FLOW VISUALIZATION STUDY OF WATER TUNNEL FOR MICRO-HYDROKINETIC TURBINE APPLICATION

TEO CHEN LUNG

SCHOOL OF AEROSPACE ENGINEERING
UNIVERSITI SAINS MALAYSIA

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FLOW VISUALIZATION STUDY OF WATER TUNNEL FOR MICRO-HYDROKINETIC TURBINE APPLICATION

by

TEO CHEN LUNG

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ENDORSEMENT

I, Teo Chen Lung, hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

(Signature of Student)

Date:

(Signature of Supervisor)

Name:

Date:

(Signature of Examiner)

Name:

Date:

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date:

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FLOW VISUALIZATION STUDY OF WATER TUNNEL FOR MICRO-HYDROKINETIC TURBINE APPLICATION

ABSTRACT

The use of flow visualization often plays a defining role in the understanding of many fluid flow problems. The purpose of this research is to establish an experimental set-up for flow visualization study of micro-hydrokinetic turbine in water tunnel and to investigate the flow behaviour around a micro-hydrokinetic turbine. Dye injection method was used as the flow visualization technique in this research. The dye mixtures consisted of dye with water, dye with milk, dye with ethanol, and milk. Each mixture has different ratio combination, the combination of ratio tested were 1:9, 3:7 and 5:5 for dye-water; 1:5:4, 3:3:4 and 5:1:4 for dye-water-milk; 3:6:1 and 3:6.5:0.5 for dye-water-ethanol. All these solutions were being investigated in different flow regimes such as the static flow, and dynamic flow at 46rpm, 176rpm, and 864rpm. These mixtures were tested and analysed in terms of clarity of the image and video taken, rate of dispersion in water, and the flow path line of the dye upon released from the dye ejector to find out the best type of mixture and combination ratios in different flow regimes. The experimental set-up is a simple, low-cost, and feasible set-up with the aid of the gravity-feed system. The experimental set-up was performed on a water tunnel with a savonius turbine. A savonius turbine model for hydrokinetic application was placed in the test section of the water tunnel to visualize and study the flow behaviour around the model. Dye-water (3:7) added with alcohol (ethanol) gives the best solution for flow visualization study in static flow. The alcohol (ethanol) added gives a straight path line to the dye so that successful interpretation of fluid flow can be performed accurately. While milk, dye-water, and dye-water-milk mixtures showed a downward curve movement once ejected from the ejector

due to their density being higher than water, in other words, they are not neutrally buoyant. Thus, a straight path line could not be obtained, which concluded that they were not applicable in the static flow condition. In dynamic flow at 46rpm, dye-water (1:9) gives the best clarity in terms of flow pattern observation around the turbine. It did not dissolve quickly at this speed and there was no concentrated spot in the dye region. However, the turbine has to be placed closer to the ejector (6cm) to get a straight dye path line. In dynamic flow at 176rpm, all dye solutions without milk started to dissolve quickly once ejected. The dye-water-milk (3:3:4) was the best solution because milk prolonged the diffusion of dye at this speed, keeping the flow pattern visible by retaining the dye traces in the water, the fat content in the milk helps to retard the diffusion of dye. In dynamic high-speed flow at 864rpm, the effect of milk in prolonging the diffusion of dye became more significant, the best solution was dye-water-milk (5:1:4). Hence, all types of mixtures behave differently in different flow regime. Some mixture might perform well in certain flow regime, but not necessary the other.

KAJIAN VISUALISASI ALIRAN TEROWONG AIR UNTUK APLIKASI TURBIN HYDROKINETIK

ABSTRAK

Penggunaan visualisasi aliran sering memainkan peranan penting dalam memahami masalah aliran bendalir. Tujuan penyelidikan ini adalah untuk menubuhkan satu kajian eksperimen bagi kajian visualisasi aliran turbin mikro hidrokinetik dalam terowong air dan untuk mengkaji kelakuan aliran di sekitar turbin mikro hidrokinetik. Kaedah suntikan pewarna digunakan sebagai teknik visualisasi aliran dalam kajian ini. Campuran pewarna terdiri daripada pewarna dengan air, pewarna dengan susu, pewarna dengan etanol, dan susu sahaja. Kombinasi nisbah yang digunakan untuk setiap campuran adalah berbeza, gabungan nisbah yang diuji ialah 1: 9, 3: 7 dan 5: 5 untuk pewarna-air; 1: 5: 4, 3: 3: 4 dan 5: 1: 4 untuk pewarna-air-susu; 3: 6: 1 dan 3: 6.5: 0.5 untuk pewarna-air-etanol. Semua campuran pewarna ini diuji dalam keadaan aliran yang berbeza seperti aliran statik, dan aliran dinamik pada 46rpm, 176rpm, dan 864rpm. Cara persediaan eksperimen adalah mudah dan kos-rendah, pengaliran campuran pewarna dari tangki pewarna ke tiub peluntur dibantu oleh sistem graviti. Eksperimen dijalankan dalam terowong air yang mempunyai dimensi bahagian ujian 0.25m × 0.25m × 0.85m (W × H × L), Model turbin air savonius untuk aplikasi hydrokinetic diletakkan di bahagian uji terowong air untuk kajian kelakuan aliran di sekitar model. Campuran pewarna-air (3: 7) dengan 10 titisan alkohol adalah campuran terbaik dalam keadaan aliran statik. Alkohol (etanol) menyebabkan laluan pewarna melintang dalam air supaya penafsiran medan aliran boleh dilakukan dengan tepat. Susu, pewarna-air, dan pewarna-air-susu menunjukkan pergerakan pewarna lengkung ke bawah apabila dikeluarkan daripada tiub peluntur kerana ketumpatannya lebih tinggi daripada air. Ini menyebabakan garis laluan lurus

