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Design and Analysis of Cross-Flow Turbine in a Sewage System

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Abstract: ***Energy usage is inevitable to man's daily living as we become more civilized our consumption of electricity has drastically increased. It is obvious for us to find various ways to produce electricity without the usage of fossil-fuels. In our analysis, we have identified a sewage system flowing in our locality and analyzed flow rate entering and leaving the sewage treatment plant. Later, the kinetic energy of the treated sewage water is exploited for generating electricity. The out-flow discharge characteristics varies from season to season. To meet this varying discharge a cross-flow turbine is placed at the exit of preliminary treated sewage treatment plant. Several factors like pressure co-efficient, total pressure, dynamic viscosity, strain rate, turbulence intensity, velocity, cell weight and volume are determined for cross- flow turbine blade setup using ansys fluent. The analysis thereby demonstrates the future possibilities of generating electricity and supplying them for residential areas, private complexes and government buildings***.

Keywords: Cross-flow Turbine, Sewage system, Design parameters, Numerical Investigation

1. Introduction

According to survey conducted for "India infrastructure report 2011" by J.S.Kamyotra and R.M.Bhardwaj, estimated around 38,354 million liter per day (MLD) of wastewater is generated in urban centers of Class-I Cities and Class-II Towns. This is a tremendous amount of water could be in turn be used for irrigation of 7 million hectares of land. Out of estimated 38,354 MLD sewage only 11,786 MLD is treated in the major cities of India. This constitute that more than 66% of sewage generated or untreated and reaches the water bodies like lakes, rivers, and oceans, etc. Similarly, only 60% of industrial waste water, mostly large scale industries, is treated. Performance of state owned sewage treatment plants, for treating municipal waste water, and common effluent treatment plants, for treating effluent from small scale industries, is also not complying with prescribed standards.

This waste water have tremendous amount of energy which could be proper utilized for greater deeds. If their energy is properly exploited we could able to meet expectation of the ever increasing demand of electricity. In our project we have designed a cross flow turbine to meet the varying out-flow discharge characteristics at exit of sewage treatment plant.

2. Literature Review

A group of Japanese engineers namely Tomomi Uchiyama, Satoshi Honda, Tomoko Okayama and Tomohiro Degawa studied "A Feasibility Study Of Power Generation from Sewage Using a Hollow Pico-Hydraulic Turbine". The main objective of this study is to identify the best design for the hollow pico turbine. For this we analyze and then compare the results of a number of designs for the pico turbine. The pico turbine differs from other turbines as it contains circular hole at the centre, which acts as a pathway for the minute residual solid waste that pass on from the main filtration process, to pass through.

Various designs of pico turbine were designed, each with certain differentiating parameters that could improve the efficiency of the turbine. Once the various models are designed then they are analyzed to determine the most efficient design. The pico turbine essentially consists of the blades positioned at corresponding angles with the central circular pathway for foreign particulate matter. Hence if any changes are to be primarily made to the number of blades, angle of positioning of the blades, the dimensioning of the blades and that of the hole and possibly the base surface of the turbine.

Hence keeping in view of the possible areas of improvement, certain designs are made each trying to improve the efficiency of the pico turbine in unique aspects. Thus considering the necessary factors and taking all the additional variables and factors into consideration, the analysis of the various designs are done under closed-loop test rig. There is greater chance for the efficiency of pico turbine could be less than 20% because whenever turbine comes into physical environment there is a large chance for turbine to be clogged and this lead to back flowing in sewer system.

3. Sewage Water Treatment Plant

The Sewage system is a waste water carrier which is used to transfer from one place to another. Sewage is a closed system which restricts the movement of air. Sewage treatment is the process of removing contaminants from wastewater, primarily from household sewage using physical, chemical, and biological processes. The normal sewage treatment plant has four treatment process namely preliminary, primary, secondary and tertiary process.

In our system there is preliminary treatment setup whose one end is connected to sewage system and other end is connected to inlet of the cross-flow turbine. The role of preliminary treatment plant is to remove floating materials (leaves, papers, rags) and settle able inorganic solids (sand, grit), besides oily substances (fats, oils, greases).

4. Physical Description of Cross-Flow Turbine

Cross-flow turbine is a low head (~10m) and low discharge turbine (~2m^3/sec) is used for power generation. It is simple to construct low operational and capital cost. It has flat efficiency curve under variable load and also not clogged by any foreign materials.

