American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-5, pp-115-123
www.ajer.org
Research Paper Open Access

Utilization of Water Flow in Existing Canal System for Power Generation through Flow Acceleration Using Converging Nozzles

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ABSTRACT: *Energy crisis has remained a serious concern for developing countries like Pakistan. The problem can be addressed in two different ways: First is to start mega projects like construction of dams, power plants and nuclear reactors etc, while another method is to go for micro projects, like installation of wind turbines or micro-hydro projects. This paper presents a feasibility report on using convergent nozzles for run-of-river turbines and also to devise a method for silt reduction in open flow channels. Ghazi-Barotha Canal has been used for the analysis based on its easily available data. The work has been carried out through analytical and numerical analyses.*

Keywords*: Alternate energy resources, Open channel flow, CFD*

I. Introduction

To meet power requirements of a country, both mega projects and micro projects are important. To satisfy urgent power requirements, micro-projects are more useful; micro-hydro projects and installation of wind turbines are two examples. In this regard, different concepts should always be welcomed and tested.

Small scale hydro or micro-hydro power has been increasingly used as an alternative energy source, especially in remote areas where other power sources are not viable. Small scale hydro power systems can be installed in small rivers or streams with little or no discernable environmental effect on things such as fish migration. Most small scale hydro power systems do not require a dam or major water diversion, but rather use water wheels with little environmental impact.

Utilization of the existing canal flow for this purpose using converging nozzles to accelerate the flow to get more power is a fairly new concept, and very little work has been done in this field.

II. Objectives

To prepare a feasibility report on using converging nozzles in Ghazi Barotha Power Channel to install power turbines for electricity generation and also to devise a method for silt reduction, are the main objectives of this paper. A recommendation of a turbine will also be made at the end of the paper.

III. Motivation

By installing run-of-river power turbines throughout the length of the canal, a good amount of extra power can be generated in addition to the original power capacity of the power plant at the end of the channel. Also, this concept can be utilized on other rivers and power channels.

Moreover, the concept of vortex generators for silt reduction may reduce the cleansing cost of canals by millions of dollars per years.

IV. Procedure and Methods Adopted

To undertake the project, methodology includes both the analytical solution of the problem and the CFD analysis of the open channel i.e. Ghazi Barotha Canal. First the analytical solution was carried out and then CFD has been used to validate the results.

4.1. Analytical Analysis.

Open Channel flows are governed by equations like Chezy's formula and Manning's equation. Manning's equation is accepted worldwide and is the most reliable equation. Ghazi Barotha Canal has a trapezoidal cross section for which Manning's equation says:-

$$V = \frac{1}{n} \times R^{2/3} \times S^{1/2}$$

Where V is the velocity of the flow, R is the hydraulic radius of the Channel cross section and it is found by dividing the cross sectional area (A) of the channel with its wetted perimeter (P) and S is the bed slope of the channel. For Ghazi-Barotha Canal the bed slope is 1:9600. The factor "n" is called Manning's constant, and is a function of channel's roughness and material. Its value can be found from Manning's table. For Ghazi-Barotha Canal, its value is 0.016.

Dimensions were obtained from Ghazi-Barotha Head Offices near Kamra in Hettian for analysis. Different values are listed below:-

- Bottom width=58.4 m
- Bed slope=1:9600
- Side slope=1V:2H
- Height= 9 m
- Total length of the canal=51906 m

Using the above data the top width of the channel was calculated to be 94.4 m.
Velocity of flow in the channel was calculated to be 2.33 m/s using the above mentioned equation, and discharge to be 1600 m^3/sec.

4.2. Power in Water and Area Calculations.

Power is available in water both in kinetic and potential energy form, and can be utilized in both the ways. Potential energy of water can be used by dropping it from certain height on to the turbine blades directly to get the power output. It is shown mathematically as:-

$$P = \rho \times g \times h \times \dot{V}$$

Where P is power in watts, ρ is density in kg/m^3, g is the acceleration due to gravity, h is the height from which water drops and $\dot{V}$ is the flow rate of water in m^3/s.

The running velocity of water can be used to extract kinetic energy from water. It is shown mathematically as:-

$$P = \frac{1}{2} \times \rho \times \phi \times V^2$$

Where P is power in watts, ρ is density in kg/m^3, ϕ is flow rate in m^3/s and V is the velocity of flow in meters.