pewarna tidak dapat diperolehi. Ini menyimpulkan bahawa jenis campuran pewarna ini tidak boleh digunakan dalam keadaan aliran statik. Dalam aliran dinamik pada 46rpm, pewarna-air (1: 9) memberikan imej yang jelas dari segi pemerhatian corak aliran sekitar turbin, campuran nisbah ini tidak larut dalam air dengan pantas, tetapi turbin perlu diletakkan dekat dengan tiub peluntur (6cm) untuk mendapatkan laluan pewarna yang menlintang. Dalam aliran dinamik pada 176 rpm, semua campuran pewarna tanpa susu larut dengan cepat apabila dikeluarkan ke dalam aliran air. Pewarna-air-susu (3: 3: 4) adalah campuran yang terbaik kerana susu memanjangkan penyebaran pewarna dan menyebabkan aliran pewaran kelihatan cerah dan jelas dengan mengekalkan trajektori pewarna di dalam air, kandungan lemak dalam susu membantu melambatkan penyebaran pewarna. Dalam aliran dinamik berkelajuan tinggi pada 864rpm, kesan susu dalam memanjangkan penyebaran pewarna menjadi lebih jelas, campuran pewarna yang terbaik ialah pewarna-air susu (5: 1: 4). Semua jenis campuran bersifat berbeza dalam rejim aliran yang berlainan. Sesetengah campuran mungkin berfungsi dengan baik dalam rejim aliran tertentu, tetapi tidak semestinya yang lain.

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CHAPTER 1
INTRODUCTION

1.1 Overview

According to United Nation, there are approximately 3 billion people who lack access to clean cooking solutions and slightly less than 1 billion people functioning without electricity. These people account for 13% of the global population (United Nation, 2018).Fortunately, progress has been made in the past decade regarding the use of renewable electricity from water, solar, and wind power (United Nation, 2018). It is crucial to promote clean and affordable energy so that the community on the outskirts as well as other remote areas that are left behind will get to experience a living standard that is in parity with the developed areas. According to the minister of Energy, Green Technology and Water, Datuk Seri Dr Maximus Johnity Ongkili, Malaysia is on its way to reaching the 50% renewable energy target by 2050, with current levels at around 21.70%. It is also stated that current efforts include hydro power and wave power generation (Kristy Inus, 2018). Hence, the government will encourage any activities that are in alignment with our vision to create a more efficient environment and at the same time to mitigate the huge difference between the standard of living between people in a country or region.

The renewable energy, especially hydropower, are a growing market facing the challenge to supply the world’s increasing electric power demand. Hydropower is one of the most important renewable energy sources, with an amount of 3402 billion kwh electricity generation in 2010, it is expected to increase about 83% from 2010 to the year 2040 (Ruopp et al., 2014). This technology seems to be promising for local electrical energy supply in developing countries such that an operation in isolated networks is possible. There are number of types of water resources from which it is possible to generate electricity from kinetic energy. Capturing the energy contained in near and off-shore waves is thought to have the greatest energy production potential amongst the hydrokinetic options. It is said that by extracting only 15% of the energy is US coastal waves would generate as much electricity as we currently produce at conventional hydroelectric dams. Other hydrokinetic options such as ocean currents, which result from winds and equatorial solar heating; free-flowing rivers, from which energy captured is possible without any intrusive dams; and even constructed waterways, such as irrigation canals. While stream-based hydrokinetic energy research is not as evolved as its wave energy counterpart, initial estimates expect these water resources could fulfill all of the electricity needs for an additional 23 million typical homes. Stream hydrokinetics could prove to be a particularly valuable resource for rural regions or regions with lower wind energy potential.

The technologies developed to generate energy from waves and currents, called hydrokinetic conversion devices, are generally categorized as either wave-energy converters (WECs) or rotating devices (Muratore, 2008). WECs utilize the motion of two or more bodies relative to each other, while rotating devices capture the kinetic energy of a flow of water, such as a tidal stream, ocean current or river, as it passes across a rotor. Rotating devices used in a stream-based hydrokinetic energy system look very similar to the wind turbines already in widespread use today. These devices are called hydrokinetic turbine, or micro-hydrokinetic turbine in a smaller scale. These turbines are placed in rivers, estuaries, or tidal flows to convert kinetic energy of moving water into electrical energy. Therefore, it is crucial to study the behavior of the river flow around the turbine before installing. The study of this flow behavior is known as fluid flow study.

Fluid flow is an important field of research. The areas in which fluid flow plays a role are numerous. Gaseous flows are studied for the development of cars, aircraft, spacecrafts, and for the design of machines such as engines and turbines (Post and Walsum, 1993). One of the methods used in fluid flow study is flow visualization. Flow visualization is an important part of fluid mechanics research, performing flow visualization can serve the first step toward more detailed flow analysis. Flow visualization can provide a quick, qualitative assessment of a new flow field, guiding initial concepts and the design of more detailed experiments. Some visualization techniques also provide detailed quantitative information. Unlike many velocity probes that provide information at only one point or along one line, flow visualization has the advantage of describing the entire flow field. For example, in unsteady flow, visualization can render details of the flow field far more quickly than a compilation of point-by-point measurements. Often the most effective scheme is to use flow visualization to describe the general characteristics of the field, and then to use select point measurements to provide detail.

Experimental flow visualization has been the main visualization aid in fluid flow research, experimental flow visualization techniques are applied for several reasons such as to get an impression on the flow behavior around a scale model of a real object, to aid in development and enhancement of fluid flow theories, as well as to verify a new theory or model (Post and Walsum, 1993). In experimental fluid dynamics, there are three methods used to visualize the flow such as surface flow visualization, particle tracer methods, and optical methods (Smits and Lim, 2012). Surface flow visualization reveals the flow streamlines in the limit as a solid surface is approached. For example, a colored oil applied to the surface of a wind tunnel model responds to the surface shear stress and forms pattern. In particle tracer methods, particles such as smoke, microspheres or dye can be added to a flow to trace the fluid motion. While in optical methods, some flows reveal their patterns by way of changes in their optical refractive index.

