

**EXPERIMENTAL AND NUMERICAL STUDY OF
MODULAR HYDRO TURBINE BASED ON CANAL FLOW**

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1. Abstract

The depletion of fossil fuel supply due to excessive usage and its negative environmental impacts are the main factors driving the search for creative, sustainable methods of producing clean energy. The conventional electricity produced by the hydroelectric plant is generally unaffordable and inaccessible to rural and isolated people. Given the catastrophic effects of climate change and the world's continually increasing demand for power, it is critical to quickly accelerate this trend and transition to a portfolio dominated by renewable energy that significantly lowers carbon emissions within the next ten years. Utilizing proven and affordable renewable energy conversion technologies, such solar, hydro, and wind turbines, to quickly grow utility-scale renewable energy projects and markets is a major way to do this. The hydrokinetic turbine (HKT), which generates electricity from flowing water, is the most cost-effective solution for meeting these locations' power needs. Using the potential of rivers, canals, and oceans to generate electricity is also a clean, sustainable, and practical solution.

In the first stage of this research work, a comparative numerical assessment of various turbulence models was carried out at trapezoidal open canal situated on Tapi River, Surat, Gujarat, India, to find a possible site for HKT installation. Various flow parameters like longitudinal velocity along the depth and width as well as secondary vectors were utilised with different turbulence models such as $k - \varepsilon$ Standard, $k - \varepsilon$ Renormalization group (RNG), $k - \varepsilon$ Realizable, $k - \omega$ Standard and $k - \omega$ shear stress transport (SST). For predicting the potential HKT installation and understanding the flow physics phenomena, velocity vectors as well as water power density were analysed. The simulation results were validated using the experiments performed at the selected locations. Based on the error analysis, the $k - \omega$ SST model found to be more accurate providing the potential site for HKT installation. The potential site is capable enough to provide the flow velocity (U_m) of 0.42 m/s, with estimated power generation of 1.2 kW. The maximum velocity in the canal is found to be 1.06 m/s. This velocity is not available throughout a year.

In the second stage, using the obtained canal flow and preferred HKT installation site, the comparative analysis of Savonius hydrokinetic turbine (SHKT) and Michell-Banki hydrokinetic turbine (MBHKT) was carried out in a canal. For numerical analysis, $k - \omega$ SST turbulence model has been applied to the Reynolds-Averaged Navier-Stokes (RANS) solver with two different inlet U_m of 0.42 m/s and 1.06 m/s for a wide range of 0.1 to 1.0 tip speed ratio (TSR). Based on the investigation, the maximum power coefficient (C_{Pmax}) obtained was 0.065 and 0.072 at 0.6 TSR for SHKT and; 0.112 and 0.125 at 0.4 TSR for MBHKT, at 0.42

m/s and 1.06 m/s velocity, respectively. Additionally, the fluid flow visualisations surrounding the rotors have been examined and discussed for comparing the performance of HKTs. Because of these characteristics, the MBHKT provides a straightforward, reliable, and clog resistant cross-flow option for decentralized zero-head hydrokinetic power generation.

In the third stage of this research work, experimental study of MBHKT was performed at state-of-the-art open channel testing facility established at Fluid Mechanics and Fluid Machine Laboratory, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India. The numerical simulation was validated with the experimental results for MBHKT fully submerged (100% immersion) and partially submerged (75% and 50% immersion) at different velocities. Based on the experimental study, the C_{Pmax} obtained was 0.185 at 1.03 TSR; 0.152 at 1.08 TSR; and 0.143 at 0.79 TSR, of 100%, 75% and 50% immersion, respectively.

In the final and forth stage of the present work, the numerical optimization of three different blade profiles (flat profile, round profile and sharp-edged profile) was performed considered an open channel testing facility established at Fluid Mechanics and Fluid Machine Laboratory, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India. The results show that the sharp-edged blade profile provided the better performance across the different U_m , achieving the C_{Pmax} of 0.252 at 1.03 TSR. Furthermore, the C_{Pmax} of flat blade profile & round blade profile were 0.192 & 0.105 at 1.03 TSR. Additionally, based on the optimum blade profile, the various augmentations combining the nozzle and diffuser were also numerically simulated to find out the optimum design of augmentation. The augmentation systems can accelerate the water flow in open channels, especially in low-velocity regions. Based on the numerical investigation, performance of the augmentation system-3 was found better than other three augmentation systems. The C_{Pmax} of augmentation system-3 with sharp-edged blade profile was found 0.552 at 1.03 TSR. Also, performance of the MBHKT with augmentation system-3 was 2.2 times higher that of the without augmentation. The C_{Pmax} of augmentation system-1, augmentation system-2 & augmentation system-4 was found to be 0.418, 0.525 & 0.531 at 1.03 TSR.

The outcome of this present work may be useful for developing a modular hydrokinetic turbine designed for a specific capacity, which can then be installed at any suitable water potential site.

2. Introduction and Literature Review

The depletion of fossil fuel supply due to excessive usage and its negative environmental repercussions are the main factors driving the search for creative, sustainable methods of producing clean energy. Between 1995 and 2015, the percentage of primary energy consumed from fossil fuels decreased from 87% to 85%, and by 2035, consumption is predicted to drop even further to 78% [1]. In recent years, renewable energy sources have added over 2179 GW (~34% of installed power capacity worldwide) to the global energy generation. Hydropower is the biggest contribution, making up over 1151 GW, or nearly 18% of the installed power capacity globally [2,3]. However, about 1.5 billion people worldwide do not have access to sufficient power, especially in developing and underprivileged nations. [4]. The conventional electricity produced by the hydroelectric plant is generally unaffordable and inaccessible to rural and isolated people. Given the catastrophic effects of climate change and the world's continually increasing demand for power, it is critical to quickly accelerate this trend and transition to a portfolio dominated by renewable energy that significantly lowers carbon emissions within the next ten years. Utilizing proven and affordable renewable energy conversion technologies, such solar, hydro, and wind turbines, to quickly grow utility-scale renewable energy projects and markets is a major way to do this. The hydrokinetic turbine (HKT), which generates electricity from open water channels, is the most cost-effective solution for meeting these locations' power needs. Using the potential of rivers, canals, and oceans to generate electricity is also a clean, sustainable, and practical solution.

