Jurnal Teknologi

Full paper

A Review on Micro Hydro Gravitational Vortex Power and Turbine Systems

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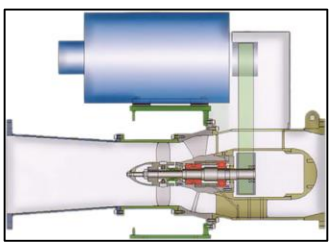
Article history

Received :22 February 2014
Received in revised form :
3 March 2014
Accepted :25 May 2014

Graphical abstract



Abstract

Electrical power is essential in commercial and social investments like lighting, heating, communications, computers, industrial equipment, transport etc. Therefore hydropower energy is one of the most suitable and efficient source of renewable energy which depends on more than century of experience for this issue. The power capacity and facility are two criteria required for the classification of hydropower plant. The first one consists of five technologies: dammed reservoir, run of river, pumped storage, in stream technology and new technology gravitational vortex. The other one is classified according to power scale is Large, Small, Micro and Pico Hydropower. This paper is focusing on micro hydropower especially gravitational vortex power which increases the sustainability and health of the water as a whole. It presents an overview from both flow and power points of view by discussing the free surface vortex (FSV) and the suitable turbine systems which are used in micro hydropower.

Keywords: Micro hydropower; FSV; turbines

1.0 INTRODUCTION

Nowadays, the awareness about the importance of a sustainable environment is increasing, it has been recognized that traditional dependence on fossil fuel extracts a heavy cost from the environment. The role of renewable energy has been recognized as great significance for the global environmental concerns. Hydro-power is a good example of renewable energy and its potential application to future power generation cannot be underestimated [1]. The concept of micro hydropower system is promising technology in renewable energy. Micro hydro power systems are capable of generating electricity up to a capacity of 100 kW [2]. The energy in rural, remote and hilly areas is inadequate, poor and unreliable supply of energy services, micro hydropower able to provide rural area where grid extension is too costly and consumers have low incomes [3] [4]. In general Hydropower plants produce no air emissions but in most cases affect the water quality, wildlife habitats and especially prevent the fish migration [5], gravitational water vortex power system which classified as micro hydropower can provide a solution for this environmental problem, it is a horizontal form of the hydroelectric dam. The benefits of using an artificially induced vortex above gravity- accelerated water increases efficiency, decreases cost, and not only lowers the negative impact on the environment, but actually increases the sustainability and health of the river as a whole . Gravitational water vortex power system is one kind of the Free Surface Vortex (FSV) which is an important phenomenon in the field of hydraulic engineering [6]. Micro turbines have a growing interest because of its small and simple structure, as well as a high possibility of using in micro and small hydropower applications [7].

2.0 FREE SURFACE VORTEX

The Free Surface Vortex is an important phenomenon in the field of hydraulic engineering. It can be considered as a harmful or useful source according to its location. Many researchers studied this phenomenon in terms of factors affecting its strength or describing its structure and location, whether to eliminate or to strengthen it. So literature in the following section is reviewed according to FSV usefulness or harmfulness or disregarding to its influence.

2.1 FSV Structure Disregarding to Its Influence

Reference [8] Used PIV and numerical simulation to predict position & structure of FSV, his numerical simulation agreed with the experiments. But he didn’t consider the influencing factors on FSV as shown in Figure 1.

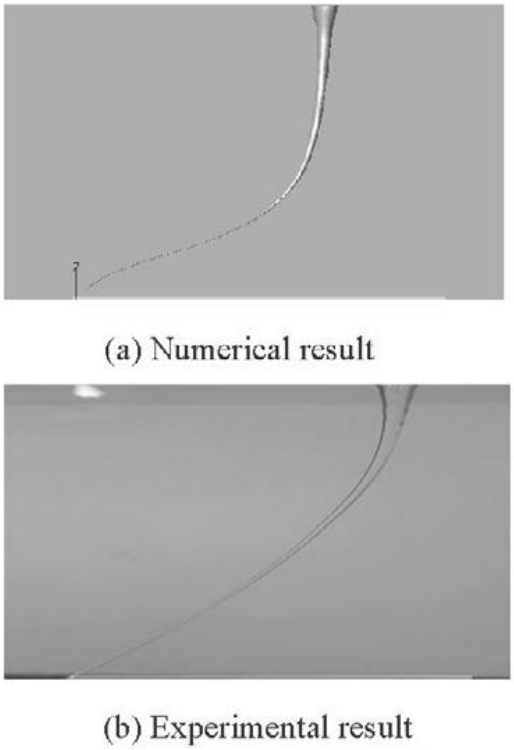


Figure 1 Numerical and experimental result [8]

After that in 2009 in another paper [9] he used VFM based on NS eqs. & CF effect to investigate the FSV formation. His results showed that the major factor in forming FSV is the Coriolis force. Jeong 2012 [10] did an analytical analysis of Free Surface shape using stokes' approximation, taking surface tension effect into account. However, the effects of gravity, air (the second fluid outside) near the surface, unsteadiness, variable surface tension are not considered.