1.2 Motivation

People living in less developed areas such as Sabah, Sarawak, and other rural areas in Malaysia are having lower access to electrical energy compared to more developed areas. For instance, Peninsular Malaysia has almost 100% electrification, whereas in East Malaysia, Sabah and Sarawak electrification rates are decidedly lower, which is at 77% and 67% respectively (Rahim Abd et al., 2010). Hence, some of the regions in East Malaysia are facing inadequate amount of clean affordable energy. In response to this problem, one of the measures is to harness the river flow to provide clean sustainable energy by installing a hydrokinetic turbine in the river. Prior to the design and installation of a hydrokinetic turbine, there are several important aspects of study needed to be considered and carried out to ensure the implementation yields a quality outcome. One of the studies is the flow behavior around the hydrokinetic turbine. By establishing a flow visualization study on the hydrokinetic turbine, necessary insight on the entire flow field around the turbine can be gathered. Thus, it is important to first visualize and study the flow around the hydrokinetic turbine which could potentially affects its performance and output. By establishing an experimental set-up to investigate the flow visualization of water tunnel for micro-hydro kinetic turbine application, major contributions can be made to the ultimate goal as successful interpretation of fluid flow patterns can be done accurately.

1.3 Objectives

The objectives of this project are:

- To establish an experimental set-up for flow visualization study of micro-hydrokinetic turbine in water tunnel
- To investigate the flow behavior across a micro-hydrokinetic turbine in water tunnel

1.4 Thesis Outline

This dissertation is categorized into 5 chapters with each of the chapter describing the details on the overall project for different aspect. In Chapter 1, the overview of the flow visualization application on a hydrokinetic turbine, project motivation and objectives are described to provide a general insight on the current project investigation. In chapter 2, the literature review that includes relevant studies and researches are discussed. As for Chapter 3, the methodology of conducting the project from the experimental set-up of dye injection method to the investigation of flow behaviour around a micro-hydrokinetic turbine are discussed to provide a clear view on the flow field around the turbine in different flow conditions. Next, Chapter 4 presents all experimental results obtained from the case studies, together with discussions and justification using qualitative analysis approach. In Chapter 5, conclusion is made to summarize all the significant findings, several improvements on the water tunnel are also suggested to facilitate any experimental work in the future.

CHAPTER 2
LITERATURE REVIEW

This chapter discusses about the relevant researches that have been carried out. Firstly, various flow visualization technique that is used to study the flow structures around a test model is discussed. Out of the techniques, flow visualization experiment on water medium is the primary focus in this study, thus a detailed look into the differences between the dye injection method and Particle Image Velocimetry (PIV) and the selection of flow visualization method are discussed. The dye injection system technique used in the past researches are also discussed in more detail, these include the dye injection system experimental set-up, experimental methodology as well as the results and findings of the experiments. Next, the water tunnel and its primary components used are discussed to provide an insight on the conventional configuration of water tunnel. After that, the micro-hydrokinetic turbine and its application in water tunnel are discussed. Lastly, the relevance of the literature review and the current project is discussed as well.

2.1 Flow visualization technique

Flow visualization is a process of making different phenomenon of the fluid flow visible (Kalyankar et al., 2015). It is crucial to aid researchers in understanding flow behaviour by providing the overall picture of the flow field (Ristić, 2007a) and formulating more fluid flow theories. Flow visualization technique simplifies the analysis of the flow structure around an object into qualitative analysis instead of quantitative analysis (Kalyankar et al., 2015). There are various forms of experiment set-ups for flow visualization of a low speed water tunnel. The visualization techniques are classified into three categories (Merzkirch, 2012). The flow visualization technique and its application medium as well as the flow regime are summarized in table 2.1.

Table 2.1: Flow visualization techniques

Visualization technique	**Application medium**	**Flow regime**
Dye injection	Water	Low speeds
Particle image velocimetry		Low speeds
Wake imaging		Low to moderate speeds
Smoke visualization	Air	Low subsonic speed (M<0.3)
Pressure sensitive paint		High speeds
Shadow graphs		Compressive flow
Schlieren imaging		Supersonic speeds

Dye injection and particle image velocimetry are used in the flow visualization of water tunnel. Dye injection technique is a low cost technique where it can be set-up easily and also provides high quality of pictorial representation (Merzkirch, 2012). Dye can be used to mark and visualize particular regions of flow or individual fluid streamlines. To mark a streamline within the fluid, dye can be released from a thin needle aligned to the local flow. However, care must be taken to minimize disruption to the existing flow field. For instance, the injection velocity should match the local velocity. The injection velocity can be controlled with a syringe pump or a constant head reservoir. To ensure that the tracer faithfully follows the undisturbed flow field, the density of the tracer must match that of the experimental fluid (Merzkirch, 2012).

Aside from conventional dye, dye injection system with a fluorescent dye can also be used. Under normal lighting, a dilute fluorescent dye solution appears almost transparent, but when illuminated with light source (usually a laser) the dye fluoresces. This process is often referred to as laser-induced-fluorescence (LIF). Apart from flow visualization, this technique has been used for quantitative measurements of species concentration, temperature, velocity and pressure. Since fluorescent dye fluoresces only when it is excited by a laser that closely matches the excitation frequency of the dye, illuminating the flow with a thin laser light sheet reveals cross-section of the flow field. Some of the common fluorescent dyes used in flow visualization include fluorescein, rhodamine-B, and rhodamine-6G. When illuminated with argon ion laser, fluorescein displays a green colour, while rhodamine-B and rhodamine-6G give dark red and yellow colours respectively (Smits and Lim, 2012).

