A research paper on a comparative study of generation of electricity from waste water

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Abstract:

This paper describes a new and renewable energy source based on waste water for electric power generation and presents a new methodology for evaluation of the reliability of the hybrid- micro hydro power system using Gaussian distribution approach and flow duration curve (FDC). A new idea to reuse municipal waste water of the city offers a stable, inflation proof, economical, reliable and new & renewable energy source of electricity that uses proven and available technologies. Appropriately designed and implemented micro hydro electric power generation using municipal waste water and sewage system can provide inexpensive energy to all cities of the world for many years of the 21st century. Combined micro-hydro electric power and photo-voltaic system is a non-depleting, non-polluting and non-depending energy source that can provide reliable and economical power as a most promising new and renewable energy source of the 21st century. The hydro potential of waste water from community flowing through sewage system has been determined to produce a flow duration curve (FDC) by ordering the recorded water flows from maximum to minimum flow. The generating capacity of the system depends on the flow rate of the sewage treatment plant connected to existing sewage system of the city. The probability of difference in maximum and minimum flow between winter and summer is small and this will not affect the power output produced by municipal waste water of the sewage plant. Several factors as design pressure, the roughness of the pipe's interior surface, method of joining, weight and ease of installation, accessibility to the sewage system, design life and maintenance, weather conditions, availability of material, related cost and likelihood of structural damage have been considered for a particular penstock of the micro hydro power system. The selection criteria of the turbine has been explained according to design flow, head of the sewage plant and desired running speed of the generator. A hybrid system such as micro hydro electric power and photo voltaic system has been proposed to provide reliable electric energy to Banaras Hindu University, Varanasi (India).

1. INTRODUCTION:

Waste water treatment plants are often the largest consumer of energy in their accounting the approximately 4% of the electricity used in the US and the other developed country.

In addition to wind and solar energy the so called bio fuels are becoming increasingly common, generation energy through burning vaporising or terminating bio mass such as leftover plant material vegetable waste and manure are well tried method. A new shot on this branch of energy production is the turbine generator unit which is capable of directly generating energy from substance such as waste water . at present time this has only been done in the lab but the first result and the application of this new technology are very promising.

Hydropower is produced from the extracted energy of water moving from higher to lower locations. It is predictable, economical and commercial technology. The overall efficiency of the station (water to wire operation) is almost 90% efficiency. On the other hand, the start-up cost of hydropower schemes is high, but it has low operation and maintenance cost, thus it is more efficient in long terms. The hydro power extracted from the potential energy of water is driving turbines to produce power. The energy extracted from water depends on the capacity and head between down and up streams. The general equation for any hydro system's power output is:

$$P = \eta \rho g Q H$$

Where P is the mechanical power produced at the turbine shaft (watts), η is the hydraulic efficiency of the turbine, ρ is the density of water volume (kg/$m3$), g is the acceleration due to gravity (m/$s2$), Q is the flow rate passing through the turbine ($m3$/s) and H is the effective pressure head of water across the turbine (m).

Objective of the project:-

- Collection of water waste from various resources
- Construction and design of the new technology to producing the electricity
- Comparison analysis between the various resources
- Produced clean and clear water
- Optimizing the process of generation of electricity
- The process involving the lab scale to semi pilot industrial scale operation for commercial utilisation of waste water and generation of electricity.

2. LITERATURE REVIEW:

The use of sewage waste water in agriculture has a long history and is receiving renewed attention in the light of increased global water scarcity. It is currently used to irrigate agricultural crops in Middle East, North and South Africa, South America, Asia, Australia, and in parts of Europe (Bastian, 2006). Countries and regions in which water reuse is on the rise include the US, Western in Europe, Australia, and Israel (Miller, 2006). Therefore, in this review attempt has been made to include the literature related to the studies made worldwide on the effect of waste water on wheat and some other crop plants. Wheat makes high demand for nutrient elements from the soil and N, P and K are considered to be of prime importance as these are absorbed and utilized in larger quantities. However, waste water cannot meet the high nutrient requirement of the crop and thus, supplemental fertilizer needs to be added to get the optimum yield. Therefore, the role played by NPK in the growth and yield of wheat was also taken into account. It may be pointed out that work on wheat in respect to NPK fertilizers abounds, therefore only some of the recent references have been reviewed in the end of this chapter to give an idea about the nutritional requirement of wheat when grown without wastewater.