From the above equations a relation between power gained by dropping from certain height and power gained by using certain velocity was found. Then both the power equations i.e. the K.E power and P.E power were equated to get the velocity required to get the same power as gained by dropping water from certain height. After the velocity required was found, continuity equation was used to calculate area changes required to achieve the above velocity. Continuity equation says:-

$$A_1 V_1 \rho_1 = A_2 V_2 \rho_2$$

Where ρ is density, and in this case density of water which remains constant and has a value of 1000 kg/m^3. A_1 and A_2 are the areas before and after the velocity change and V_1 and V_2 are the initial and final velocities of the flow.

The area calculated above was used to find the new bed width of the channel. After that, using the new bed width, for a 50m long converging nozzle, required nozzle angle was calculated.

Different increase in velocity is required to get power from the running water equal to what we get from dropping it from different heights. Hence different new bed areas will be required and so converging nozzles of different angles are needed. Velocities required and nozzle angles against few heads are shown in the table:-

Water head(m)	Required velocity (m/s)	Nozzle angle(deg)
1	4.42	19.92
2	6.26	25.62
3	7.67	28.02
4	8.85	29.389

Table 1: Nozzle Angle Required

The table says that to have the same power as gained by dropping water from 1 m of head, flow in the channel should be accelerated to 4.42 m/s from its initial velocity of 2.33 m/s and for that a nozzle of 19.92 degrees is required. Similarly, for 2m, 3m and 4m heads, the required velocities and nozzle angles are calculated and shown above.

4.3. CFD Analysis.

To do the CFD analysis of the Ghazi Barotha Canal with the nozzles, an assumption was made that the channel is straight and only a portion of it i.e. 500 m length was analyzed to study the behaviour of flow upstream and downstream of the nozzles.

4.3.1. Methodology.

Following methodology was followed for the CFD:-

- Geometry modelling in Gambit software.
- Meshing of the geometry and assignment of boundary conditions in Gambit.
- Exporting the meshed model to Fluent software for analysis.
- Pre-processing in Fluent.
- Iterations and solution.
- Finally contours and results are obtained.

4.3.2. Cases

Following cases were modelled in gambit and analyzed in Fluent:-

- A clean channel of 500 m length.
- Channels with 50 m long nozzles of 5^0, 10^0, 20^0 and 25^0.
- Channels with different kinds of vortex generators.
- Channels with 20^0 nozzle and turbines.

4.4. Results

Results were obtained in the form of velocity and pressure contours for all the above mentioned cases. From these contours final conclusion and recommendations will be made. Now all the cases will be discussed in detail.

4.4.1 Clean Channel.

From the velocity contours of the clean channel no velocity increase was observed, which is in complete accordance with the Manning's equation. Velocity vectors were also smooth and straight. The velocity contours are shown in the figure below:-

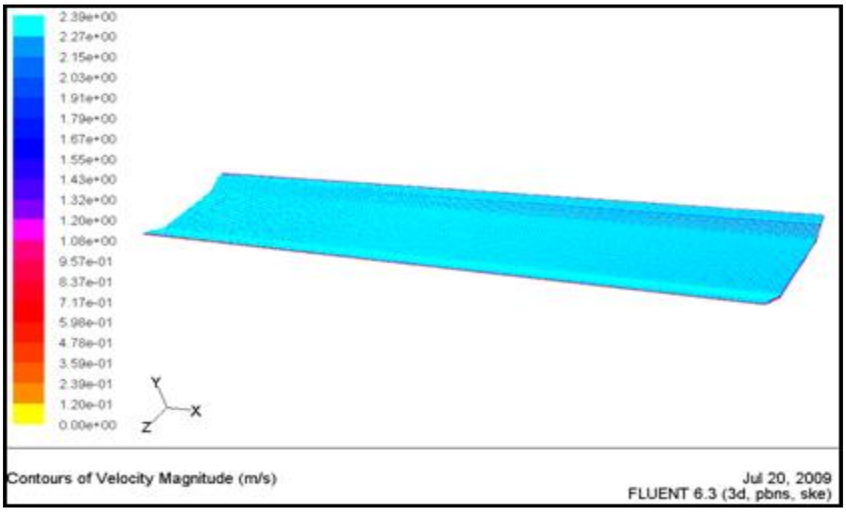

Fig 1: Velocity Contours of the Clean Channel

4.4.2. Channel with 5 Deg Nozzle.

For the channel with 5 deg nozzle, velocity contours show an increase in velocity. The velocity is maximum near the edges of the nozzle, but normal channel flow behaviour dominates. This effect is shown in the figure below:-

