainer which separates large floating garbage or other suspended objects. This ensures better turbine life and also reduces problem of blockage within the plant. Since turbines are built in low lying areas, sufficient PE conversion of water can also be utilised. Gradual slope increases the head on succeeding turbine stages. This makes power input to each stage nearly constant. After sufficient no of turbine stages, final chemical treatment such as UASB is done and improved water is discharged into the river.

5.1 . Aeration of Water during Vortex flow

The gravitational vortex created at the centre of the circular basin increases the surface area of water. It also maximises the velocity of flow on the water surface area. As a result of this increased water surface area and high velocity of flow, water gets aerated naturally.

5.2. Cooling Effect

Vortex flow in various stages decreases water temperature. The cooling effect will have a promoting effect on aquatic life.

5.3. Power Generation from Gravitational Vortex Turbine

GVPP is able to generate power with a flow rate of 50 L/S with very low head of 0.5 to 3 meters .Estimated efficiency ranges from 63 to 84 %.

5.4. Gravitational Vortex Turbine Reference Cases

A 6.5 m diameter plant established in the village of Schoftland in Switzerland having a head of just 1.5 m of water generates b/w 10 to 15 kW annual 35,000 kWh ideal to fulfil the electricity needs of 20-25 Swiss households for a year.

In Austrian top count village, a unit with 5.5 m diameter under 1.5 m head, 0.9 m^3/s flow rate produced 60,000 kW annually. The frequency of rotation of turbine is 33 min^{-1} (0.55 Hz).

6. APPLICABILITY OF GVPP IN DELHI'S DRAINAGE SYSTEM:

The national capital territory (NCT) of Delhi is one of the fastest growing metropolitan cities in the world. Delhi faces the problem of voluminous generation of waste water. Much of the water needs for the city is met by the river Yamuna. Water is tapped from the upstream portion at Wazirabad and waste drain water is released downstream. The colour of river changes from bluish green to dark grey downstream at Wazirabad where the Najafgarh drain joins Yamuna. It's the biggest drain in NCT Delhi discharging about 287.5 MLD into Yamuna. This accounts for 60% of the total waste water drained from Delhi into the river.[5]

The sheer volume of water discharged per day could be better channelized for power generation and simultaneous aeration. This would have a profound impact on downstream Yamuna River and its aquatic life.

Available discharge of drain water per day = 287.5 million litres per day = .2875 million m^3 per day.

Discharge per second (Q) **= 3.328 m^3/s.**

Usually Delhi's central drains have water up to a height of 1.5m. so a turbine that operates on 1.5 m head is considered.

Height of vortex (H_v) = **1.5 m**

Input power to turbine:

$$P_{in} = \rho g Q H_v = 1000 \times 9.81 \times 3.328 \times 1.5 = 48.9\ KW$$

With reference to the efficiency of already established vortex turbine, an average efficiency of **70%** is taken.

$\eta = 0.70$

$$P_{out} = \eta \times P_{in} = 0.70 \times 48.9 = 34.23\ KW$$

Thus, the power output of a single turbine per day will be nearly 820 kWh. Annual electricity production will be about 300MWh per single turbine. The above said multi stage plant such as a four stage plant can generate up to 1200MWh of electricity per year.

Delhi's average per capita electricity consumption is about 1447.72 kWh [6[. So a four member house needs about 5800kWh annually. So the power generated from the plant could meet the annual electricity requirements of 200 houses in Delhi.

Considering such an attempt in all the metropolitan cities enough power can be generated on a large scale.

$$\textit{waste water generated per day in indian cities} = 23826\ MLD$$
$$\textit{Discharge available} = 275.8\ m^3/s$$

Such massive amount of water even under a low head of one metre will generate about 1900 kW, which means 45600 kWh per day. India has an installed capacity of 227.356 GW and is the world's fifth largest [7]. Out of this 87.55% power comes from non renewable power plants and remaining 12.45% from renewable energy sources.