3. METHODOLOGY AND DATA COLLECTION:

Energy consumed during the treatment process is observed to be in the form of electrical, manual, chemical, and mechanical energy. Chemical energy can be considered as indirect energy, human or manual energy as renewable energy and others as non-renewable energy. Each form of energy consumption is calculated in terms of kWh/m3 of wastewater treated. Primary data have been collected through field monitoring and corroborated with historical data through discussions with plant operators. Log-book and records of transactions and consumptions are also referred for validation. Field monitoring has been done for 15 days spread over 2 months during June–July, 2011. Equal representation of weekdays and weekends is considered for the monitoring days. Time measurement is done using a stopwatch.

Estimation of electrical energy input:

The electrical energy input is estimated by considering the electrical load of the pump/motor (kW), time in hours (h) for which the motor is operated and total amount of wastewater treated (Eq. 1).

$E_p = P*T/Q$

where, Ep is the electrical energy kWh/m3, Q the total flow of wastewater in m3/day, P the rated power of the electrical motor in kilo Watt (kW), and T is the operation hours in a day (h/day).

The motor efficiency is assumed as 80 % (Fadare et al. 2010). Table 2 shows the average of values as obtained in the field.

Table1: Details of mechanical equipment specification

Treatment unit	Type of equipment	No. of working units	P (KW)
Water collection tank	storage	1	-
Turbine	Power generation	1	.19 app.
synchronous motor	For constant speed	1	-
Generator	Electricity producer	1	.20 app.
Filter	Filtration	1	-
Water slag collection	Waste slag	1	-
Water collection	Collector	1	-

Design of the Turbine/Generator System for generation of electricity

The design of the turbine/generator system was driven by a review of requirements for various wastewater treatment facilities. Emphasis was placed on New York State plants, with the expectation that plants in other states and countries would have similar requirements.

Specification Development

A review of data from the NYS Department of Environmental Conservation indicates that there are 78 WWTPs with a rated flow of 5 MGD, broken down as follows:

- 28 in the range of 5 to 10 MGD
- 29 in the range of 10 to 40 MGD; and • 21 above 40 MGD.

The plants having flow rates in the range of 10 to 40 MGD was selected for further analysis. Seven of these plants were visited. Detailed flow data were collected from 15 plants. Survey data and interviews were conducted with 25 plants. Subcontractor Clark Engineering & Surveying, P.C. assisted with this effort

It was concluded by the design team that critical factors for commercial success include:

- The available head or velocity at the plant.
- The ability of the turbine/generator unit to be tolerant of submergence.
- Ease of installation access
- Ease of maintenance access
- Absolutely no backwater impact on the process or EPA testing; and
- Proximity to power usage is an important factor in the installation cost.

Figure 1 depicts the possible locations of the turbine/generator equipment. From the survey, it was clear that the equipment needed to be downstream of the last process. Beyond that, location is driven by energy capture, ease of installation, ease of maintenance, and minimizing installation cost. Given that cable lengths are minimized by locating the turbine/generator equipment close to the final outfall, Figure 2 suggests the preferred placement of the equipment.

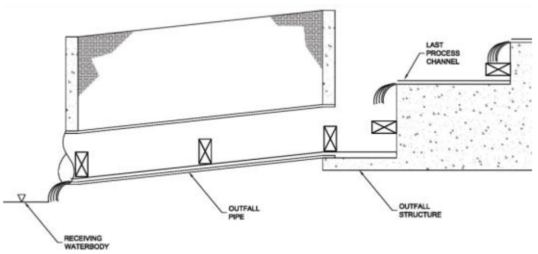

Figure 1 : possible locations for turbine/generator system.