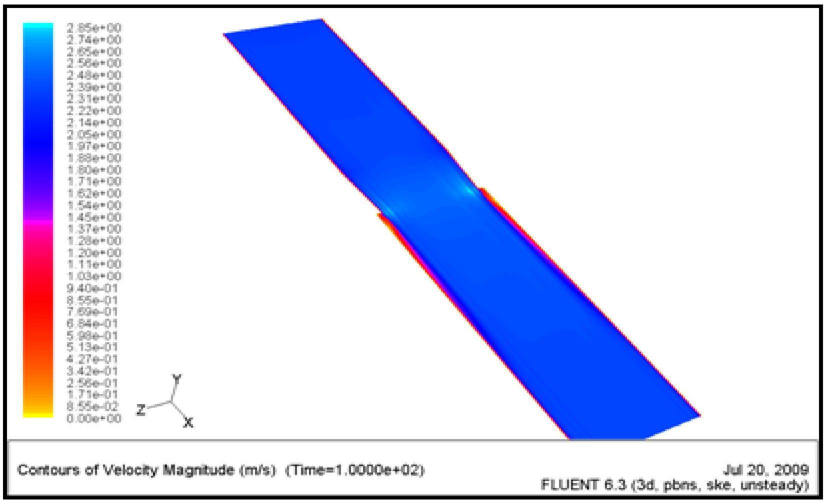

Fig 2: velocity Contours of Channel with 5 deg Nozzle

The figure says that acceleration starts at the centre earlier and is sustained for a longer time. Also on the edges of the nozzle vortices are observed. The vortices are shown below:-

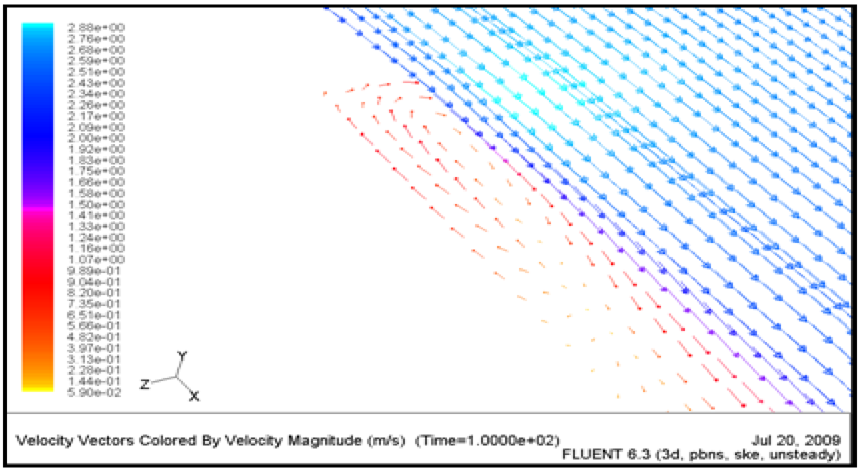

Fig 3: Vortices Produce by the Nozzle Edge

4.4.3. Channel with 10 Deg Nozzle.

Similar results are obtained for 10 deg nozzle, except that the acceleration is a little more and the effect is maintained for a longer distance. This is shown in the figure below:-