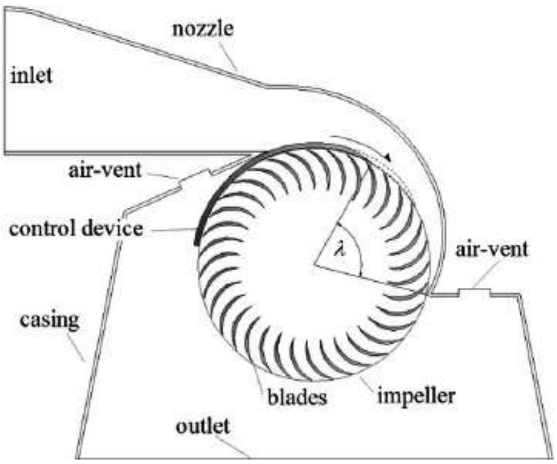

Figure 1: Schematic Diagram of Cross-flow Turine

The Cross-flow Turbine consist of a runner, nozzle, blades, shaft, bearing, casing, draft tube, guide vane and air valve .The heart of the any turbine is runner. The runner is in the shape of an empty wheel, which consist of two circular plates linked by a series of blades, which are shaped so that the jet is directed towards the center of the wheel and then again crossing other blades before exiting. The jet then passes through the runner and this is the origin of the name "cross-flow". The runner is connected to the generator for the electricity production. The function of the runner is the conversion of water energy into mechanical energy. In the case of wider runner, the blades have multiple interposed by the supporting board.

5. Design Calculation

For designing a model cross-flow turbine following assumptions were made:

- Efficiency (η) of the system is 60%
- Entry angle to the runner (α) is 16º
- Nozzle entry arc (β) is 30º
- Number of blades is 20

5.1 Determining the length (L) and diameter (D) of the runner Turbine

$LD_1 = 2.627 * Q / \sqrt{H}$
where L – Runner length, D_1 – Outer runner diameter, Q – Flow rate is 0.18 m^3/sec and H – Head is 2 m
$LD_1 = 2.627 * 0.2 / \sqrt{2}$
$LD_1 = 0.3715$
Assume runner diameter be 470 mm
$L * 0.470 = 0.3715$
$L = 0.79$ m

5.2 Radius of the curvature of the blade (r)

$r = 0.326\ R_1$
where r – radius of curvature of the blade and
R_1 – Outer runner diameter = 235 mm
= 0.326 * 235
= 76.61 mm

5.3 Inner diameter of the runner (D_2)

$D_2 = 0.666\ D_1$
where D_2 – Inner runner diameter and D_1 – Outer runner diameter is 470 mm
= 0.666 * 470
= 313.02 mm

5.4 Thickness of the blade (t)

$t = k_1 * D_1$
where t – Thickness of the blade, k_1 – Constant of proportionality is 0.0177 and D_1 – Outer runner diameter is 470 mm
= 0.0177 * 470
= 8.3 mm

5.5 Diameter of the axle shaft (d)

$d = 0.22\ D_1$
where d – diameter of the axle shaft and D_1 – Outer runner diameter is 470 mm
= 0.22 * 470
= 103.4 mm

5.6 Speed at full load (N)

$N = 39.81\ \sqrt{H}/D_1$
where N – Speed at full load, H – Head = 2 m,
D_1 – Outer runner diameter is 0.470 m
$N = 39.81\ \sqrt{2}/0.47D_1$
= 119.76 rpm

5.7 Determination of blade Spacing (S)

$S = KD1/ \sin \beta$

Where S – Blade spacing, K – Constant, D_1 – Outer runner diameter is 470 mm, β – Angle of nozzle entry arc is 30º

= 0.087 * 470 / sin 30

= 81.78 mm

5.8 Power Determination (P)

Power = Head x Flow x Gravitational force x efficiency

Where power is measured in Watts, head is 2 meters, flow is 120 liters per second, acceleration due to gravity is 9.81 m/sec^2, and efficiency is 60 %

= 2 x 120 x 9.81 x 0.6

= 1413 watts

6. Numerical Investigation and Design Specifications

Due to the high manufacturing, analysis cost and time taken for the study of this complex flow through the turbine entails, all the simulations are carried out at the design conditions (H,Q) varying the runner speed. The three dimensional viscous steady CFD simulations are performed by using the commercial software ansys fluent. As turbulence model , k-ε Turbulence model closure with scalable wall functions is used. This near-wall treatment can be applied on arbitrarily fine grids and allows the user to perform consistent grid refinement independent of Reynolds number of the application.

6.1 Design Parameters

The dimensions used in this project are those of Cross-Flow Turbine which are tested at operation efficiency of 60% at 2 m head and 120 rpm.