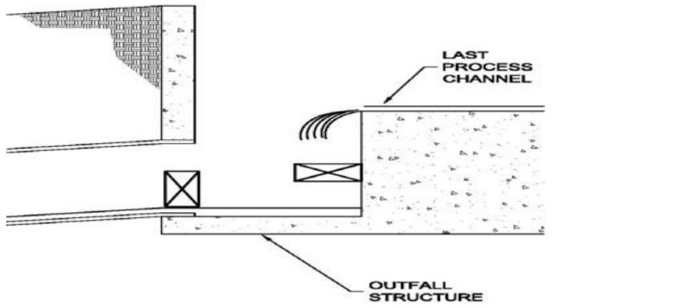

Figure 2: the most desirable location for turbine / generator, at the outfall following the final process.

Figure 3 provides a distribution of the head and flow for the surveyed plants. The plants with the highest product of head and flow represent the best opportunities. For the prototype system, emphasis was placed on average daily flows in excess of 10 MGD and heads of 10 ft or more.

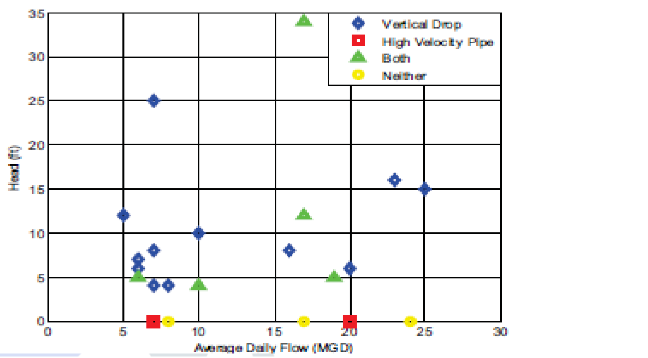

Figure 3: The distribution of head and flow for the surveyed WWTPs.

A summary of operator data collected during the interviews includes:

- 75% of the WWTPs have suitable hydraulic drop for energy recovery, with over 50% in “ideal” range
- 30% of the WWTPs have pipes with significant velocity head; some have both pipes and outfall opportunity
- 25% of the WWTPs could accommodate 2 or more units Only 15% of the WWTPs have neither suitable hydraulic drop nor significant velocity head
- Two thirds of the operators expressed a very strong interest in the project and are willing to provide additional review and feedback
- 80% of the operators have a 480V MCC and/or equipment for power utilization in close proximity to the outfall; and
- A 5 year return on investment is essential for energy saving capital budget approval.

Specifications elements driven by market research include:

- Intake design must be flexible to match site requirements to turbine/ generator capacity.
- Allow for customization and low cost.
- Ease and low cost of installation, removal, and maintenance.

- The equipment must survive constant contact with the effluent and Have a usable life of 10 to 30 years.

Table 1 summarizes the operational parameter range of the turbine/generator with the design target for the experimental prototype.

Table 1: A summary of turbine/generator parameters, practical ranges to address the WWTP market, and the design targets for the experimental system.

Parameter	Range	Prototype Design Target	Units
Fluid	Water with debris, aeration, turbulence	Water with debris, aeration, turbulence	
Head	1 – 20	10 – 12	feet
Volumetric Flow Rate	5 – 100	5 – 20	MGD
Rotational Speed	400 – 800	600	rpm
Turbine Efficiency	75 – 95	> 90	%
Output Power	1 – 200	15	kW

TURBINE DESIGN:-

Turbo Solutions Engineering assisted Advanced Energy Conversion (AEC) in the design of a turbo-generator for use in wastewater treatment plants. Figure 4 shows a turbine selection curve based on head and flow. Because of the low head in the intended application, the selected turbine runner is a fixed-pitch propeller type turbine with no wicket gates to assist in the control of the flow entering the runner. Structural struts are located just downstream of the runner. This type of hydraulic turbine tends to have efficiency characteristic with a sharp peak because it has fixed geometry developed for a specific operating condition. As shown in Figure 5, if the turbine is operating slightly off the design condition, the efficiency will be reduced dramatically.