On the other hand, Particle Image Velocimetry (PIV) provides whole field measurement technique which allows it to record images of large parts of flow fields and to extract the velocity and direction information out of these images. The purpose of many flow measurements is to gain information on the gross flow pattern in a whole region or cross section of the flow, the PIV technique is able to provide this kind of information faster with less date collection time. It also provides additional information such as velocity. The ability to capture instantaneous image and high spatial resolution of PIV allow the detection of spatial structures even in unsteady flow fields (Visscher, 2010).

2.2 Dye injection method

This proposed study will focus on dye injection experiment as the visualization of flow is our primary focus. In a flow visualization study using dye injection method carried out by (Smits and Lim, 2012), it is stated that food dye is most often used because it is safe to handle and easily available commercially. His study also found that reds, blues, and greens colour generally produce better picture contrast than other colours. Generally, commercially available food dye has a specific gravity greater than one, which means the density of the food dye is greater than the density of the water, unless it is made neutrally buoyant, the dye will not follow the flow field as intended, this can lead to serious misinterpretation of flow visualization results. Methanol and ethanol are normally added to prevent this incident to occur (Smits and Lim, 2012). The exact amount needed entails some degree of trial and error because commercial grade alcohols do not all come with the same degree of purity. Once the dye mixture is neutrally buoyant, it is then diluted with the operating fluid from the tunnel to ensure the temperature difference between dye mixture and the working fluid is kept to a minimum (Smits and Lim, 2012) .

In a dye injection system study carried out by (Kalyankar et al., 2015), food colouring dye of colour red, blue, green is chosen to study the flow visualization of bluff body in a low speed water tunnel. 25-gram approximation of dye powder is added in 500ml of water and properly mixed, this mixture is used as visualization medium. The dye mixture is filled in inverted bottles with holes at bottom top and bottom surface of the bottle, infusion IV set is used to ensure controlled flow of dye to the syringe. The syringe chosen is 18G 1.5TW (1.2mm diameter of orifice, x 38mm length of syringe). This syringe is chosen after trial & error observing the vortex shedding pattern with syringes of different gauges (orifice diameters). These syringes are then tied with plastic locks to L-bend steel rods. The location of syringes is chosen appropriately according to the cylinder test piece diameter.

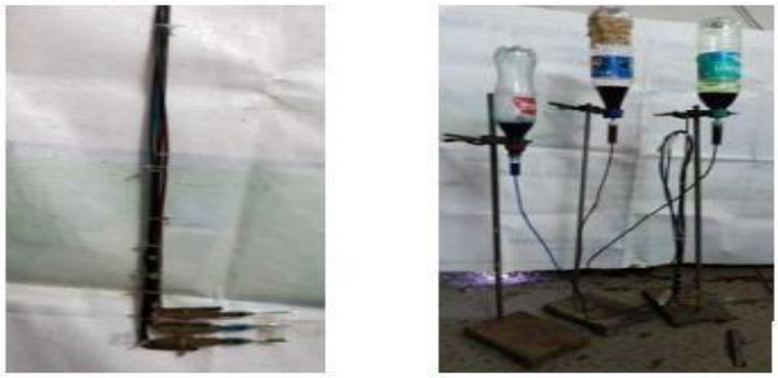

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Figure 2.1: Syringe needle(left), dye injection system (right) (Kalyankar et al., 2015).

In a study carried out to conduct a flow visualization tests for three airfoil models; with the Clark Y 11.7% as the base airfoil and the same airfoil with a slot and a flap. Dye injection method is used to visualize the flow structures of the airfoil. The presented results of flow visualization around models as shown in figure 2.2 and 2.3 with use of dye confirmed the effectiveness of the applied methodology (Filipiak, 2016).

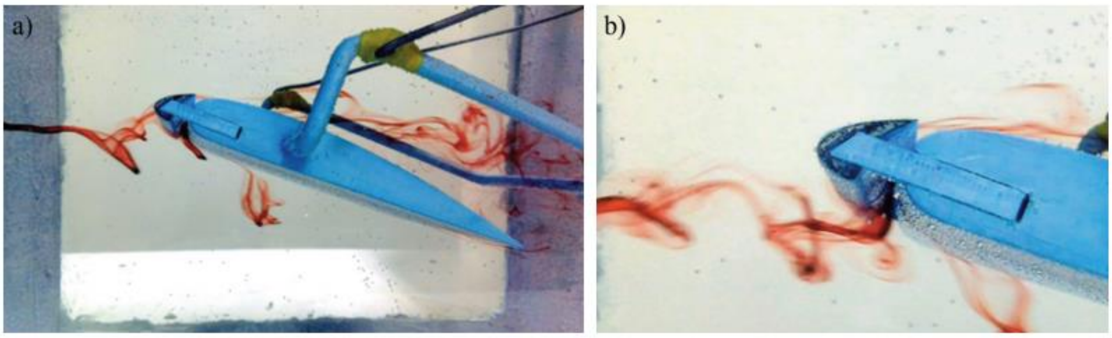


Figure 2.2: (a) An airfoil with a slot (b) closed-up view, very clearly visible sucking in of the stream into the slot gap (Filipiak, 2016)

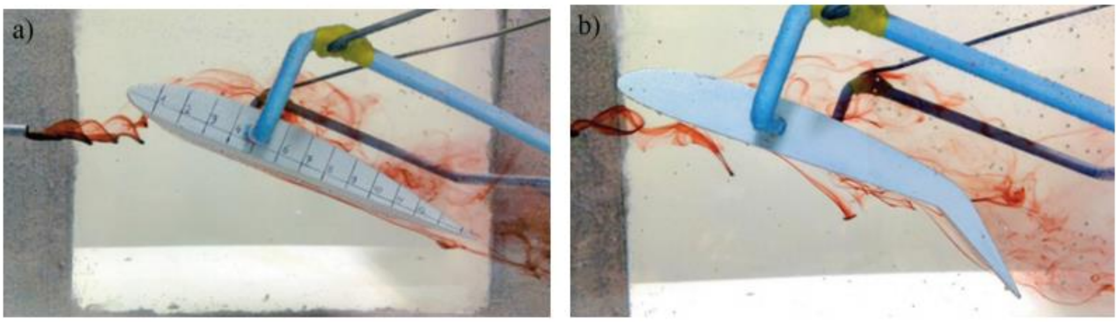


Figure 2.3: (a) Base airfoil and (b) airfoil with flap (Filipiak, 2016)