A Ministry of New and Renewable Energy (MNRE) evaluation indicates that India has 21133.65 MW of potential for run-of-the-river, or small hydropower, across the nation [5]. Several HKTs would be the best option for accomplishing these energy goals if they are grouped in an array with adequate distance between them to produce electricity and supply it to the grid. Similar to wind turbines, HKT systems are a form of "zero-head" hydropower where energy is extracted from the kinetic energy of flowing water rather than the potential energy of falling water. Free-flowing rivers or streams can have these systems installed [6]. Hydrokinetic (HK) energy generation avoids many of the problems associated with more traditional forms of hydropower, such as high civil works costs and the need for a viable and exploitable potential energy head. The development of HK technologies can be divided into multiple stages, beginning with the traditional era that gave origin to the waterwheel concept and concluding with the more recent empirical era highlighted by improved pilot plants and testing, even though they are among the earliest forms of hydropower. The advancement of technology is

currently in its rising phase, with several HK development projects appearing within river, tidal, and wave energy systems [7]. HKTs don't require a reservoir or spillway, making them comparatively simple designs. According to preliminary research, these devices have a negligible environmental impact, and their ease of use makes installation and maintenance reasonably priced. Because of their simplicity, these systems might be useful in isolated or rural locations. Though HKTs face some operational difficulties. For instance, a minimum water flow speed of 1 to 3 m/s is usually needed, depending on the type of turbine and its orientation. The location must be three meters broad and at least two meters deep [8]. Debris in the stream, low energy capacity and efficiency, the lack of indigenous technology, and the complexity, importation, and inability to adjust current technology to site specifications.

Many researchers have tried to identify about the favourable site for HKT in various canal sections. This analysis might be studied using analytical, experimental, and computational fluid dynamics (CFD) methods. When studying turbulent flows in open channels, hydraulic engineers frequently use CFD and experimental studies to comprehend the different flow components [9–14]. An effort is made to create a numerical technique to forecast the flow in river bends (curves) in the research article by Kamel et al. [15]. Their approach makes use of the 3-D non-linear $k - \varepsilon$ model for a compound channel that meanders and has a rectangular cross-section for HKT installation. Furthermore, downstream of hydro power plant were assessed for HKT installation using the power curve by Holanda et al. [16]. Song et al. [17] used an efficient numerical method based on actual geometry statistics to study the turbulent flows in simplified Dragon type river channels with a constant critical curvature and various single-short-branch characteristics. Based on the simulations performed using RNG $k - \varepsilon$ model, they found that the location shift of the main and branch channels' greatest flow impact under various circumstances to direct the strategic positioning of river engineering structures. The performance of several low Reynolds number turbulence models was compared to direct numerical simulations by Gorji et al. [18] and found that $k - \varepsilon$ yield the accurate predictions for the wall shear stress of open channels. Recently in 2025, Benoumessed et al. [19] modelled the flow velocity profiles for irregular shaped open channels using the $k - \varepsilon$ simulation model. The principal flow in the curved segment first moves toward the inner bank before being redirected toward the outer bank by centrifugal force. Elevation close to the outside wall and depression close to the inner wall indicate a significant rotational displacement in the free surface.

In 1920, Sigurd J. Savonius developed drag-based and “S” shaped HKT known as Savonius hydrokinetic turbine (SHKT) [20]. The design of SHKT was originated from cutting cylinder along its axis into two halves and then putting the two half surfaces sideways. Kumar and Saini [21,22] optimised the blade arc angle, blade twist angle and blade shape factor of single stage SHKT using numerical analysis. They found that at 0.9 TSR and mean flow velocity (U_m) of 2 m/s, the maximum power coefficient ($C_{P,max}$) of 0.426 was obtained for 150° blade arc angle and 0.6 blade shape factor; while 0.390 for 12.5° blade twist angle. Talukdar et al. [23] evaluated the performance of SHKT by varying the no. of blades (two and three); shape of blade (semi-circular and elliptical) and depth of immersion (100% fully submerged and 60% partially submerged). The two bladed semi-circular fully submerged SHKT imparts the highest $C_{P,max}$ of 0.28 at 0.89 TSR. A novel deflector plate added SHKT with NACA6409 blades instead of conventional semi-circular blades were numerically investigated by Chaudhari and Shah [24]. Their study found that the $C_{P,max}$ for NACA6409 blades SHKT and conventional SHKT with deflector is 0.227 at 0.8 TSR and 0.25 at 0.8 TSR, respectively. Also, NACA6409 blades SHKT with deflector has a lesser performance than conventional SHKT with deflector. Shanegowda et al. [25] numerically investigated the performance of SHKT for straight and curved (30°, 60° and 90°) bend channels. The most efficient bend condition is 30° with $C_{P,max}$ of 0.24 at 1 TSR.

In the early 20th century, three scientists Anthony Michell, Donát Bánki, and Fritz Ossberger developed the cross flow Michell-Banki hydrokinetic turbine (MBHKT) [26]. This MBHKT is cost-effective, easy to construct, and more practical than other micro HKTs now available. These HKTs are also experienced with high and medium flow rates, as well as low head, and can generate an average efficiency of 80% for modest and micro power outputs. Mereke et al. [27] evaluated the performance of MBHKT in conjunction with nozzle and diffuser attachment for ultra-low head application. The speed of conventional MBHKT obtained was 344 rpm, while 1025 rpm was obtained for MBHKT with nozzle and diffuser attachment. For small hydro power plants, the applicability of reaction MBHKT was evaluated Lukes et al. [28] using ANSYS CFX. The rotational speed of 220 rpm with an efficiency of 79.43% was obtained for the design parameters.

3. Problem Definition and Contribution by the Thesis

Few researchers have focused on MBHKT, despite the abundance of literature reviews accessible for SHKT performance improvement. The majority of study to date has focused on

MBHKT performance through numerical analysis; nevertheless, there is a dearth of literature based on experimental examination. Additionally, research on the MBHKT's performance is conducted for water channels such rivers and irrigation canals. The majority of the work has been done on various nozzle settings and blade shapes for other HKTs. Investigating the best blade and nozzle parameter values for MBHKT that are appropriate for the given hydro potential location is therefore necessary. Additionally, the literature review that is currently accessible concentrates on using these HKTs horizontally to harness energy. The main objectives of this study is to evaluate the performance of vertical axis MBHKT in terms of torque coefficient (C_m) and power coefficient (C_p) for various conditions and locations.

To fill the research gap and to explore the practical feasibility of actual system, the performance of MBHKT was evaluated in four stages of this research work. In the first stage, the actual experimental velocity of the actual canal flow was measured. Also, with the help of the comparative numerical assessment of various turbulence models, the potential HKT installation site was determined. In the second stage, using the obtained canal flow and preferred HKT installation site, the comparative analysis of Savonius hydrokinetic turbine (SHKT) and Michell-Banki hydrokinetic turbine (MBHKT) was carried out in a canal. In the third stage of this research work, experimental study of MBHKT was performed at state-of-the-art open channel testing facility established at Fluid Mechanics and Fluid Machine Laboratory, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India. In the final and forth stage of the present investigation, the numerical optimization of three different blade profiles (flat blade profile, round blade profile and sharp-edged blade profile) was performed for the open channel testing facility. Additionally, based on the optimum blade profile, the various augmentations combining the nozzle and diffuser were also numerically simulated to find out the optimum augmentation design.