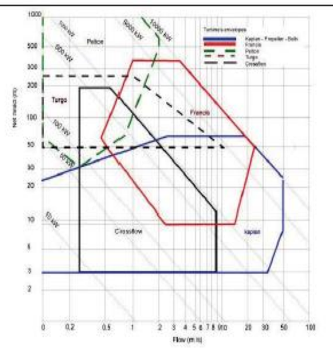

Figure 4: A turbine selection chart based on flow and head.

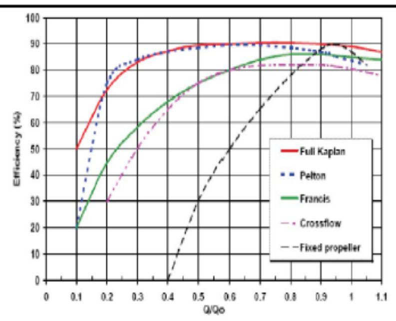

Figure 5: Efficiency characteristics as a function of normalized flow for different types of turbines.

Turbine design was based on one- and three-dimensional hydrodynamic design and analysis. Computational fluid dynamic (CFD) analysis was used to refine the design. Solid modeling of the rotor, inlet, housing, diffuser, and structural supports were developed to build a complete picture of the turbine design. Figure 6 shows the volumetric flow rate as a function of head at different turbine rotational speeds, with contours of hydraulic efficiency superimposed. Figure 7 shows the power output available as a function of head consistent with the turbine curves shown in Figure 6. To maximize power output, operation at higher turbine speed is preferable. This is also consistent with the desire to minimize generator size.

Structural analysis was performed to determine rotor steady state stresses and natural frequencies. Structural analysis was also applied to the rotor support structure.

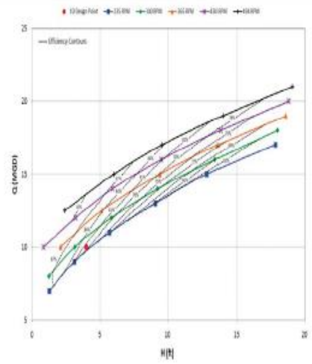

Figure 6: Volume flow rate as a function of head for turbine operation at various speeds.

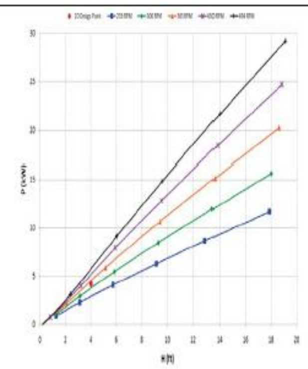

Figure 7: Turbine power as a function of head for operation at various speeds.

A summary of the turbine design is given in Table 2.

In the given table we mention the numbers of blade which are used in turbine to provide the maximum efficiency for the output and also included which speed is best for the turbine/ generator.

Table 2: A summary of turbine design parameters.

Hub diameter (in)	7.200	Number of Blades	5
Tip diameter (in)	18.000	Volumetric Flow Rate (MGD)	23.00
Solidity at hub	1.00	Head (ft)	12.00
Solidity at midspan	0.91	Rotational speed (RPM)	500
Solidity at tip	0.56	Estimated rotor hydraulic efficiency	0.880
Max thickness-to-chord at hub	0.150	Rotor Power (kW)	31.793
Max thickness-to-chord at midspan	0.07	Specific speed	146
Max thickness-to-chord at tip	0.070	Flow coefficient	1.75
Blade angle from tangential at hub LE	56.77	Tip speed (ft/s)	39.27
Blade angle from tangential at midspan LE	41.09	Inlet velocity (ft/s)	23.97
Blade angle from tangential at tip LE	31.40	Tip speed/Inlet velocity	1.64