In the preparation of dye feeder, a long aluminium tube with a diameter of 5mm is placed in the water tunnel connected with dye feed to supply dye stream in front of the models. The tube is drilled from the inside of the outlet section to decrease wall thickness and minimize disruptions formed when mixing the dye with water. The dye formed a slightly disrupted stream at low flow rate, gradually blurring along with the increasing distance from the outlet. While increasing the flow rate resulted in thickening of the stream. At a greater mass flow rate, gravitational settling of the dye can be observed, this is caused by the density of the dye being greater than the water. Figure 2.4 shows the dye stream from the tube. This conducted study helped to identify problems and benefits of using dyes in a water tunnel. It also can be concluded that flow visualization is a method which is useful in the process of identifying certain type of phenomena occurring during aerodynamic tests (Filipiak, 2016)..

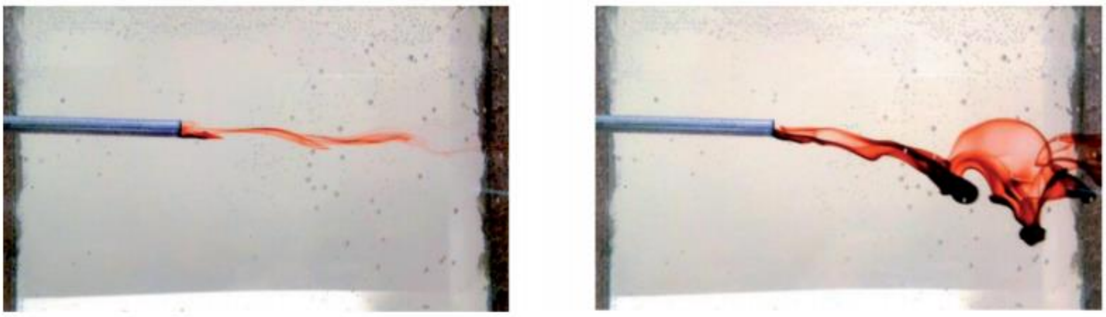


Figure 2.4: (a) Dye stream from a tube at low flow rate (b) Dye stream from a tube at medium flow rate, visible dye settling (Filipiak, 2016).

2.3 Water tunnel and its components

The principle of operation of the water tunnel resembles the wind tunnel but in the wind tunnel, air is used as working fluid instead of water. Water tunnel has higher capacity for pumping of flow than wind tunnel. In water tunnel, visualization of flow is easier than wind tunnel due to higher viscosity of water and various kinds of techniques for visualization can be used (Saeed, M. et al, 2018). The general configuration of a design of a water tunnel are shown in figure 2.5. The water tunnel is in the form of three components connected in the sequence of inlet module, test section and the outlet module. The function of the plumbing system is to recirculate the water from the outlet module to the inlet module through the motor and pump of the water tunnel (Kalyankar et al., 2015).

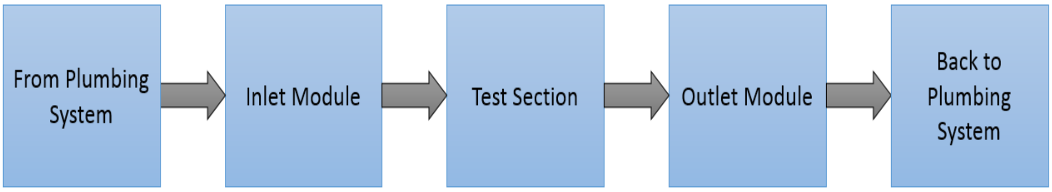


Figure 2.5: General configuration of water tunnel components (Kalyankar et al., 2015).

A typical commercially available water tunnel consists of several components such as the inlet module (flow conditioning), convergent section (Inlet module), test section, diffuser (outlet module), motor and pump, and return leg piping (Daniel, 2012). The flow conditioning is needed to suppress the free-stream turbulence and creating flow straightening effect. The convergent section will accelerate the flow and reduce the turbulence level of the fluid entering the test section. For the test section, it is a region where the test model is placed to conduct flow visualization test. The flow stream quality hinged on the design of the test section, the test section should be design in way that it minimizes the turbulence of the stream flowing into it (Daniel, L., 2012).

Next, the diffuser is developed to slow down the flow and regain the pressure of the flow stream and the motor and pump are used to provide the required pressure differential to drive the water around the water tunnel. This helps to recirculate the water around the closed-circuit water tunnel. Return leg piping and their sizing are determined by the integration requirements with other components, drain locations, and also for the avoidance of flow separation (Daniel et al., 2015). All of the aforementioned components are the primary components that are needed in conventional water tunnel.

2.4 Micro-Hydrokinetic Turbine and its Application in Water Tunnel

The advantages of hydrokinetics system over the conventional hydropower is that the system requires minimum civil works. This means, the system not required to construct a water storage system or reservoir to accumulate the water. Compared to a conventional hydroelectric system which is required the reservoirs and penstocks to extract the potential energy of falling water. this type of energy harvesting systems provides a good choice of electrification for off-grid remote communities which is transmission lines do not exist (Ibrahim, W. I., 2018). In addition, hydrokinetic turbine systems are advantageous due to “zero-head” and mobility (Haifeng, L., 2014). The turbines use hydrokinetic power from flowing water to generate power. In many ways, hydrokinetic turbines resemble wind turbines. The most notable difference is in density; the density of water is approximately 850 times greater than the density of air. Thus, more energy is expected from a hydrokinetic turbine (Haifeng, L., 2014).