2.2 FSV as a Harmful Source:

For example at hydraulic intakes research as in [11] explored the hydraulic characteristics of the vertical vortex flow using the improved formulae for three velocity components of the vertical vortex flow were deduced by using the method of separation of variables. Furthermore, he investigated an effective numerical model for simulating vertical vortex showing that RNG k-ε model is more suitable than standard k-ε model to the rapidly strained and great curving streamline flows. From other side, reference [12] considered hydrodynamic properties of FSV, derived three new formulations based on NS eqs. One of them showed good agreement with experiments, and he also used PTV instead of PIV to measure velocity fields. Further investigation done by Ref. [12] to improve the formulae accuracy. Reference [13] simulated a vortex in a small chamber in order to understand and to predict the surface vortex numerically. His results indicated that the SAS-CC turbulence model could be a good choice for a simulation of a pump intake. Finally, ref. [14] studied the free-surface vortex to provide some theoretical proposals and to get the mechanism of circulation propagation and vortex formation.

Not only FSV has been studied but also anti-vortex devices are used to eliminate its bad effect as in [15] who presented a new funnel-shaped device whose performance is proved experimentally to be successful. In the Mold Casting field, "Ref". [16] conducted a water model experiment to observe the vortexing flow in the steel slab continuous casting mold, he also developed numerical model to analyze the vortexing flow. Also he developed a mathematical model to understand the vortex flow in the thin slab continuous casting mold associated with the effect of electromagnetic brake [17].

Chemical engineering specially hydrocyclone harmfully influenced by vortex formation, since Gupta 2008 [18] did experiments and CFD-modelling for different inlet flow rate in presence as well as in absence of gas-core to qualify the pressure drop characteristics of the hydrocyclone . Moreover, Evans 2008 [19] performed simulations of the flow within the solid–liquid hydrocyclone operating with an air core and with an inserted metal rod using Finite-volume method and Reynolds stresses model (RSM) to model the turbulence characteristic of the flow.

Liquid Propulsion System also is an important field which is highly affected by FSV, so Basu 2013 [20] carried out simulations using Volume of fluid method to investigate air- core vortex formation, and finally his validation done from literature results.

Finally, based on the Navier-Stokes equations and LES (large-eddy simulation) model, Zeng 2012 [21] calculated the three-dimensional unsteady turbulent flow in the draft tube of a Francis turbine using SIMPLE algorithm with the help of FLUENT software. He used PIV in measuring the flow field distribution. The results obtained from numerical simulations agree with the experimental results.

2.3 FSV as a Useful Source

In the field of petroleum separation as in reference [22] who presented a method for oil separation based on vortex separation technique. He developed a numerical solution using flexPDE software for geometrical dimensions of waste recovery system, and determined the movement of the free surface shape of the formed funnel, spectrum movement, and velocity distribution [22].

Also chemical engineering and processing field depends on FSV in mixing fluids. In this trend Glover 2007 [23] presented a numerical model of vortex formation in an unbaffled stirred tank reactor. Preliminary results of a second investigation into the effect of liquid phase properties of the vortex formed are also presented. Furthermore, Ref. [24] offered measurements using a laser dopplervelocimetry, and numerical simulations using ANSYS CFX of turbulent flows with free-surface vortex in an unbaffled reactor agitated by a cylindrical magnetic stirrer. The predicted general shape of the liquid free-surface agreed with measurements, While the vortex depth couldn't be predicted.

At last in the field of renewable energy, not only electric energy can be generated from FSV but alsowater can be aerated and a considerable amount of oxygen can be introduced to living energy to generate electric power. Therefore future study will investigate the optimization of the vortex pool of this geometry to determine the specifications of a gravitational water vortex pool prototype [6].