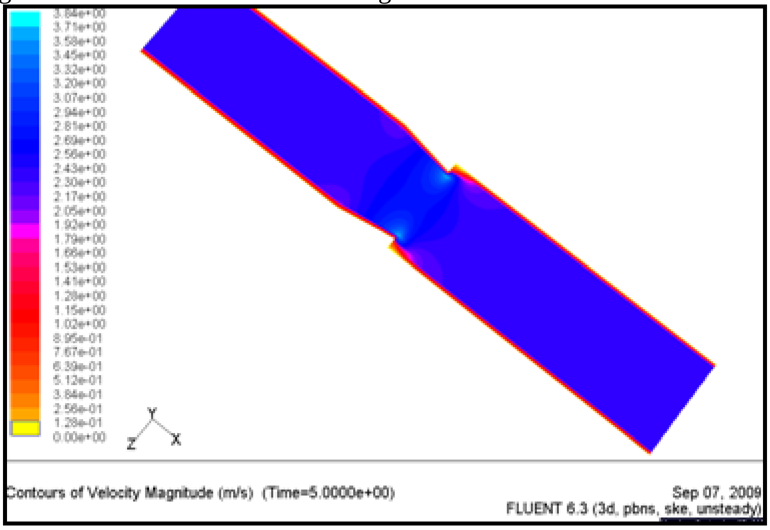

Fig 4: Velocity Contour for Channel with 10 deg Nozzle

In this case the vortices produced at the nozzle edges are more refined, as shown below:-

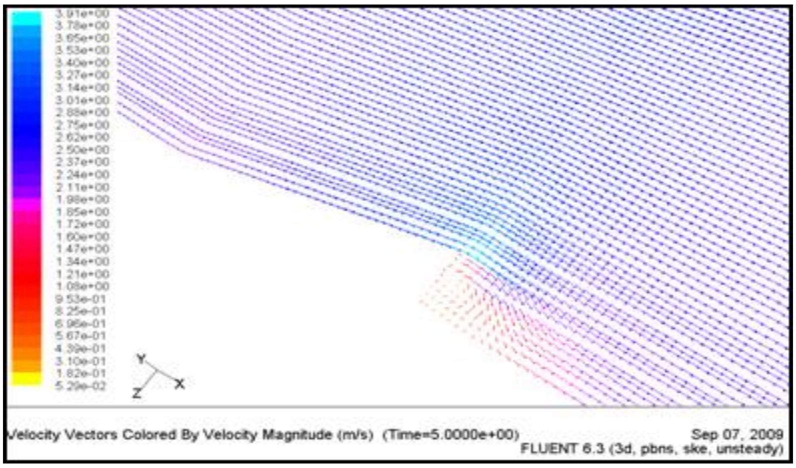

Fig 5: Vortices Produce by the Nozzle Edge

4.4.4. Channel with 20 Deg Nozzle.

Similar results are obtained for 20 deg nozzle, except that the acceleration is even more and the effect is maintained for a longer distance. This is shown in the figure below:-