Hydrokinetic turbine electricity generation is mainly aimed for rural use at sites remote from existing electricity grids (Kailash, G., 2012). It is a useful tool for improving the quality of life of people in these locations. Different designs of water turbine are available for the extraction of energy from the river water. There are two common types of hydrokinetic turbine. They are horizontal axis turbine (axial turbines) and vertical axis turbine (cross-flow turbines). One of the commonly used vertical axis turbines is Savonius turbine (Kailash, G., 2012). Savonius rotor is a vertical axis rotor with simple in design and easy to fabricate at lower cost. The rotation of the rotor is due to the drag difference between the advancing blade and returning blade. Net driving force can be increased by reducing the reverse force on the returning blade or increasing the positive force on the advancing blade (Kailash, G., 2012). One of the benefits of savonius turbine is that it is easier to be installed compared to other types and its design can be scaled down to small sizes (Haines, C., 2019). Figure 2.6 shows a typical savonius rotor.

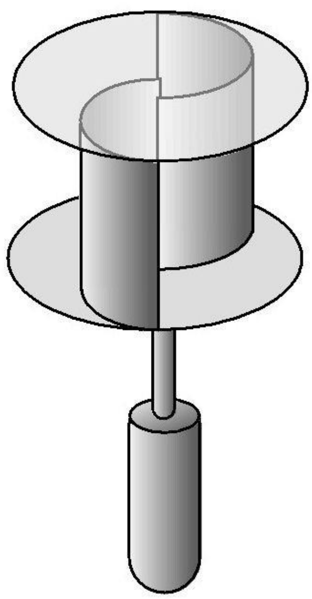


Figure 2.6: Savonius rotor

One of the important aspects is to investigate the hydrokinetic turbine in a water tunnel before going to real-life application. Water tunnel is capable to perform various kind of experiment including the study of hydrodynamic behavior of a model. The model can be any model ranges from car, aircraft, or wing prototype to even a micro-hydrokinetic turbine model. However, the water tunnel design and specification must meet the requirement by the micro-hydrokinetic turbine model so that the experimental work can be conducted. The requirement by the water tunnel to test the micro-hydrokinetic turbine model involved is the size of the micro-hydrokinetic turbine model which defined the size of the test section of water tunnel required. The micro scale of hydrokinetic turbines generally have a dimension of 15 - 25cm in diameter. (Khan et al., 2008)

2.5 Relevance between Literature Review and Current Project

One of the significance of the literature reviews carried out on the past researches and studies is the water tunnel design and the primary components used for flow visualization experiment. The design of water tunnel has an impact on the flow stream quality (Daniel, L., 2012). The components used in this project and the water tunnel design is based on the criteria used by the water tunnel designed by (Kalyankar et al., 2015) and (Daniel, 2012, Daniel et al., 2015).

Next, the literature reviews conducted on the micro-hydrokinetic turbine size are essential when making decision on what type and dimension of the turbine should be used. In addition, the survey conducted on the flow visualization techniques aimed to select a feasible and practical flow visualization method for the study of flow field around the hydrokinetic turbine given the facilities available to complete this project.

Lastly, the literature reviews conducted on the past studies of dye injection method help to identify a practical experimental set-up and dye usage for flow visualization experiment. The selection of dye in this project is based on the properties of each individual dye discussed in this survey, as well as to confirm and justify past studies claims or findings. The in-depth process of the dye injection system discussed in the literature review also acts as a framework to provide guidance and direction to the flow visualization experiment carried out in this project such as the experimental set-up procedure, care and precaution, materials needed, and applicability of dye.

CHAPTER 3
METHODOLOGY

This chapter will present the flow visualization technique, fabrication, experimental set-up, and experimental procedure for the analysis of flow visualization across a micro-hydrokinetic turbine. For this project, only the qualitative analysis will be performed. Qualitative method analysis is used to analyse the flow behaviour of the fluid across the micro-hydrokinetic turbine. Figure 3.1 below shows the overview of this chapter.

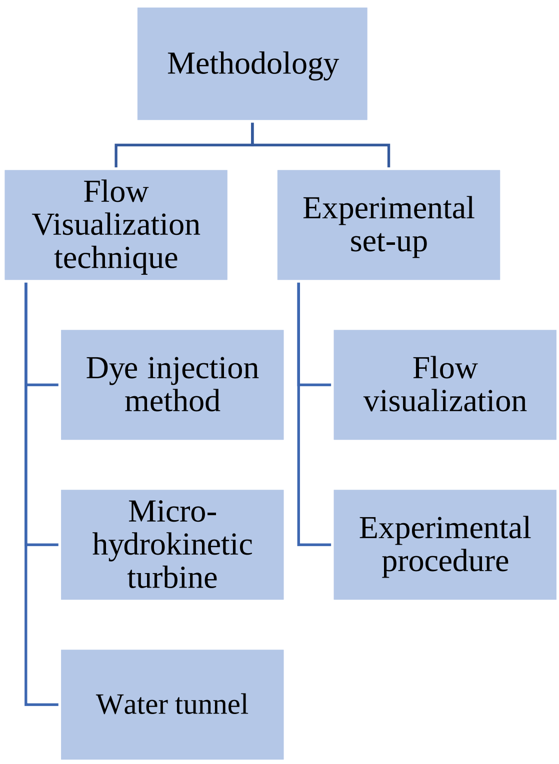
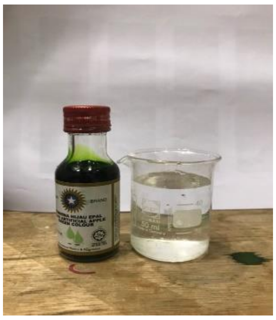
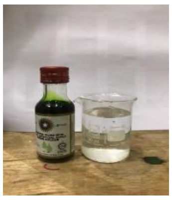
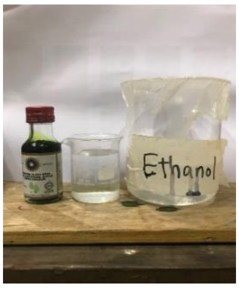


Figure 3.1: Overview of methodology

3.1 Dye injection method

The flow visualization technique selected to conduct the experiment on water tunnel is dye injection method. This is because a dye injection method can be set up easily and it provides a high quality of pictorial representation (Merzkirch, 2012). In this approach, variety of dye mixtures are being tested to show the comparisons in terms of clarity of image taken, rate of dispersion in water, as well as the flow direction or trajectory of the dye. There is a total of 4 mixtures and these mixtures include dye with water, dye with milk, dye with ethanol, and milk only as shown in table 3.1 together with their respective ratios being tested.