■3.0 MICRO HYDROPOWER TURBINES SYSTEMS

Micro hydro turbines have a rapid response for power generation and so the power may be used to supply both base load and peak demand requirements on a grid supply. Power generation efficiencies may be as high as 90% [25]. Water turbines generate very reliable power with very simple designs, turbines are of two types: impulse and reaction turbines, each suitable for different types of water flow, Figure 2 shows the various types of hydropower turbines.

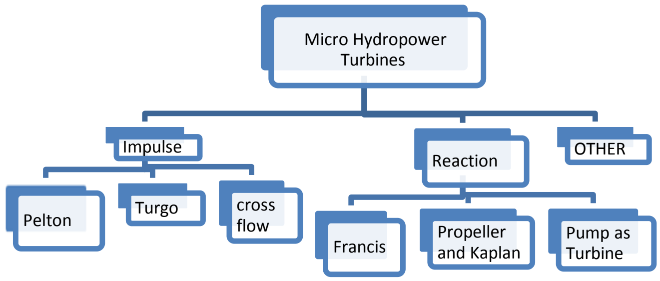


Figure 2 Micro hydropower turbines classification

3.1.1 Turgo Turbines

By 1920 Gilbert Gilkes Ltd invented Turgo turbine (Figure 3) [27]. They are commonly used as high and medium head impulse turbines [28], recently they can be used for all head categories, Energy Systems & Design Ltd. [29] produces a Turgo turbine stream engine which can be operated between 3 and 150 m head. S.J. Williamson *et al.* [27] developed model of a single-jet Turgo turbine at low heads of 3.5 m down to 1 m to improve the design and set up the parameters. The Turgo can handle significantly higher water flow rates [30] [31], allowing for efficient operation in lower head ranges because it can generate significant power by using more water with less head [30] [32].

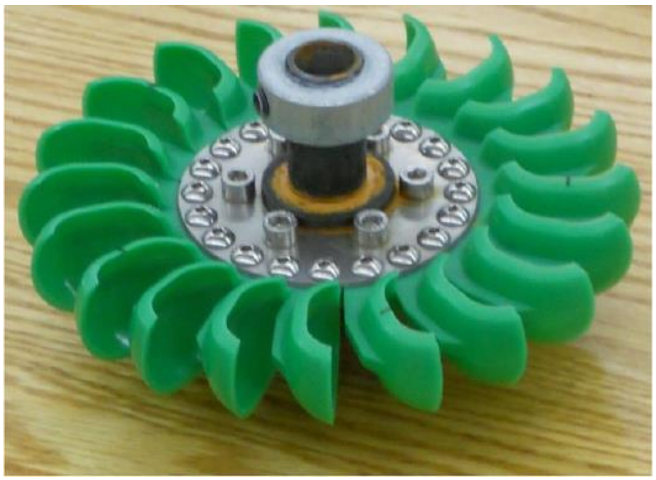


Figure 3 Turgo turbine [27]

3.1.2 Pelton Turbines

In a Pelton turbine as shown in Figure (4), water jets from nozzles strike cups or buckets arranged on a circumference of a runner or wheel, causing the wheel to rotate [32] [33]. A Pelton wheel has one or multi free jets. Pelton turbines are suited for high head, low flow applications, recently Pelton turbines can also be used for small and Micro hydropower systems. [33] [34] [35]. For these systems, a single water jet is typically used [32].

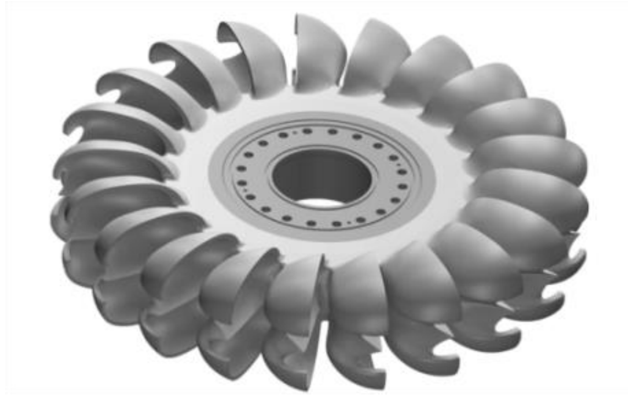


Figure 4 The original design of Pelton wheel [32]

3.1.3 Cross Flow Turbines

A cross-flow turbine is designed by Ossberger Co, so it known as an Ossberger turbine, is shaped like a drum and uses an extended, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner [34]. The cross-flow turbine allows the water to flow through the blades twice. During the first pass, water flows from the outside of the blades to the inside; the second pass is from the inside back out. These types of turbines can be used both in horizontal and vertical orientations (Figure 5). These turbines can familiar with micro hydro, higher water flow and lower head than the Pelton turbine [34] [36] [37].