4. Objectives of the Present Work

1. To identify a suitable HKT installation site through comparative assessment of turbulence models in open channel flow.
2. To analyse flow characteristics and water power density for accurate prediction of hydrokinetic energy potential.
3. To perform comparative numerical evaluation of SHKT and MBHKT for optimal performance under canal flow conditions.

(Y1), 1.2 m (Y2), 1.8 m (Y3), 2.4 m (Y4), and 3 m (Y5) water depth above the canal bed. Longitudinal velocity along water depth at the different vertical lines is drawn in Fig. 2. The maximum average velocity of 0.44 m/s was obtained at location X1 while minimum average velocity was 0.20 m/s at X3. Similarly, longitudinal velocity along width of canal at the different horizontal lines is depicted in Fig. 3. At the free water's surface (Y5), the maximum velocity was found to be 0.61 m/s at middle of the width of the canal (X0). According to the present study, the areas Y5 to Y2 and X2' to X2 have the maximum potential for HKT installation.

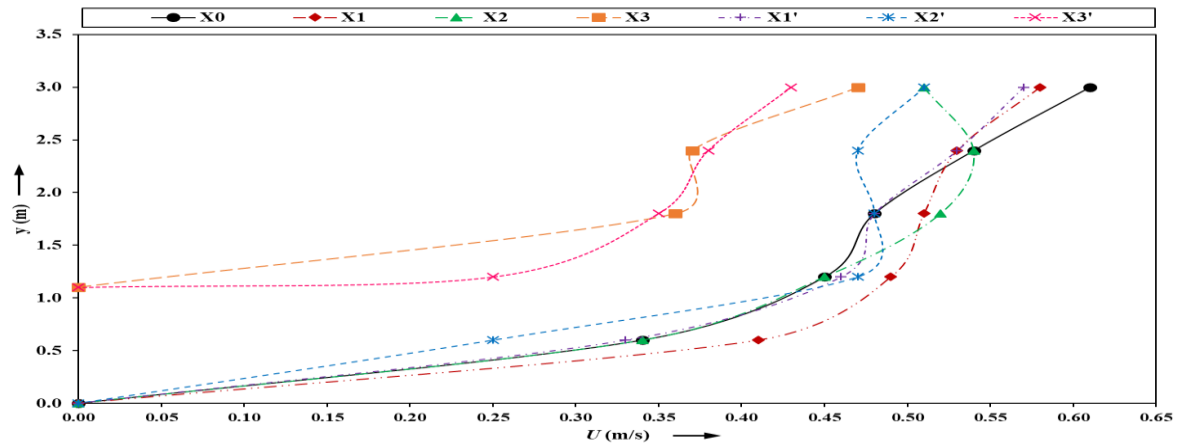


Fig. 2. Longitudinal velocity along water depth at the different vertical lines.

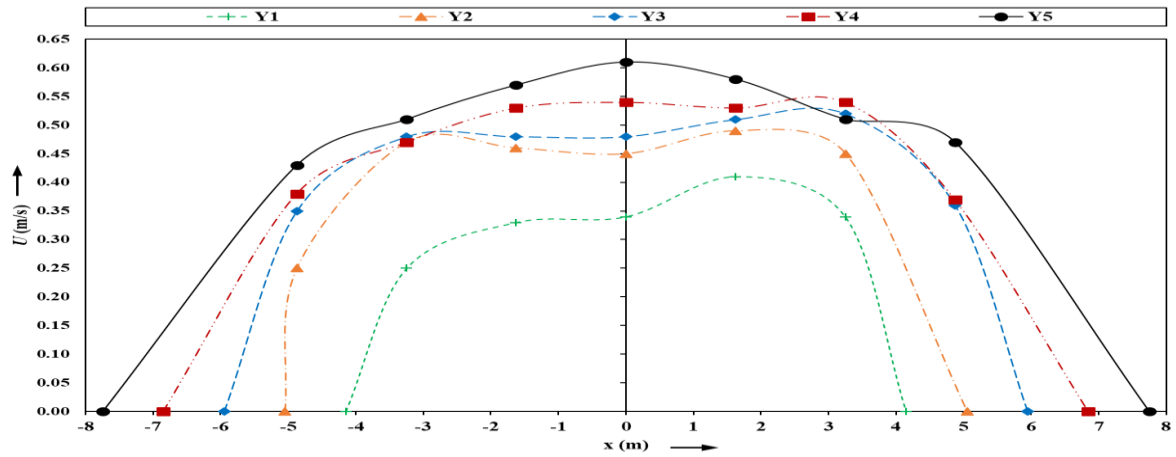


Fig. 3. Longitudinal velocity along width of canal at the different horizontal lines.

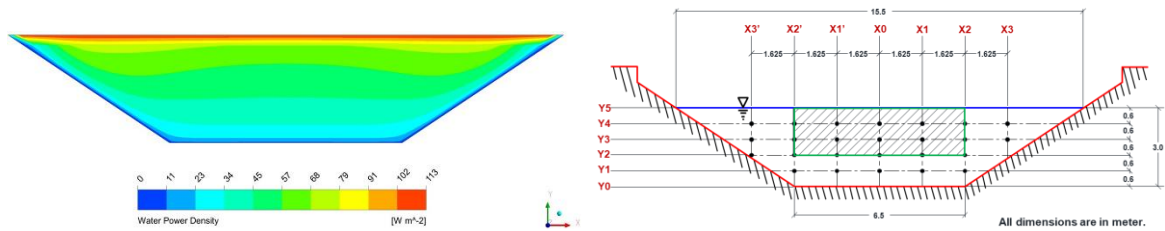


Fig. 4. (a) contour of Water power density and (b) Maximum potential region for HKT installation.

Based on the numerical study of the canal flow, the water power density is maximum at the middle portion of the trapezoidal canal and near the water surface, as shown in Fig. 4 (a) and the average water power density is found to be 63 W/m^2 . The rectangular area of 1.8 m water depth (Y5 to Y2) and 6.5 m length (X2' to X2) is taken into consideration for a suitable site to identify the initial HKT installation site among various locations, as illustrated in Fig. 4 (b).

