Run River Pico-Hydro System from Water Treatment Effluent Discharge

by

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16831

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons.)
(Mechanical)

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CERTIFICATION OF APPROVAL

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May 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

M. AMIR ADLI BIN NAZARUDIN

ABSTRACT

Hydropower is a type of renewable energy which is derived from the energy possesses within water available from natural sources. Pico-hydro power is a small scheme hydro power plant where the power generation is less than 5 kW. Sewage Treatment Plant in Universiti Teknologi PETRONAS has components which requires at least 125 kW for operation. With increment in the electricity rate and tariff from national utility company, implementation of hydro system which can extract power from the water effluent discharge is realized. This project focuses on the possibility of installing a pico-hydro scheme at the treatment facilities in order to produce self-sufficient power; where low head water stream is available. Pelton turbine is a type of impulse turbine which is commonly used in a micro-hydro scheme throughout the world. The usage of Pelton turbine in this project will provide a relation on the performance of the turbine related to the velocity of water flowing in the stream. Hydro system components have been fabricated through manufacturing processes (e.g. welding, lathe). Site testing for drainage is assessed for feasibility in which other method is considered if the project is unachievable at site. The performance of the turbine in terms of power output and efficiency has been evaluated based on results obtained through tap water testing.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and Most Merciful. I am grateful to his blessings and supervision that the completion of this project has been attained. The journey and challenges taken have led to countless experiences which will help the author to learn, improve and achieve for the future.

Further highest appreciation towards my supervisor, Mr. Mohd. Faizairi B. Mohd. Nor for his valuable input and ideas as well as advices during the past 28 weeks to complete this final year project. There are various issues persisting during the course and with the assistance of Mr. Faizairi, I was able to continue and complete the project within the time frame.

Besides, special thanks and appreciation to the technologist Mr. Jani Alang Ahmad which helps a lot in term of fabrication and improvement of the hydropower system. His experiences and knowledge have contributed towards the penstock, turbine casing as well as turbine connector to the generator (shaft). Without his guidance, the completion of this project may not have taken well until the end of 28 weeks.

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CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy in general constitutes the sources of energy obtained from naturally occurrence phenomena which possess flows of energy within its local environment [1]. As an example, this energy regenerates and persists itself even after harnessing from a specially made equipments such as solar (sunlight), rain, tides, geothermal, heat and wind. In terms of sustainability, the renewable energy itself must be inexhaustible and does not have any adverse effect towards the environment which include the climate system [1]. In a long term, the energy itself must be substantial where it is affordable, meets the society requirement as well as compatible with the latest development [1].

Water power which is a form of renewable energy has been utilized since thousand years ago with the construction of water turbines or mills for irrigation purposes [3]. The energy is available from various types of moving bodies of water such as large ocean, rivers and small brook or stream. There are numerous types of water power being harnessed in recent times such as hydroelectric energy, damless hydro system, ocean energy, tidal power, wave power and deep lake water cooling [2]. The process of acquiring the water energy may involves allowing a stream of moving water impinging the blades or vanes of a horizontal axis water-wheel. The potential energy possesses by the water would be transferred to the wheel which is rotating that produces a mechanical energy. By integrating the system with a generator, the conversion of mechanical energy mainly called as rotational energy to electrical energy took place. There are various techniques that have been used to maximize and generate greater efficiency of the water power system developed [3].

Utilization of hydro power had commenced since the 1700s where flowing water of rivers and streams has been used to produce electricity in small or large-scale hydroelectric plants [8]. Differences between the large-scale and small-scale hydroelectric include the output produced by the respective plants in relative to the potential energy of the falling water stream. Usually large-scale hydroelectric projects involve high dams which are built across rivers that creates large reservoirs. The falling water is controlled through valves or pumps that determine the water streams exerted to the turbines. However, small-scale hydroelectric projects have a low dam, occasionally with little or no reservoir capacity and constructed near to small streams or river [8]. There is a concern for this type of hydroelectric eventually as the seasonal water flow which varies across the year tends to affect the generation of electricity from water turbines.

Small-scale hydroelectric projects can be further classified into three types which are full-scale hydro, mini-hydro and micro-hydro plants [4]. Full-scale hydro schemes produce electricity which is sufficient to power large towns or extensive grid supplies. Usually full-scale hydro scheme can produces up to 10 MW of power during operation. Whereby, mini-hydro schemes have power ranges from 300 kW to 10 MW that is utilize in smaller capacity areas. Micro-hydro schemes in other hand are extensively implemented in rural or remote areas where the utility grid does not extend to that part of the country [4]. Basically these schemes only provide from 200 W to 300 kW of power and are utilized in rural industry or community such as providing lighting to houses within the rural residence.