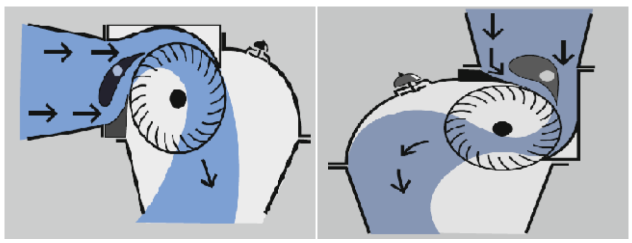


Figure 5 Inflow in horizontal and vertical orientations [36]

3.2 Reaction Turbines

Reaction Turbines have a better performance in low head and high flow sites. They have not nozzles, the blades project radially from the periphery of the runner are formed and mounted so that the spaces between the blades have, in cross section, the shape of nozzles [26] [34]. A reaction turbine generates power from the combined action of pressure and moving water [34] .In the slow operating speed, the efficiency of reaction turbines is better than the impulse turbines [26]. Also Reaction turbines are generally preferred over impulse turbines when a lower head but higher flow is available [33] [34].

3.2.1 Francis Turbines

A Francis turbine has a runner with fixed buckets (vanes), usually nine or more. Water is introduced just above the runner and all around it and then falls through, causing it to spin [34] [38]. Besides the runner, the other major components are a scroll case, wicket gates, and a draft tube The cross-sectional view of a Francis turbine is shown in (Figure 6) .The Francis turbines have a good performance for micro hydropower sites [38] [39] [40].

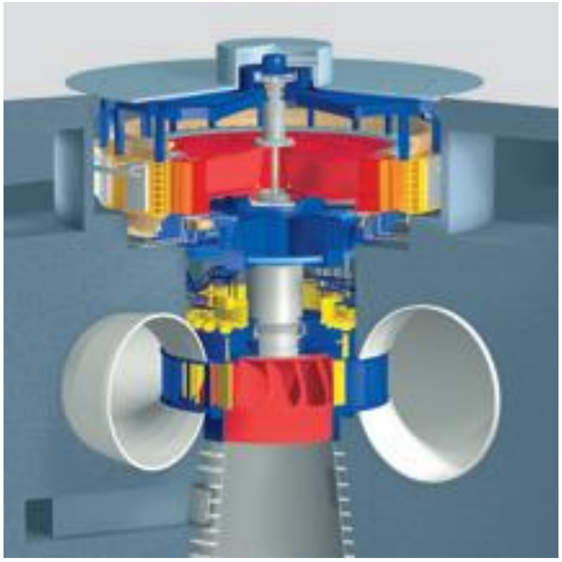


Figure 6 Cross section of a Francis turbine [38]

3.2.2 Axial Flow Turbines "Propeller and Kaplan Turbines"

Most of the reaction turbines are a propeller type turbine. A propeller turbine generally has a runner with three to six blades in which water impinges continuously at a constant rate. The pitch of the blades may be fixed or adjustable. The major components besides the runner are a scroll case, wicket gates, and a draft tube see (Figure 7) [34]. The propeller turbine design was originally motivated by the need to develop high specific speed machines for use in relatively low head situations where it would be uneconomic to use a Francis turbine [41].

Viktor Kaplan (1876-1934), an Austrian engineer, realized that changing the pitch of the blades could make a turbine with a greater range of applicability. In 1913, Kaplan designed a variable pitch propeller turbine, the Kaplan turbine. Since that time, the operating head of the Kaplan turbine has been increased, and smaller Kaplan turbines have been used for heads as high as 65 m. The Kaplan turbine runner is hydraulically similar to the propeller turbine runner except that the hub is larger to accommodate the mechanism for blade angle shifting. The servomotor to accomplish this is located in the hub in some designs [33] [34]. References [42] [43] [44] presented an axial hydro turbine with low heads micro potential flow ranged from 1 m to 5 m.