6. Numerical Study of MBHKT Based on the Canal Flow

Based on the canal flow, the comparative analysis of SHKT and MBHKT was carried out in a canal. a mesh for the whole flow domain is created by ANSYS MESH considering an unstructured grid of tetrahedral elements. The meshing of inner rotating zone containing various rotors such as SHKT and MBHKT is also depicted Fig. 5 (a) and (b).

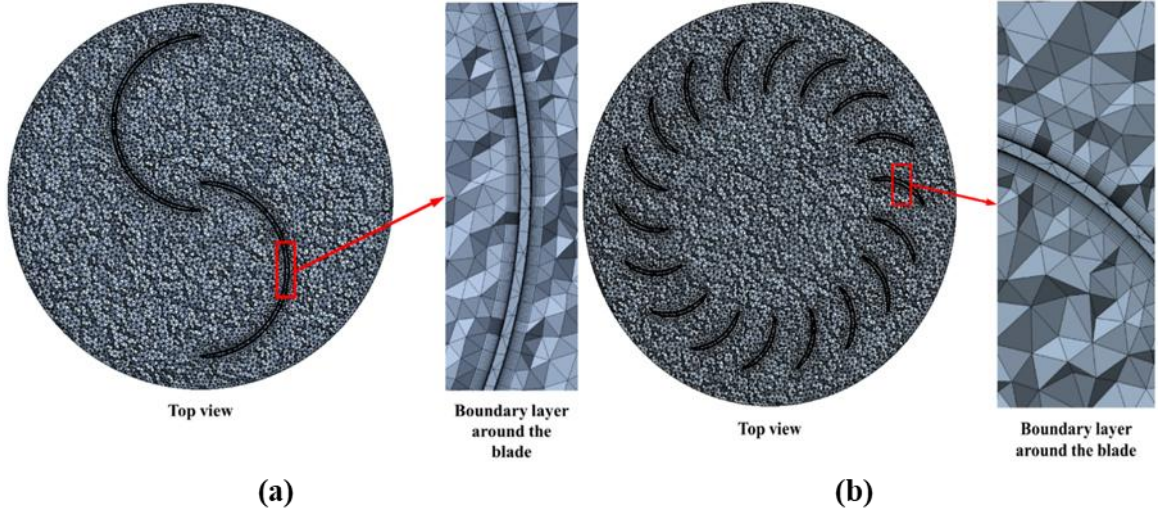


Fig. 5. Meshing of the computational fluid domain of (a) SHKT and (b) MBHKT.

Figs. 6 and 7 show the numerical results (pressure and velocity contours) of SHKT and MBHKT based on canal flow. Based on the pressure contour, the maximum pressure is applied on the convex surface of the returning blade, so the performance of SHKT is degraded (shown in Fig. 6 (a)). The velocity contour indicates that the velocity of water particles remains constant, and energy is effectively transferred in both the initial stage (outer-to-inner) and the subsequent stage (inner-to-outer) of the blade (shown in Fig. 7 (b)).

The comparative characteristic curve for all the HKTs at two different velocities 0.42 m/s and 1.06 m/s is depicted in Fig. 8 (a) and (b). For a velocity of 0.42 m/s and 1.06 m/s, the $C_{P,max}$ obtained is 0.065 and 0.072 at 0.6 TSR for SHKT; and 0.112 and 0.125 at 0.4 TSR for MBHKT, respectively. SHKT and MBHKT are operated at a low tip speed ratio. According to numerical analysis, performance of MBHKT is better than that of SHKT.

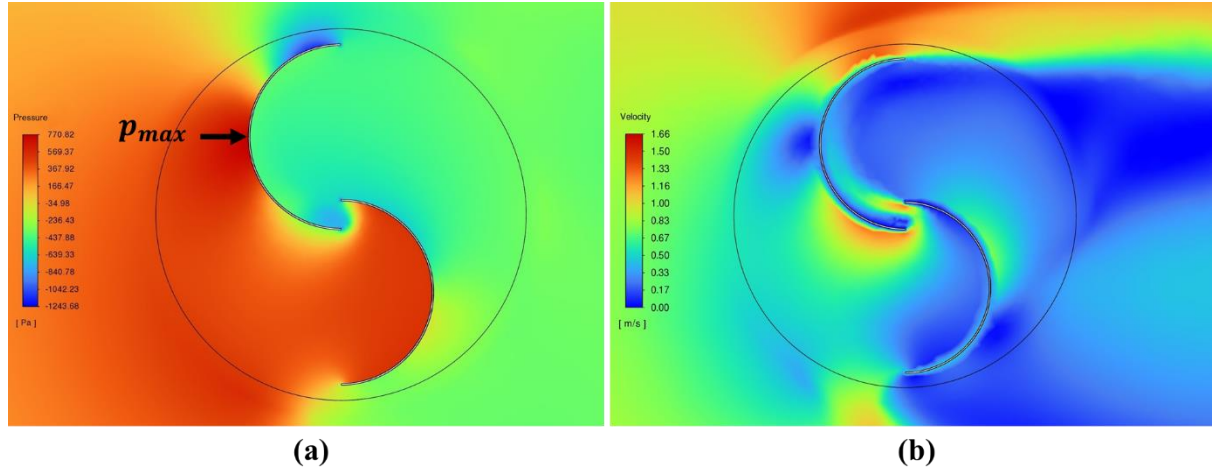


Fig. 6. Numerical results of SHKT (a) Pressure contour and (b) velocity contour.

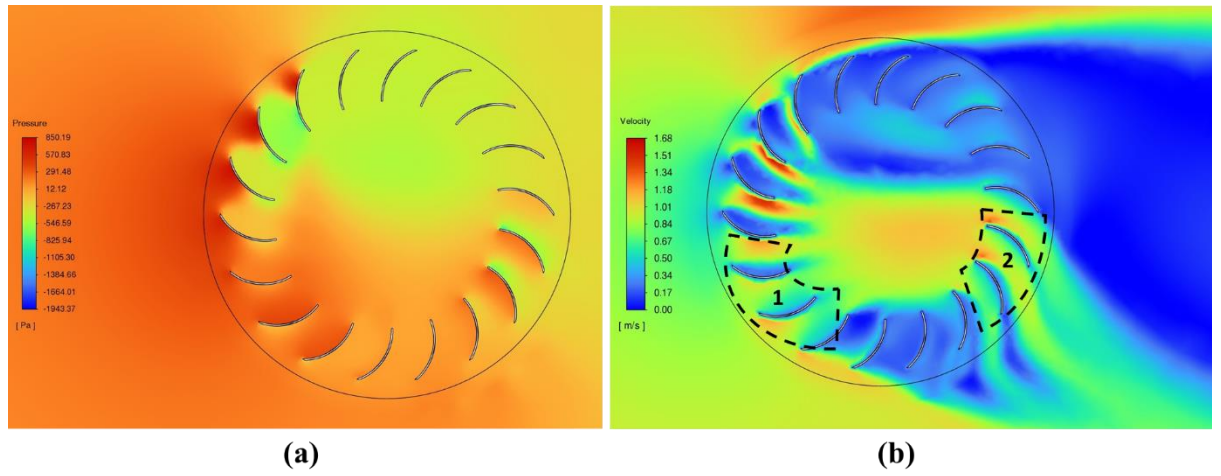


Fig. 7. Numerical results of MBHKT (a) Pressure contour and (b) velocity contour.