Table 1: Model Cross-Flow Turbine Description

Sl. N0.	*Description*	*Symbol*	*Value*
1.	Outer diameter of runner	D_1	470 mm
2.	Inner diameter of runner	D_2	313 mm
3.	Blade Thickness	t	8.3 mm
4.	Angle of attack	α	16°
5.	Radius of blade curvature	r	76.61 mm
6.	Speed at Full Load	N	119.76 rpm
7.	Radius of pitch circle	R_0	55.35 mm
8.	Radial rim width	a	25 mm
9.	Diameter of the axle shaft	d	103.4 mm
10.	Central angle of each blade	δ	73º
11.	Inlet blade angle	β	30°
12.	Number of blade	z	20
13.	Width of nozzle	b	200 mm

6.2 Design Modeler and Meshing

The numerical analysis for this study was performed in ANSYS Workbench 17 where Ansys fluent Project with its subprograms, namely: Geometry, Mesh, Asnsys fluent-Pre, Ansys fluent solver and Ansys Post-processing, was used. As stated already, numerical analysis require coming up with a flow domain which has to be meshed. The flow domain shows in was designed in 'Geometry' sub-program using the ANSYS Design Modeler. The flow domain consists of the blades, fluid domain. The blade was designed in Creo 2.0. In the Ansys Design Modeler, the blade was imported and positioned at the required central position.

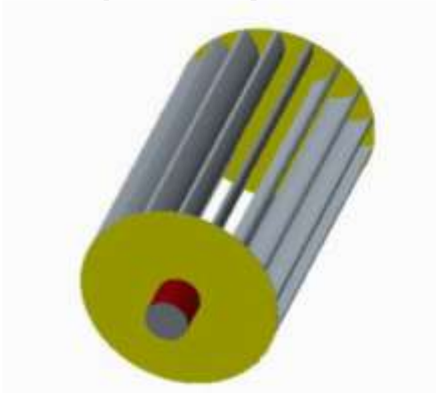

Figure 2: Isometric view of Cross-flow Turine

Now the cross flow turbine blade is coarse meshed to get 47232 nodes and 21124 elements. further this blades are enclosed in a liquid domain and boundary conditions are applied.

Table 2: Boundary Physics for Blades, Inlet and Outlet of the Cross-Flow Turbine

Location	*Assigned boundary conditions*	*Boundary condition details*	
Inlet	Inlet	Domain type	Fluid domain
		Frame type	Stationary
		Flow region	Subsonic
		Domain motion type	Rotary
		Mass and momentum	Average static pressure 3psi
Outlet	Outlet	Domain type	Fluid domain
		Frame type	Stationary
		Flow region	Subsonic
		Domain motion type	Rotary
		Mass flow rate	0.12 m^3/s
Blade	Wall	Frame type	Rotation
		Mass and momentum	No slip wall
		Wall roughness	Smooth
		Material Used	Polyester fiber
Side 1, Side 2 Side 3& Side 4	Wall	Frame type	Rotation
		Mass and momentum	No slip wall

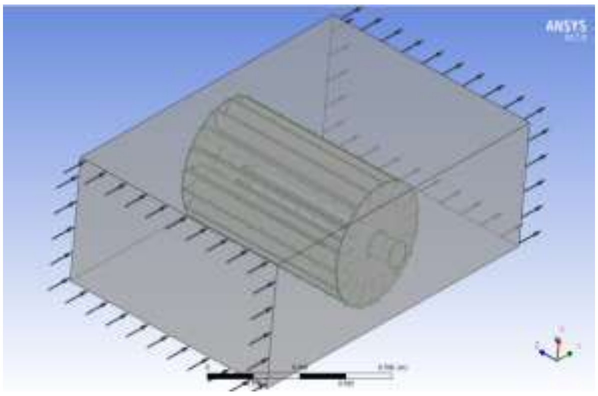

Figure 3: Applying Boundary condition on CFT Blades

6.3 ANSYS fluent Analysis

ANSYS Fluent is a very powerful and flexible tool for computational fluid dynamics software package used to model flow, turbulence, heat transfer, and reactions for industrial applications. In our setup, we have designed the cross flow turbine blades in an enclosure setup and given boundary conditions to verify whether the Blades are sustainable in the practical applications.

In this analysis, we have chosen a low mass flow rate which was analyzed at 0.12 m^3/s (118 Kg/ s) and the rpm of the blade are kept at 120 rpm are kept and results were obtained at the steady state conditions. In Ansys fluent analysis we have verified whether flow rate is able to cause the rotation of turbine blades.