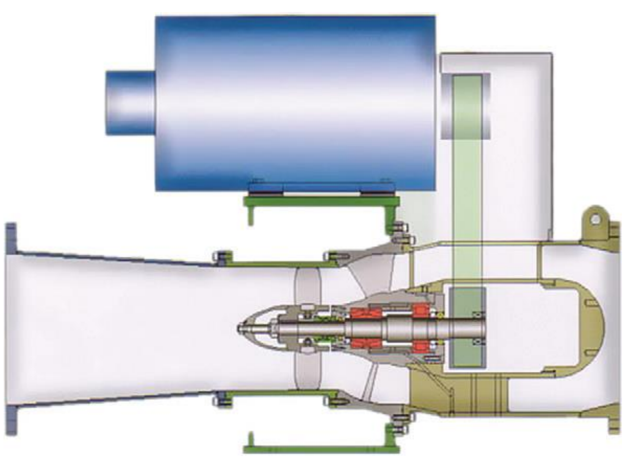


Figure 7 The Propeller turbine [46]

3.2.3 Pump as Turbine (PAT)

In pumping mode, the fluid enters at suction side of pump at low pressure and gets energized by the impeller, which is rotated by some external means, and leaves the casing at high pressure. Whereas in case of PAT in (Figure 8), the pump rotates in reverse direction, water enters in the pump at very high pressure from the casing and moves through the impeller blades and releases its pressure and kinetic energy to the impeller shaft as mechanical energy and fluid comes out from the eye of pump at low pressure [46] [47].

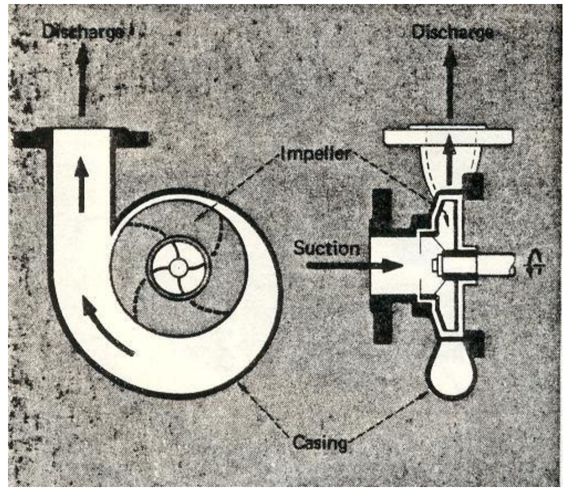


Figure 8 Radial flow pump as hydraulic turbine [47]

The research on using PAT started around 1930 and the main challenge in PAT usage was the selection of a proper PAT for a small and Micro hydro-site [48]. The main problem of using a pump as turbine is still the difficulty of predicting accurately the turbine performance, pump manufacturers do not normally provide the characteristic curves of their pumps working as turbines [48]. Hence references [46] [48] [49] [50] [51] presented methods to predict the performance of PAT which based on the data for pump performance at best efficiency a wide range of results.

3.2.4 Other Reaction Turbines

Barker's Mill

Barker's mill, which is shown diagrammatically in (Figure 9), was the first hydraulic reaction turbine and was invented in about 1740 and this machine was further refined by Pupil in 1775 and Whitelaw in 1839 .One refinement of this turbine is to feed the water into the underside of the rotor. By feeding water into the turbine from underneath, the upward action of the static pressure of the entering feed water may be used to counteract the downward gravitational force on the moving parts thereby reducing the thrust load on the bearings supporting the moving parts [52].

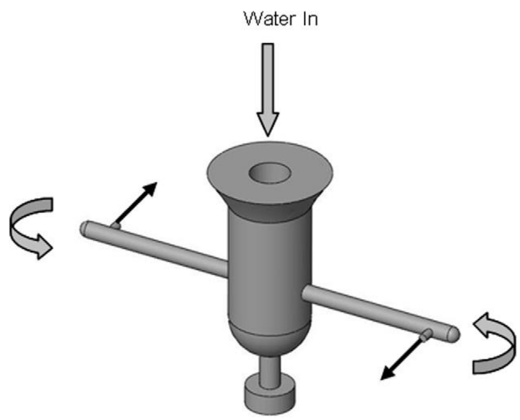


Figure 9 Barker's Mill [52].

Split Pipe Turbine

The idea of split pipe reaction turbine is influenced by the ''Savonius wind rotor''. The split pipe reaction turbine as shown in (Figure 10) is manufactured by cutting a plastic pipe into two halves and then off-set the centers and joints the top and bottom plates [53]. Reference [53] [54] presented the performance characteristics of a simple Split reaction hydro turbine for power generation.