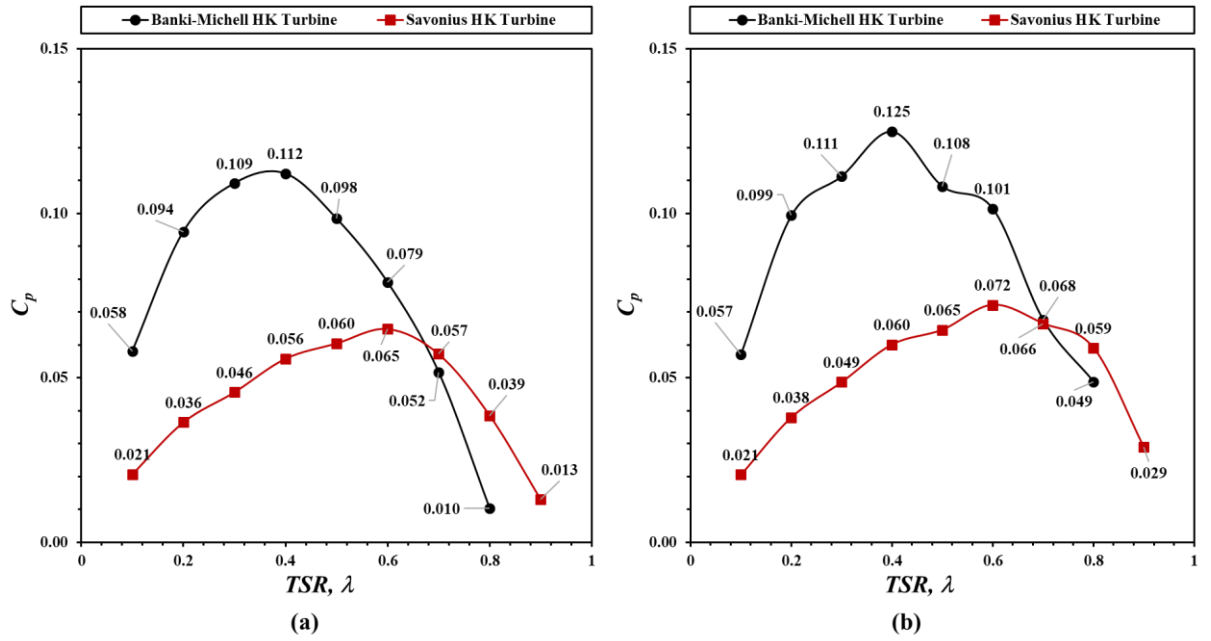
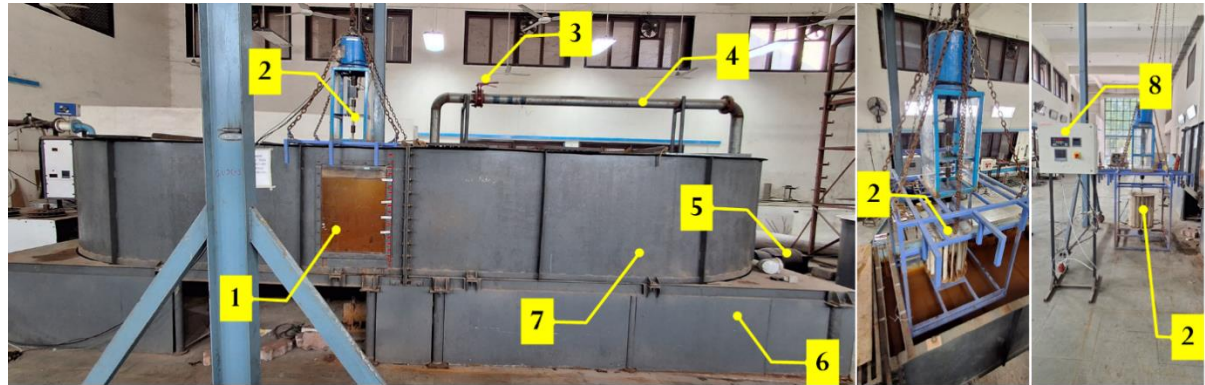


Fig. 8. Variation of C_p with TSR for all the HKTs at (a) $U_m = 0.42$ m/s and (b) $U_m = 1.06$ m/s.

7. Experimental and Numerical Study of MBHKT in Open Channel

Experiments of MBHKT were performed at open channel testing facility at Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India as shown in Fig. 9.



Part No.	Part Name	Part No.	Part Name
1	Glass window for turbine visual	5	Assembly of motor and Centrifugal pump
2	Turbine setup	6	Base of the setup
3	Flow Control Valve	7	Open channel
4	Delivery Pipe	8	Control panel

Fig. 9. An open channel testing facility Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India

Based on the experimental study, the $C_{P,max}$ obtained are 0.185 at 1.03 TSR, 0.152 at 1.08 TSR, and 0.143 at 0.79 TSR, of 100%, 75% and 50% immersion, respectively, as shown in Fig. 10.