Table 3.1: Dye mixture and their respective ratios being tested

Dye mixture	**Elements**	**Ratio being tested**
1	Dye-water 	Ratio of dye to water 3:7 1:9 5:5
2	Dye-water-milk  	Ratio of dye to water to milk 3:3:4 1:5:4 5:1:4
3	Dye-water-ethanol 	Ratio of dye to water to ethanol 3:6:1 3:6.5:0.5 3:7 + 10drops of ethanol

4	Milk only 	Milk only

The dye is mixed with water to produce a more diluted solution and to prevent dark concentrated spots of dye occur in the flow visualization process. The milk in the dye solution is used to stabilize the dye filaments so that it does not dissolve quickly once it is ejected into the water stream. Although the role of milk in this mixture has not been investigated quantitatively, it is presumed that the fattiness of the milk retards the diffusion of the dyed solution into the main bulk of water (W.Johnson, R. 1998). From table 3.1, all the ratios of dye-water-milk mixture are derived from the dye-water mixture. The concentration of the dye is kept the same while milk is added into it, giving the ratio for the dye-water-milk ratio shown. This is to obtain a more consistent and comparable result so that we can observe only the effect of milk present in the mixture. While for dye-water-ethanol, the ratios are derived from the dye-water (3:7) solution. The role of ethanol in the solution is to control and maintain the direction of the dye in straight line as it flows out into the test section. As commercially available dyes have higher density than water, the dye will sink to the bottom of the tank once it is ejected, this creates a downward movement which prevents it from reaching the turbine, thus affecting the flow visualization outcome.

The aim of this approach is to select the best mixture and combination ratio that can be used to study the flow visualization on the micro-hydrokinetic turbine in a particular flow regime. The selection of a more suitable dye is also a part of the flow visualization experimental set-up. The reason of choosing the dye injection method for this study is because it is a low-cost technique where it can be set-up easily and it provides high quality pictorial representation. As the primary concern of this study relates to the visualization of fluid flow, it is suitable to use a dye injection method because it provides an outcome that matches the primary concern of this study.

3.2 Savonius turbine for hydrokinetic application

In this project, the turbine is a savonius 3-blade turbine with a diameter of 14cm. It is a simple design that consists of a shaft with the blades attached to the bottom section of the shaft. The height of the turbine blade is 8.5cm. In the case where the turbine is required to be fixed from rotating, the turbine shaft is being clamped directly by using a retort stand. While in other cases such as the dynamic flow condition, where the turbine is required to rotate freely by the motion of the flow, a bearing is attached to the shaft of the turbine and placed upright in the test section. The bearing smoothens the rotational movement while reducing friction. This allows the incoming stream to come into contact with the blades and forces it to rotate. Figure 3.2 shows the simple model of turbine used in this experiment.

Figure 3.2: Simple model of savonius turbine

3.3 Water tunnel

The water tunnel used in this experiment consists of primary components which are the inlet flow guide, exit flow guide, test section, X crosspiece, flow conditioning system, water propeller with motor and also the support jig to hold the water propeller with motor in placed. The flow direction of the water starts from the water propeller to the X crosspiece, inlet flow guide, flow conditioning system, test section, and eventually to the exit flow guide. Figure 3.3 shows the water tunnel together with its individual components.