Pressure is an important factor in designing any turbine. It determines whether the whole setup is able to run effectively. Whenever the pressure generated in the turbine exceeds the maximum pressure of the system, leads to breakage of the components. Pressure co-efficient is analyzed so as to predict the fluid pressure at various locations of the turbine. So it is necessary to keep this in mind while designing a turbine.

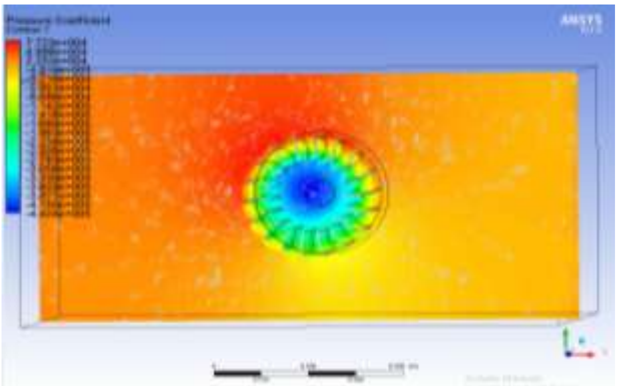

Figure 4: Pressure co-efficient of the system

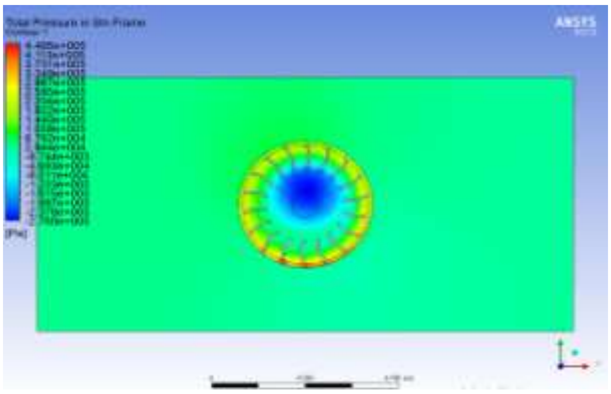

Figure 5: Total Pressure of the system

Dynamic viscosity is quantity which is used to measure the force needed to overcome internal friction in a fluid. The dynamic (shear) viscosity of a fluid expresses its resistance to shearing flows, where adjacent layers move parallel to each other with different speeds. It was observed it was high turbulent flow.

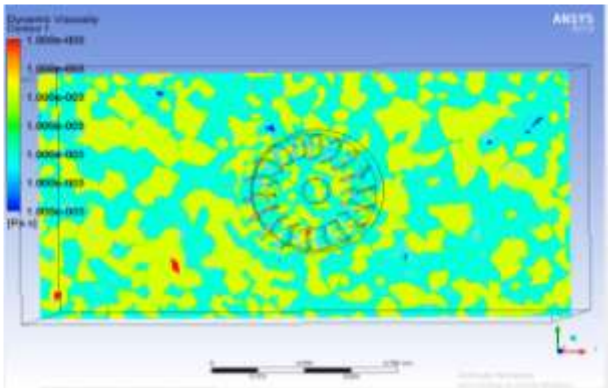

Figure 6: Dynamic viscosity of the system

Strain rate is defined as the deformation of a material with respect to time. The strain rate at a point within a material computes the rate at which the distances of adjacent parcels of the material change with time in the neighborhood of that point. It is zero if these distances do not change, when all particles in some region are moving with the same velocity and/or rotating with the same angular velocity, as if that part of the medium were a rigid body.

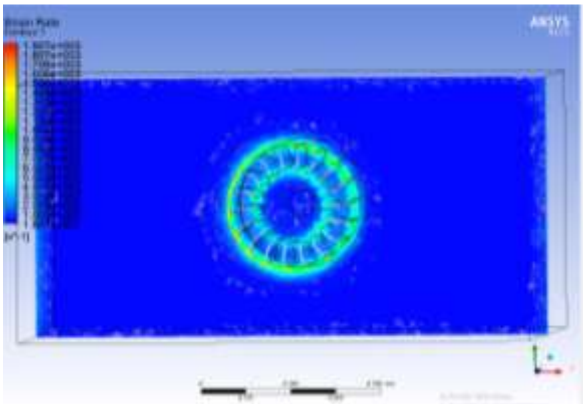

Figure 7: Strain rate of the system

The lower cell volume limit restricts the refinement process to cells with volumes greater than the limit. It is used to predict the distribution of fluid flow in the system in the given domain conditions.