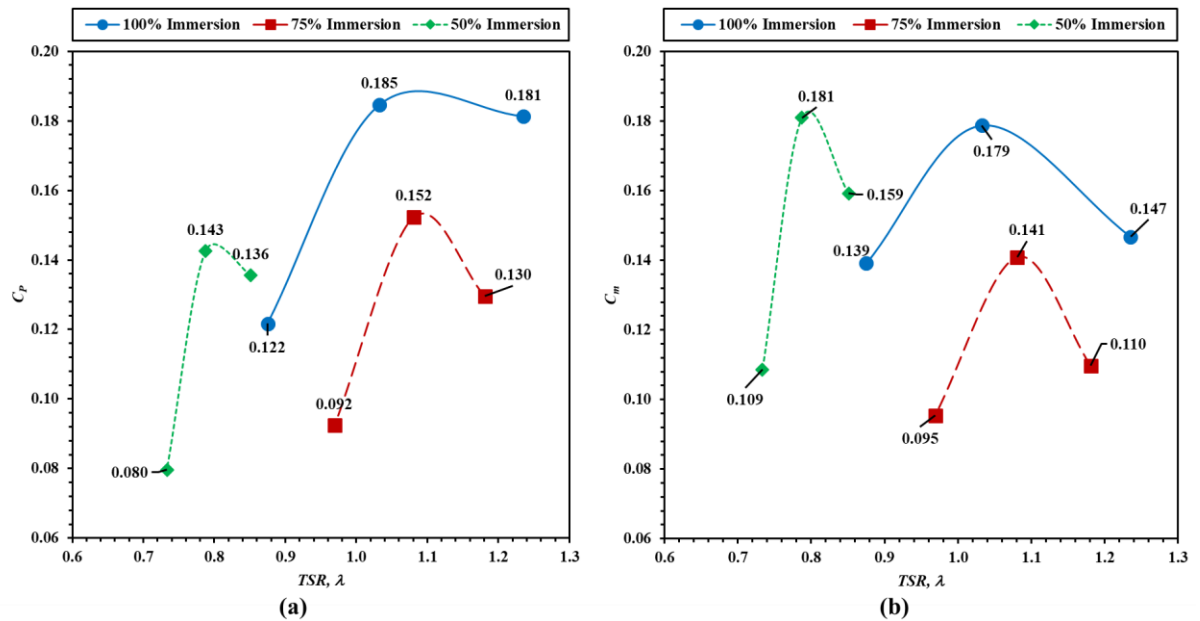


Fig. 10. (a) C_p vs. TSR and (b) C_m vs. TSR for all three submergence cases.

8. Numerical Investigation of MBHKT for Various Blade Profiles and Augmentation systems in Open Channel

Fig. 11 (a) & (b) show the results of this numerical study, the sharp-edged blade profile is better performance across the different free stream velocities, achieving the $C_{P,max}$ of 0.252 at 1.03 TSR. Furthermore, the $C_{P,max}$ of flat blade profile and round blade profile are found to be 0.192 and 0.10 at a tip speed ratio of 1.03 respectively.

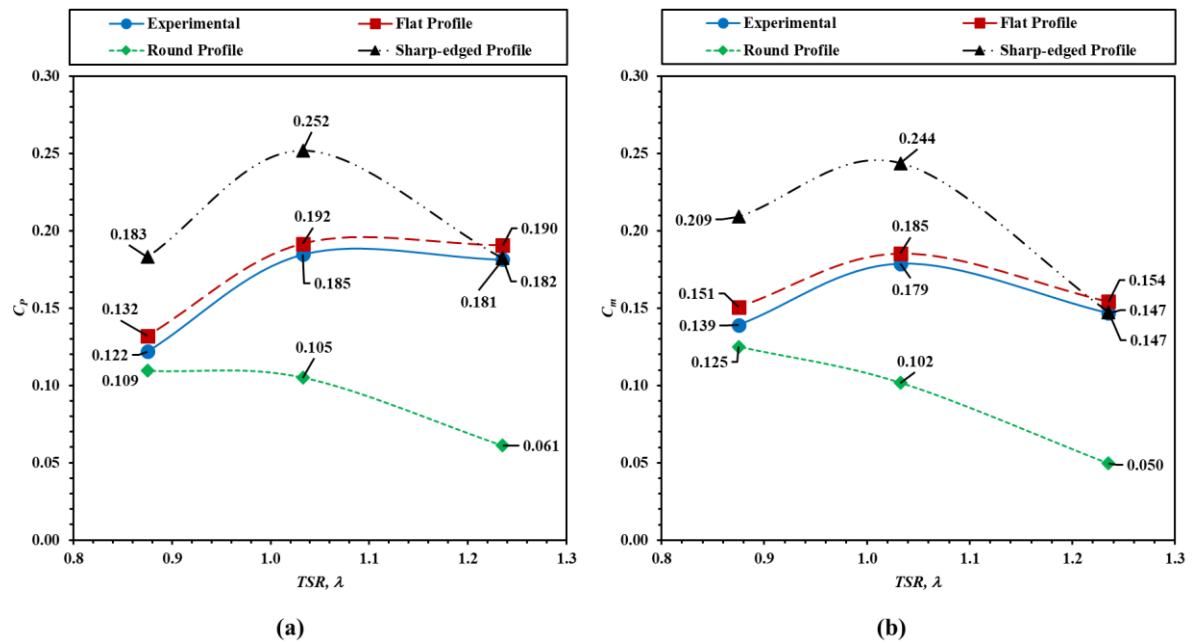


Fig. 11 (a) C_p vs. TSR and (b) C_m vs. TSR for various blade profiles.

In the last stage of this research work, four different augmentation designs were selected for optimizing the MBHKT with the various combinations of nozzle and diffuser as shown in Fig. 12.

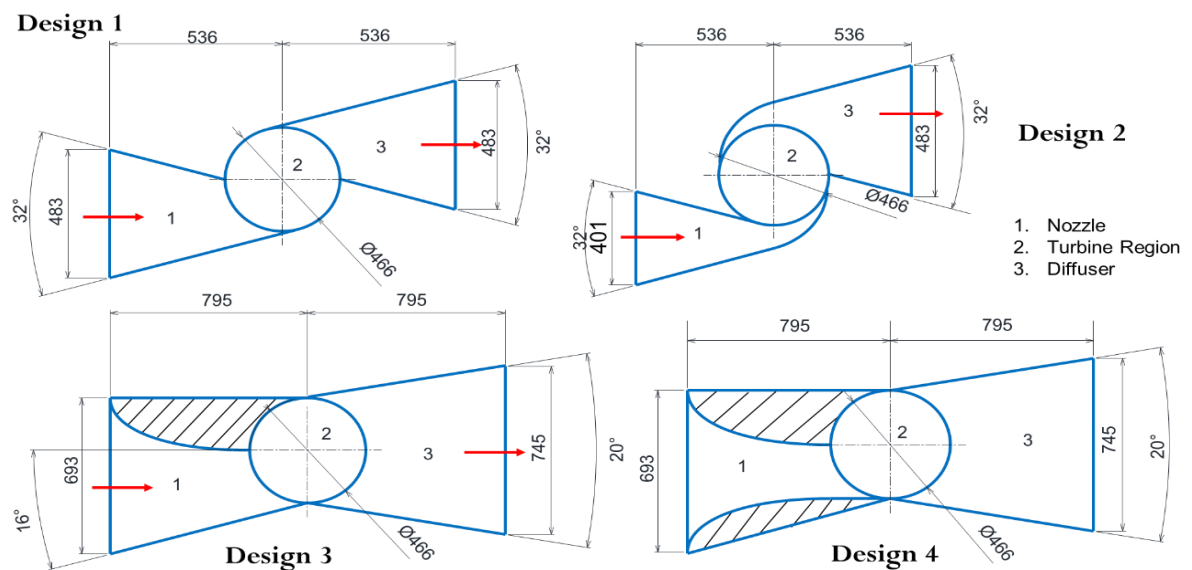


Fig. 12. Augmentation designs for MBHKT.