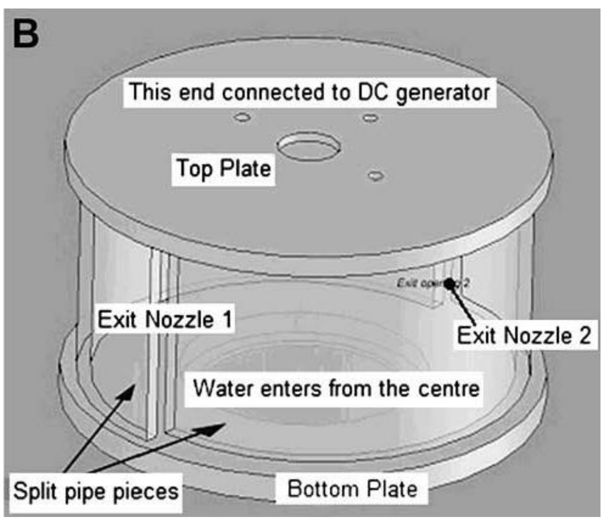


Figure 10 Split pipe reaction turbine [53]

3.3 Other Micro Hydro Turbines Types

3.3.1 Counter-Rotating Tubular Turbine

Counter-rotating tubular type micro-turbine as shown in (Figure 11) contains front runner connected to the generator stator and the rear runner connected to the generator rotor. The performance of the system is investigated experimentally and numerically in reference [55].

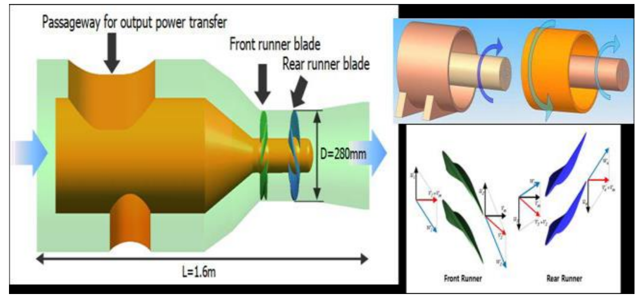


Figure 11 Schematic of the counter-rotating turbine [55]

3.3.2 Screw Turbine

The highly efficient Archimedean screw has been "re-invented" to generate electricity all year round at 24 hours per day, whilst obtaining the natural flow of the river, in combination with its natural fish friendliness and a small fish trap it is one of the few systems that is able to maintain or even improve the wildlife in and around the river. The hydropower screw turns the principle of pumping around, maintaining the advantages and generating energy using the falling water to drive the screw as shown in (Figure 12) [5].

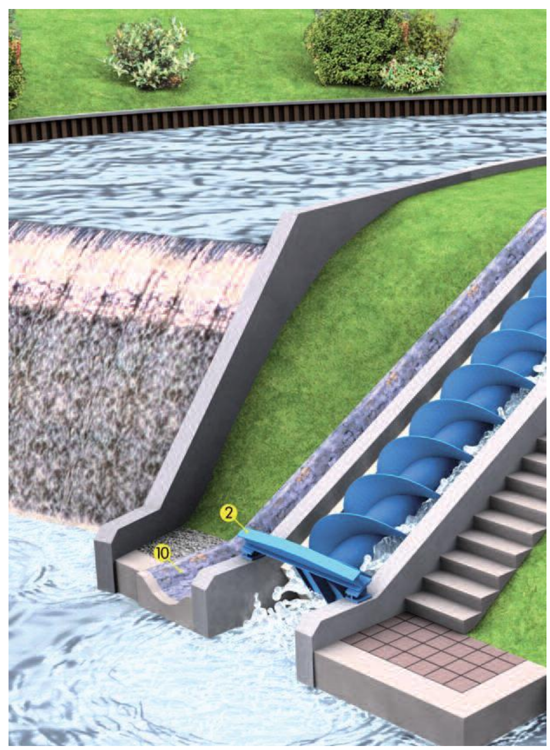


Figure 12 Screw turbine [5]

4.0 CONCLUSION

This article focused on FSV as a hydraulic phenomenon and its applications in engineering fields especially for micro hydropower sites; it indicated that FSV is a corner stone of the gravitational water vortex power plant which is achieved great significance for the global environmental concerns. On the other hand, this paper showed various types of micro hydropower turbines; it presented a general description of micro hydropower turbines systems and there various components and performance. From the above study, it can be provided a guideline to reach about the suitable turbine system which can be used in the different micro hydropower projects.

Acknowledgement

The authors would like to express our sincere gratitude to UniversitiTeknologi Malaysia (UTM) who assist and provide in the data compilation for this publication.

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