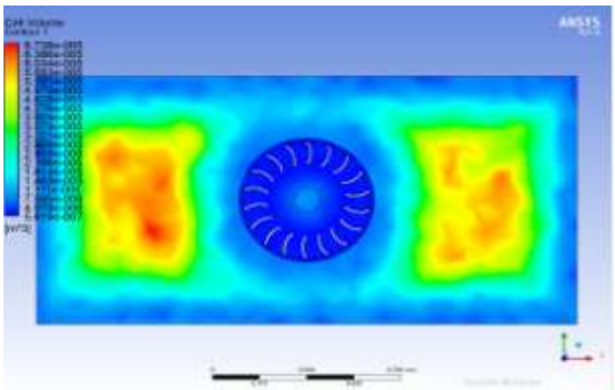

Figure 8: Cell Volume of the system

Similarly, the gradient volume weight can also be found. The zero value eliminates the volume weighting, a value of unity uses the entire volume, and values between 0 and 1 scale the volume weighting and obtain the cell volume.

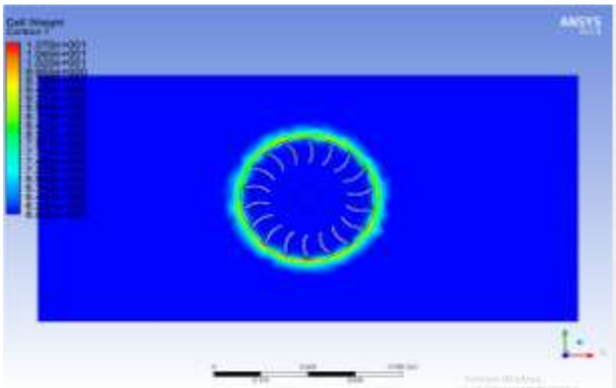

Figure 9: Cell Weight of the system

Turbulence Intensity is defined a scale characterizing turbulence measure, which is expressed as a percent. An ideal flow with absolutely no fluctuations in speed or direction would have a Turbulence Intensity value is expressed as 0%. For low turbulence value is less than 1%, medium turbulence value ranges from 1-3%, whereas the high turbulence value ranges between 5-20%.

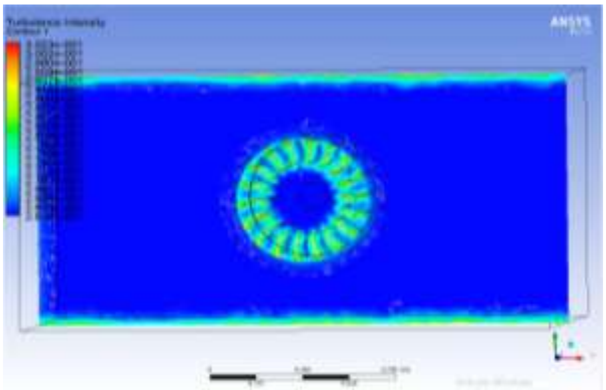

Figure 10: Turbulence Intensity of the system

There is a rotary motion of the blades due to mass flow in the turbine setup, which leads to rotation of the turbine.

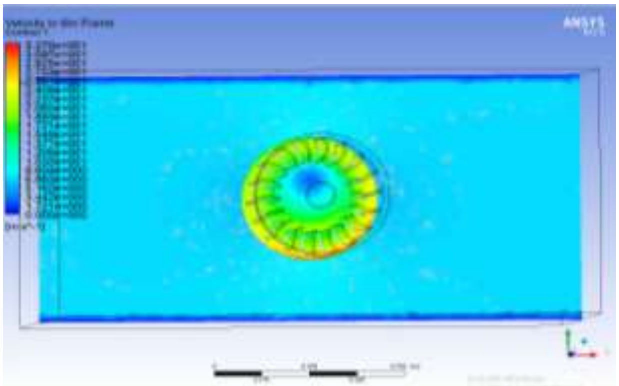

Figure 11: Velocity of the system

7. Conclusion

It is observed that whenever preliminary treated sewage water passes through the setup, the cross-flow turbine blade effectively rotates. The rotation of axle shaft of the turbine will be coupled with generator circuit for power generation.

It is also observed that for a mass flow rate of 0.12 m^3/sec cell volume is equally distributed throughout system so there is very less chance of clogging to occur. The pressure created in the system was sustainable over the period of time. The dynamic viscosity which was obtained is very low as result there is free rotation of the blades. The turbulence intensity value shows that flow in the system is turbulent in nature. The turbulent flow able to rotate the blades of the cross-flow turbine easily. This setup can be implemented so as to meet the increasing demand for electricity generation.

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