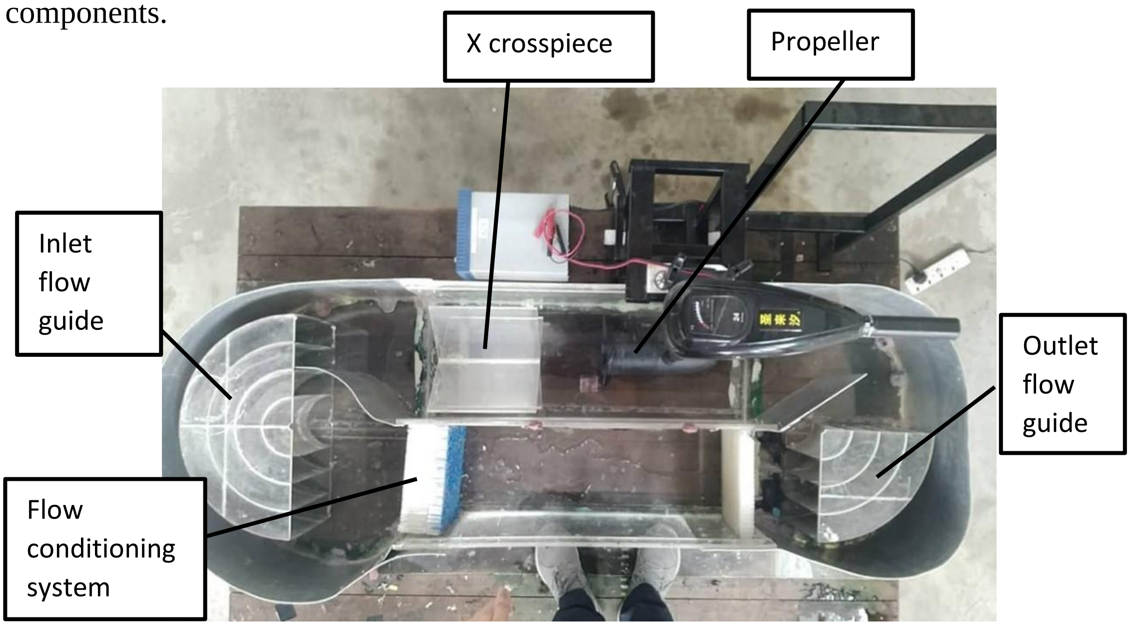


Figure 3.3: Top view of water tunnel

The X crosspiece is placed right after the water propeller to reduce the turbulence flow stream driven by the water propeller. It separates and aligns the water flow into 4 compartments. The inlet flow guide is designed with a radius of 0.30m and divided equally into 4 guide vanes. The function of the inlet flow guide is to direct the flow streams from the X crosspiece to the flow conditioning system. In addition, the 4 guide vanes of the inlet flow guide is needed to reduce the corner effect when the water changes its flow direction. Next, the flow conditioning system, or known as the honeycomb, is placed right after the inlet flow guide. There are 2 honeycombs which have a thickness of 3cm and 6cm, this adds up to a total thickness of 9cm. The first honey comb is used to damp the water flow from the inlet flow guide while the second honeycomb reduces the turbulence of the water flow and produces a smooth and uniform flow before entering the upstream of the test section. Figure 3.4 shows the X-crosspiece, inlet flow guide, and the honeycomb.

Figure 3.4: X-crosspiece(left), inlet flow guide(middle), honeycomb(right)

The last component of the water tunnel is the exit flow guide. The exit flow guide is used to guide the water flow stream from the downstream of test section to the water propeller, this produces a continuously flow of water in the water tunnel. The exit flow guide shown in figure 3.5 has a radius of 30cm and it is divided into 4 guide vanes, it is half the size of the inlet flow guide.

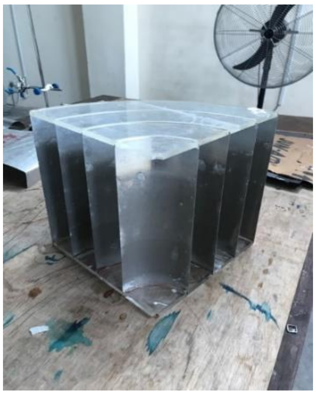


Figure 3. 5: Exit flow guide(left), turbine(right)

The water tunnel has an overall length of 183cm, overall width of 71cm, and overall height of 30cm. The dimension of the test section is 85cm x 25cm.

3.4 Experimental set-up

The experimental set up for flow visualization study around the turbine is shown in Figure 3.6, 3.7, and 3.8. Water bottles are used as dye tank to contain the dye. The bottles are cut in half and hanged on the jig, with flow valve fitted onto the bottleneck to control the dye flow rate. A white or black coloured background is used to increase the dye contrast in the water, the selected colour depends on the dye used for the experiment. For example, in an experiment involving milk as the dye mixture, the flow pattern can be better observed in a black background. Figure 3.9 shows the set-up of the dye tank. The dye tube is connected to the tank by using silicon sealant

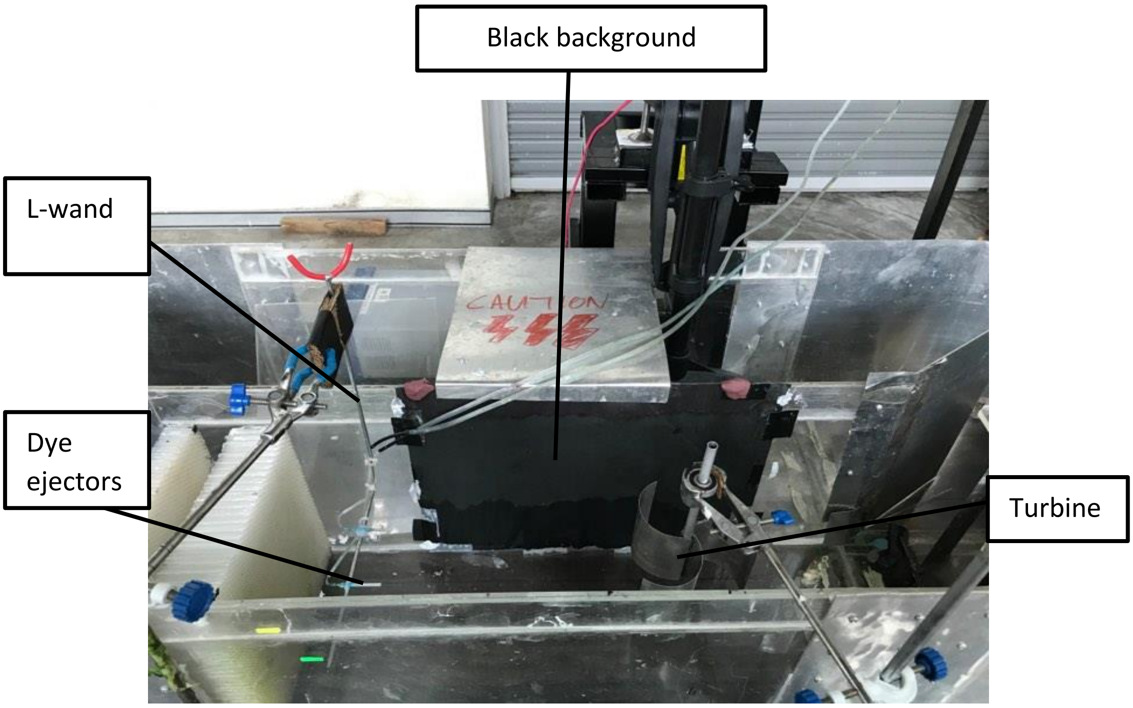


Figure 3.6: Experimental set-up (a)