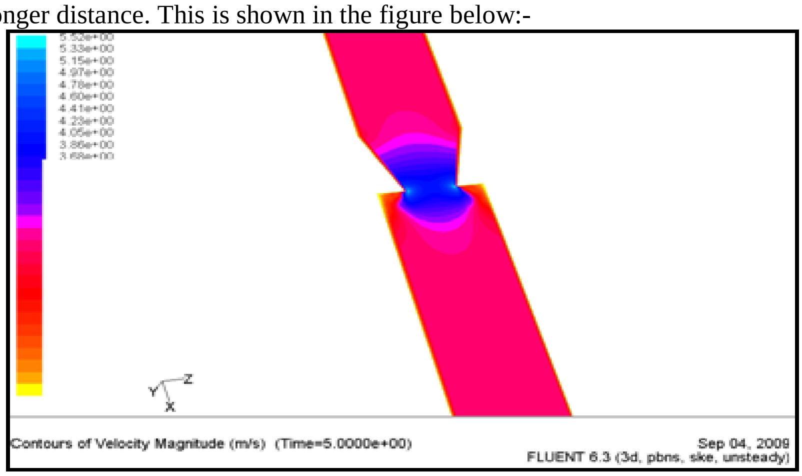

Fig 6: Velocity Contour for Channel with 20 deg Nozzle

Vortices in this case are refined further, as shown below:-

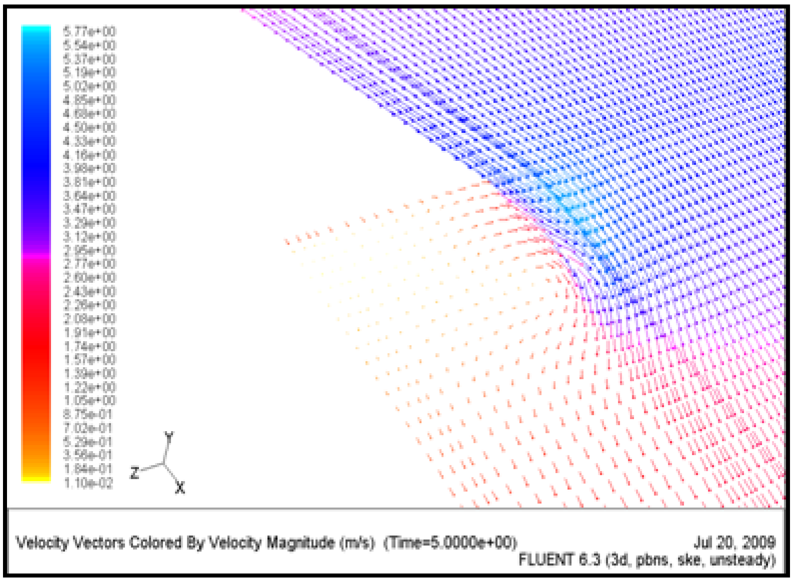

Fig 7: Vortices Produce by the Nozzle Edge

4.4.5. Channel with 25 Deg Nozzle.

Similar results are obtained for 25 deg nozzle. However, in this case the bed width becomes so small that the trapezoidal equations may lose their reliability. The velocity contours are shown below for 25 deg nozzle:-

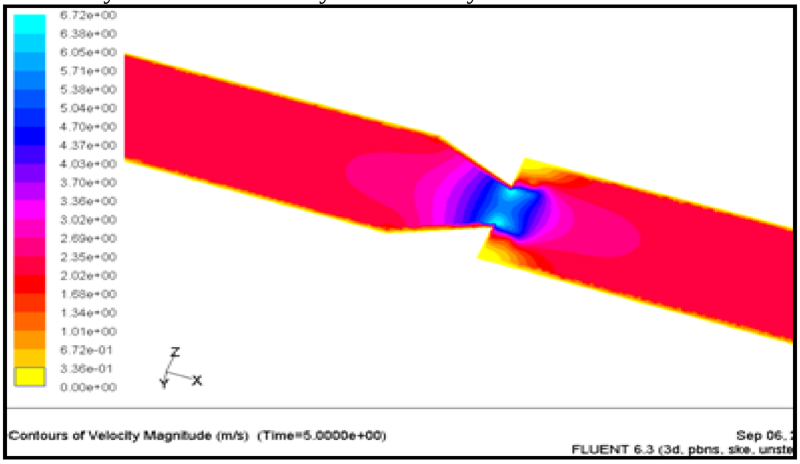

Fig 8: Velocity Contour for Channel with 25 deg Nozzle

Vortices in this case are refined further, as shown below:-

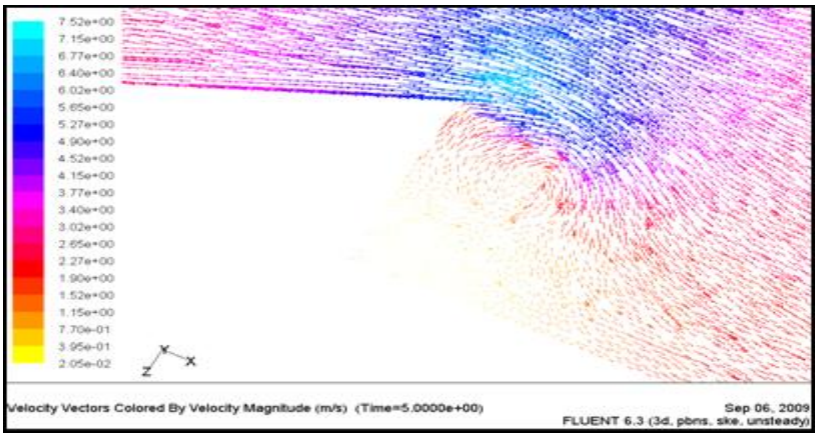

Fig 9: Vortices Produce by the Nozzle Edge

4.4.6. Vortex Generators

Vortex generators are not producing much effect. Although vortices are being produced, but they are of very low strength and diminish very soon. So they may not be very helpful in reducing the silt near the canal bed. The velocity vectors for some vortex generators modelled are shown below to show their effects:-