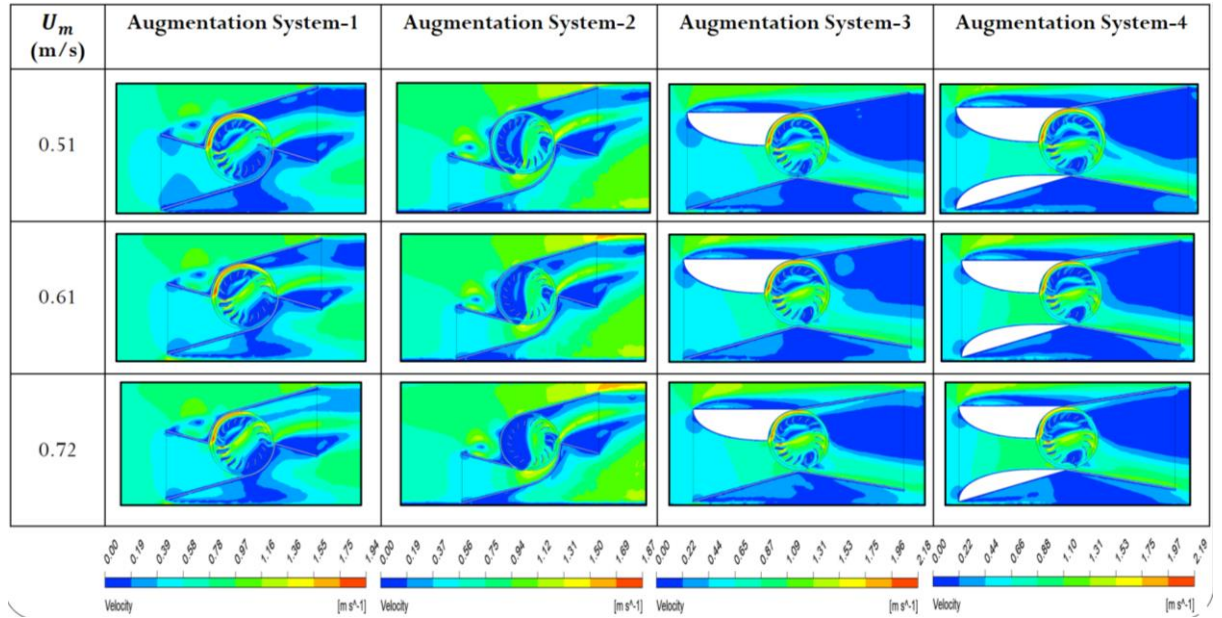
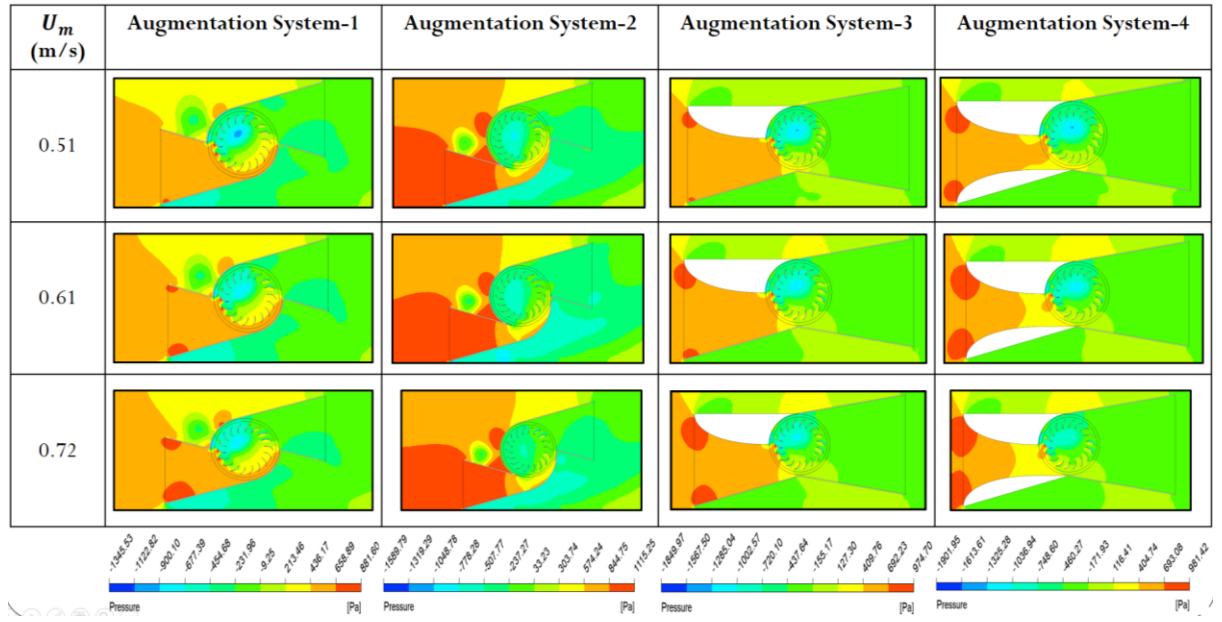


Fig. 13. (a) Pressure contours and (b) velocity contours for various augmentation designs.

The numerical simulation of various augmentations was done to find out how the designs will behave using MBHKT. The pressure contours and velocity contours of all the designs is shown in Fig. 13 (a) and (b), while the variation in C_p and C_m along the different TSR is depicted in Fig. 14 (a) & (b). The C_{pmax} of augmentation system-3 with sharp-edged blade profile was found 0.552 at 1.03 TSR. Also, performance of the MBHKT with augmentation system-3 was 2.2 times higher that of the without augmentation. The C_{pmax} of augmentation system-1, augmentation system-2 & augmentation system-4 was found to be 0.418, 0.525 & 0.531 at 1.03 TSR.