During the evolution of the design of the turbine, the design conditions changed while some of the operating parameters remained fixed. The design head was increased significantly (from 4 ft to 12 ft of head), while the diameter and rotational speed of the runner were unchanged. The reason for the change was that the design team realized that more head was available at most of the potential installation sites, and the available power is directly proportional to the head, so there was good cause for the change of the design condition. The diameter was left unchanged for packaging reasons and the rotational speed was not increased for generator reliability concerns. This resulted in changes to the turbine design parameters that impact the preferred type of turbine, or result in a performance penalty for the type of turbine that had been selected. The best hydraulic efficiency that can be expected at the appropriate design conditions for a full-size, full-optimized propeller type turbine that was selected early in the design process is about 90%, as shown in Figure 5. At the size of the AEC machine, Reynolds number and clearance effects will lower the maximum attainable efficiency. In addition, the struts downstream of the runner and exit diffuser (draft tube) restrictions will further lower the peak attainable efficiency.

The power specific speed is a parameter that is used to determine the appropriate type of turbine to us e for a given rotational speed, flow, and head. The equation for power specific Speed is $N_s = N\sqrt{P}/_{H^{5/4}}$.

In U.S. units, the N is the rotational speed in rpm, P is power in hp, and H is head in ft.

GENERATOR DESIGN:-

Magnetic Design:-

Early in the project it was determined that the priorities of the magnetic design were to maximize generator efficiency, maximize the flatness of the generator efficiency curve, and to minimize active magnetic material. Maximizing efficiency over a wide speed range ensures that the turbine generator system would be widely applicable to a variety of flow conditions. Minimizing active magnetic material reduces system cost and weight. In addition to these three priorities, all mechanical and electrical connection constraints had to be respected. Several of the constraints are explored in more depth below.

Mechanical Constraints:-

Turbine runner design at the design point of 12 ft head indicated peak efficiency at about 400 rpm with peak power delivered at 600 rpm. These speeds were used to determine generator operation point and peak efficiency point. The generator design was constrained by the turbine runner and the desire to make the turbine-generator unit mate with a 30" pipe bolt flange. The generator design was limited to a "pancake" aspect ratio by the diameter and axial length of the turbine runner. Thermal constraints limit the generator power rating.

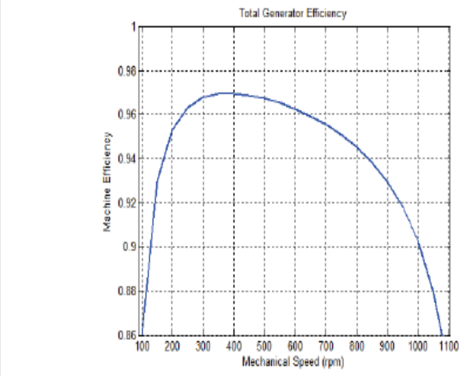

Figure 10: Analytical prediction of motor efficiency as a function of speed. Efficiency prediction relies on a predicted power curve from turbine at 12 ft head. Low efficiency at low speed is due to low motor voltage. Low efficiency at high speed is due to a reduction in the amount of power available from the turbine runner.

4. CONCLUSIONS:

The energy pattern analysis of a small-scale WWTP has been analyzed. The energy consumption is found to be about 1.046 kWh/m3 of wastewater treatment. This is significantly less than the values reported in the literature for large-scale WWTP. Further, previous studies have not included manual energy consumption in their analysis. It is found to be about 32 % of the total energy consumption. There is a lot of variation in the reported values in the literature. The plausible reason is that the energy intensity depends on the capacity of the treatment plant, extent of automation, and choice of treatment technology. This suggests that a number of such investigations are required for various categories of treatment plants so as to have a holistic view on the wastewater treatment and energy nexus. Based on the evidence of this study, it can be stated that the decentralized treatment systems have less energy intensity in comparison to a large-scale plant. This could be partly attributable to the use of manual energy in the treatment process in a small-scale plant. However, such a generalization needs to be supported with a number of analyses for various types of treatment processes and wastewater characterization in various regions of the world.

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