The large scale adaptation of such plants will definitely reduce the short and long term energy crisis of India.

7. GENERATION COST ESTIMATION AND ANALYSIS

In the case of power generation from drainage water, initial investment is in the cost of turbine units. Once built, much investment is not needed to generate electricity. Since energy source is free and maintenance cost is very low, production of an extra unit of electricity solely depends on nature, which in this case is water which is free. So marginal cost would be relatively low (zero fuel costs).This will eventually lead to a lower supply price. When there is an excess power supply to the area, the conventional plants will have to limit their production since it's not possible to limit hydraulic power generation during overflow conditions. This will lead to a lower price.

Already existing turbine units have reported generation of electricity at 1$/watt. This is a relatively cheap price when compared to other large power projects. For example Three Gorges dam in china, which is the largest hydroelectric dam in terms of generation capacity, generates electricity at 0.8$/watt. Solar energy using photovoltaic cells produces electricity at 1$/ watt and is expected to be even higher in some cases.

Capacity factor: As far as this plant is concerned, the capacity factor nearly exceeds 95% in comparison to other hydroelectric power projects which have only 52% and solar cells with 25%. The increase in capacity factor is because of the fact that drainage water is available all year long. The table below shows the capacity factor of various power plants.

Table. 2 Capacity Factor of several power plants

Source	Capacity factor	Price per watt
Hydro	52	1$
Solar	25	1$
Wind	34	2$
Coal	85	2.1$
Nuclear	90	varies
Gas cycles	87	6$
Vortex plant	Above 95	1$

Cost comparison with other turbines: Gravity vortex turbines are best suited for the low head application as in the case of drainage systems. The cost of using conventional hydraulic turbines is very high. Besides the efficiency of such turbines steadily drop when operated under low head conditions. Moreover those turbines need pipe flow whereas vortex turbine is based on open channel flow. This makes it particularly suitable for drainage water power generation. Using existing formulas, a cost comparison is made for the same head and discharge conditions and results are tabulated as shown.

Table. 3 Cost Comparison of Installation

Turbine type	Installation cost (in Euros)
Kaplan	38678.06
Francis	154029.93
Pelton	17520.765
Vortex	40000.00

From the above table, it can be seen that cost of vortex turbine is near to Kaplan turbine, higher than Pelton and very lower when compared to Francis turbine. But we cannot use other turbines here because of high chances of blade corrosion and damage and very low efficiency shown by these turbines under very low head. So vortex turbine is the best suited turbine in this case.

8. ADVANTAGES

1. Major advantage is that power is produced from waste drain water and the electricity produced is almost 97 % carbon free energy. Thus, a cleaner more sustainable & renewable energy production takes place.
2. Aeration improves the microbial & biological properties of water. Thus, the improvement in water quality is an added benefit.
3. Aeration combined with segregation improves the overall quality of drainage water. The release of this water to rivers ensures better chance of fish survival & improved aquatic river ecosystems. Water pollution as a whole is largely reduced.
4. Even floodwater during rainy seasons can be successfully channelized for power generation.
5. The turbine being placed in open, it is easy to maintain, clean and repair compared to that of other low head reaction turbine.
6. Cost effective. Easy to install
7. Eco friendly.

9. DISADVANTAGES AND CHALLENGES

1. Proper construction &town planning is necessary
2. Required geographical conditions may not always be available
3. Government restrictions & hurdles needs to be cleared.

10. CONCLUSION

Gravity vortex power plant proves to be a simple and cost effective solution for drainage disposal. The key feature of this project is the triple advantage of power generation, aeration and segregation, all of which are achieved simultaneously. Power generated from drainage water turns out to be a major source of renewable energy. Metropolitan cities such as Delhi, Mumbai and other major cities are typical regions where gravity vortex plant can function with much effect. This installation ensures reduced water pollution and in effect a better planet for all of us. Moreover the plant someway behaves as a more practical form of PMM1.

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