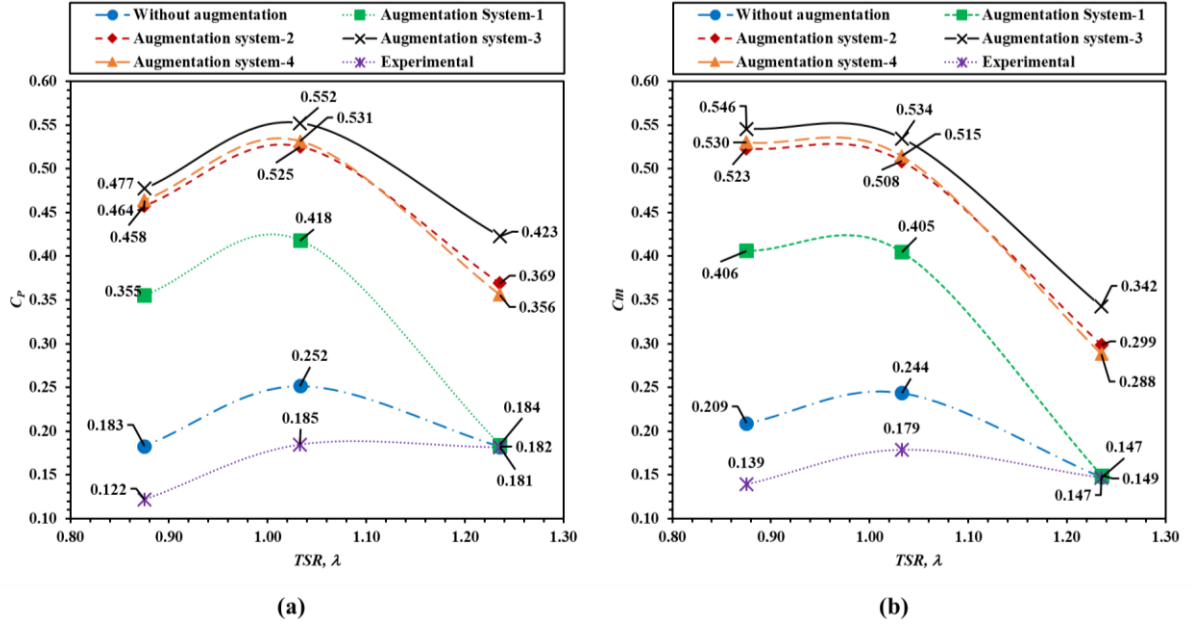


Fig. 14. (a) C_P vs. TSR and (b) C_m vs. TSR for various augmentation systems.

9. Conclusion

The concluding remarks of the current study are as follows:

- The area with the most potential for HKT installation is found by experimental and numerical study of canal flow.
- Based on the numerical investigation of various HKTs, performance of MBHKT is better than that of SHKT at same TSR value. SHKT and MBHKT are operated at a low tip speed ratio. the maximum power coefficient obtained is 0.065 and 0.072 at 0.6 TSR for SHKT; and 0.112 and 0.125 at 0.4 TSR for MBHKT, respectively for a velocity of 0.42 m/s and 1.06 m/s.
- According to experimental study, the maximum power coefficient of MBHKT is found to be 0.185 at 1.03 TSR, 0.152 at 1.08 TSR, and 0.143 at 0.79 TSR for 100% immersion, 75% immersion, and 50% immersion, respectively.
- The results of this numerical study showed that the sharp-edged blade profile is better performance across the different free stream velocities, achieving the maximum power coefficient of 0.252 at 1.03 TSR.
- The maximum power coefficient of augmentation system-3 with sharp-edged blade profile was found 0.552 at 1.03 TSR. Also, performance of the MBHKT with augmentation system-3 was 2.2 times higher that of the without augmentation.

10. Scope of the Future Work

Future work is recommended to focus on the cascading system. For example, one tested the Ukai Left Bank Canal, where the 1 kW unit can be selected, and in order to plan for generation, the higher energy can be arranged in an array manner, i.e., a hydro farm, as shown in Fig. 15.

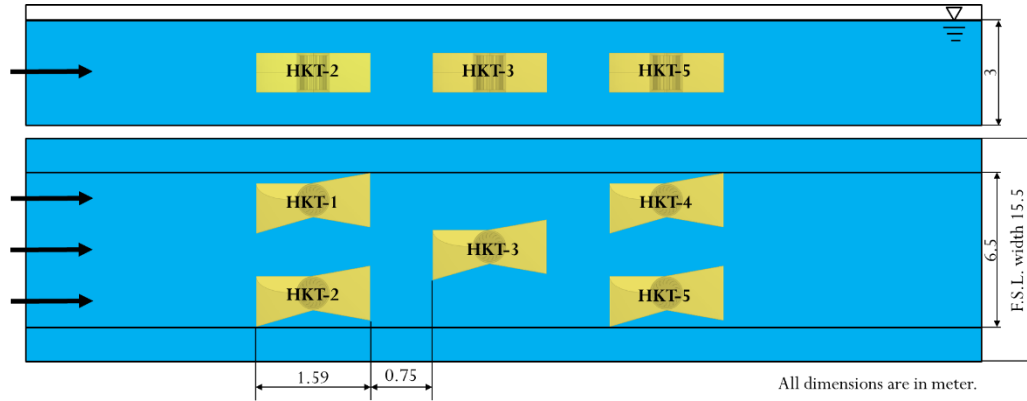


Fig. 15. Hydro-farm

11. Achievements with respect to Objectives

1. **Amit U. Mehta** and Pankaj P. Gohil, “Performance analysis of Savonius Hydrokinetic Turbine in Open Channel”, Multidisciplinary, Scientific Work and Management Journal, Volume 36 (1), pp. 4650-4655, 2026. **[Scopus Index]**
2. **Amit U. Mehta** and Pankaj P. Gohil, “Survey of India's Small Hydro Power Plants Using Hydro Turbines”, Journal of Research in Engineering and Applied Sciences, Volume 11 (01), pp. 1-9, 2026.
3. Pankaj P. Gohil, Vimal K. Patel, **Amit U. Mehta**, “Computationally Investigate Low Velocity Hydrokinetic Turbines with Variant Systems”, Journal of Applied Fluid Mechanics, Volume 18 (3), pp. 769-786, 2024. **[SCIE Index]**
4. **Amit U. Mehta** and Pankaj P. Gohil, “A Comparative Study of Turbulence Models in A Trapezoidal Open Channel for Potential Turbine Installation Site Selection”, ISH Journal of Hydraulic Engineering. **[Under Review] [ESCI Index]**
5. Dr. Pankajkumar P. Gohil and **Amit U. Mehta**, “Twin Supportive Area Box Type Telescopic Water Current Meter Structure”, Design Patent No.:357333-001, Dt: 16/03/2023, the Patent Office, Government of India. **[Design Patent]**
6. Dr. Pankajkumar P. Gohil and **Amit U. Mehta**, Water Current Meter Structure, Design Patent No.:357334-001, Dt: 07/06/2023, the Patent Office, Government of India. **[Design Patent]**

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