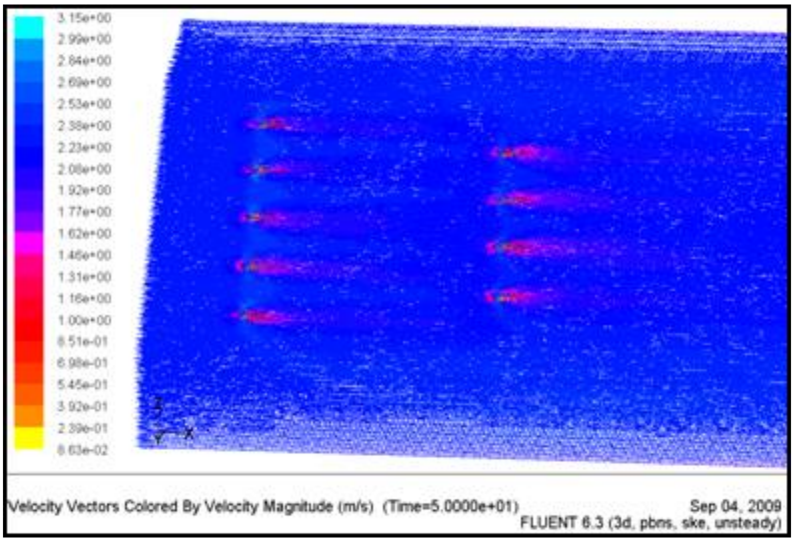

Fig 10: Vortices Produced by Vortex Generators in Cylindrical Form

V. Observations

From the results and contours, following conclusions were made:-

- The effects of nozzles i.e. the velocity changes and pressure changes are being observed almost 50-70m upstream and 200-250m downstream of the nozzle, after which the flow retains its earlier state.
- Nozzles having less than 20 degrees are not producing the required increase in velocity.
- Nozzles having larger than 20 degrees are making the new bed width very small, which can question the validity of the equations for trapezoidal channel.

VI. Recommended Solution

Following recommendations are made about the nozzles and vortex generators:-

- Nozzles of 20 degree should be used for an optimized result.
- Nozzles should be placed about 350 m apart, so that the effects of nozzles are dissipated by the flow. Nozzles placed at a distance of 350 m were also analyzed through CFD which shows the validity of this point. The velocity contours for this case is shown below:-

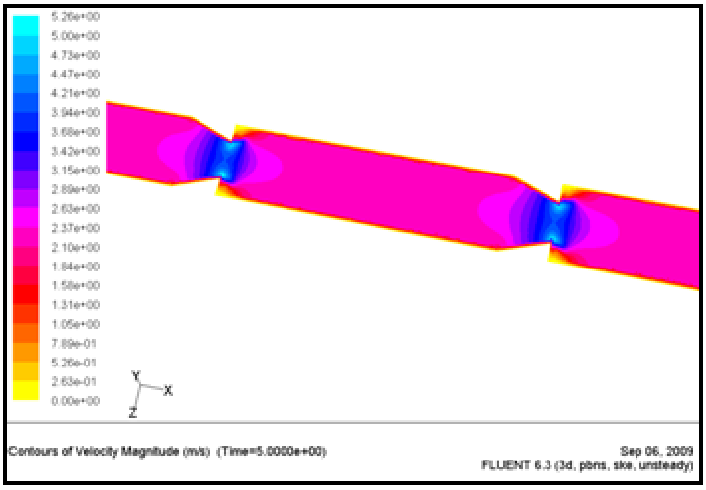

Fig 11: Velocity Contour for Channel with Two 20 deg Nozzles 350 m apart

- Static vortex generators are not helpful in reducing the silt; perhaps a moving hydrofoil kind of vortex generator will solve this problem.
- Undershot water wheels are recommended to be installed after the nozzles to extract power from the water.
- Velocity contours of the channel with undershot water wheels and nozzles are shown below:-

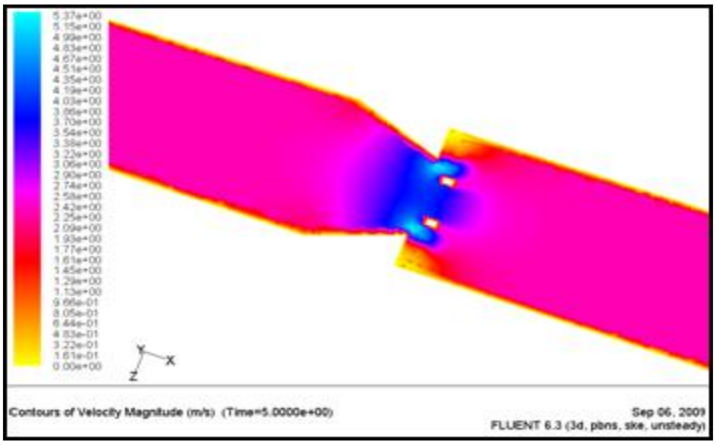

Fig 12: Velocity Contour for Channel with 20 deg Nozzle and Turbines

VII. Undershot Water Wheel Specifications

The undershot water wheel which is recommended for power generation has the following specifications:-

- Head **= 3 m = 9.842 ft**
- Diameter **= 4 × Head = 12 m = 39.37 ft**
- Width **= 0.5 × Diameter of the wheel = 0.5 ×12 = 6 m = 19.685 ft**
- Velocity of flow just after the nozzle **= 4.42 m/s = 14.5 ft**
- Design flow **= Head ×Width × Flow velocity**

$$= 9.842 \times 19.685 \times 14.5 = 2809.375\ ft^3/sec$$

- Potential power available = $\dfrac{Design\ Flow\ (ft^3/sec) \times Head\ (ft)}{11.8}\ kW$

$$= \frac{(2809.375 \times 9.842)}{11.8}\ kW$$

$$= 2343.33\ kW$$

- So, potential power available **= 2.3 MW**
- But maximum efficiency of undershot water wheel is from **50%—60%**, so:-

Single undershot water wheel power output **= 2.3 × 0.5 = 1.1 MW**

- On every nozzle two such undershot waterwheels can be installed, so:-

Single nozzle power output **= 1.1 × 2 = 2.2 MW**

- Throughout the length of the canal, 120 such nozzles can be placed at 350 m distance from each other, so:-

Total potential power output **= 2.2 × 120 = 264 MW**

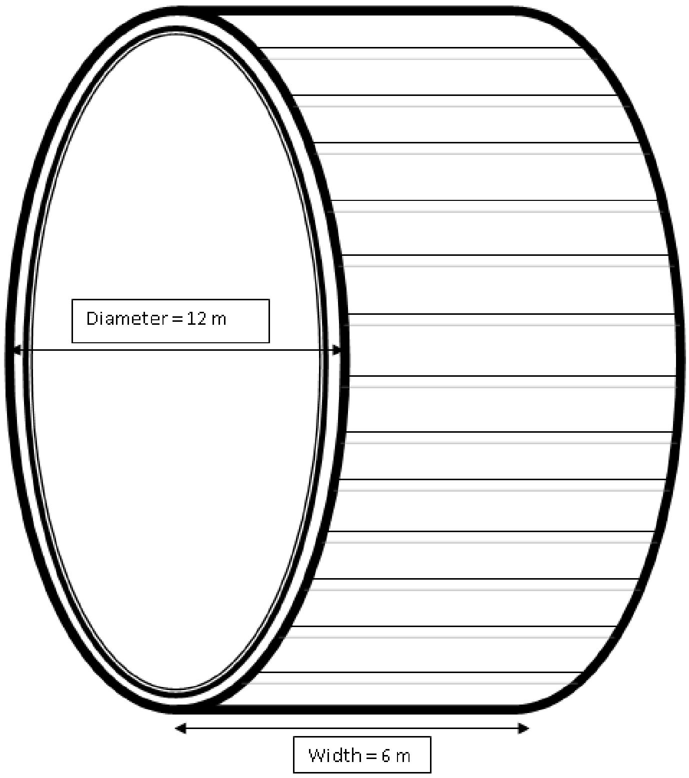

Fig 13: Water Wheel Dimensions

VIII. Conclusion

Utilizing the flow by accelerating and using undershot water wheels, a good amount of power can be extracted from running water, which may be a good addition to overcome the power shortage of the country. Although the idea is tested and analyzed in Ghazi-Barotha canal, but can be applied in any other open channel or river.

Although reduction of silt accumulation was not achieved but hopefully the problem can be solved by introducing moving vortex generators like moving hydrofoils etc. This idea can be tested in future.

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