1.2 Problem Statement

Sewage treatment plant consists of several processes namely primary treatment, secondary treatment and tertiary treatment where the sewage water will be purified for other domestic purpose. In UTP, the treatment plant is maintained by the Property Management & Maintenance Department (PMMD) under the Mechanical Section.

There are several main components within the treatment plant such as grit chamber, aeration tank, clarifier, holding tank and air blower. These components however consume substantial amount of power and hence contributes to the expense of electrical consumption. Table 1 summarizes the overall power consumption for each component:

Table 1.1: Rated power requirements for STP main components

Location	Type	Power
Primary Screen	Sump P	22 kW
Grit Chamber	Sand P	3.3 kW
Aeration Tank 2	Recycle Pump, Mixer 1 & 2	15.4 kW
Secondary Clarifier	RAS Pump 1 & 2, Clarifier Motor 1 & 2	6.6 kW
Gravity Sludge Thickness	Sludge Motor, Sludge Pump 1 & 2	4.8 kW
Sludge Holding Tank	Sludge Pump 1 & 2	4.4 kW
Air Blower	Blower 1, 2 & 3	66 kW
Overall Power Requirements		122.5 kW

With increment in the electrical rates and tariff (as of January 2014) from national utility company Tenaga Nasional Berhad., there will be an increase in cost for power consumption in the sewage treatment plant. Usually the power consumption of the overall treatment plant can be determined based on kWh/per million gallon of water treated. Hence, there will be large amount of cost incurred for the consumption of electricity to this facilities. This will also cause a concern about expenses to other related operational consideration such as maintenance and personnel. Therefore, this project will be assessing the feasibility of recouping the power which can be extracted from wastewater effluent discharge by installing a pico-hydro system.

1.3 Objectives

The objectives of implementing pico-hydro system in UTP sewage treatment plant is basically described as follow:

1. To study the feasibility of implementing pico-hydro system in sewage treatment plant which able to produce self-sufficient power.
2. To design pico-hydro system involving water catchment tank to power generation unit that is suitable for the water treatment plant.
3. To study the performance of the developed pico-hydro system at the control site.
4. To assess the utilization of Pelton turbine in a low-head water flow condition in the facilities.

1.4 Scope of Study

The project will be carry out from two different phases which are first the inception and conceptual stage and the second one is implementation and analyse stage. This project mainly focuses on the basic principle of fluid dynamics such as applying the continuity equation while assessing the area of the concept model and Bernoulli's equation to study the kinetic energy.

The first phase which is the inception and conceptual stage includes theory calculation and designing of the overall pico-hydro system. The design is carried out for various components of the hydro system such as from the forebay tank (water catchment), penstock selection, turbine consideration (e.g. no. of nozzle, buckets) and generator design. Calculation is done for each part of the components where various equations are employed during the designing stage. The concept models is initially sketched which are later translated into 3D model by using Solidworks software. Measurements are also taken at the control site in order to simulate the working environment of the system from using ANSYS Fluent software that is able to display the water flow within the model.

The second phase involves the implementation and analyse stage where the overall pico-hydro system developed will be tested at the control site. The fabrication of hydro-system components will involve metalworking process e.g. welding, Mazak tool machine to produce the turbine buckets and Perspex cutting tools to create the turbine casing as well as generator housing. After fabrication of the model, the whole system will be tested to study its performance at the control site. Site data performance such as power produced will be recorded and later analysed to confirm the feasibility of this project.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

Hydroelectricity is one of the prevalent type of renewable energy utilized in the world. Hydroelectricity potential has been assessed to be most beneficial in many countries such as Canada, Mexico, India, Western European, Denmark, United Kingdom and Asian Countries including Japan and China. The rise of hydroelectric projects in Asia is expected to increase the electricity production within the continents such as the construction of Three Gorges Dam in China as well as the commencement of Bakun Hydroelectric Project located in Sabah within Malaysia since 2000s [5]. Basically, hydroelectric plants are established within countries which contain mountainous or plateau regions where water falling from high point contributes towards the operation of the water turbines. In general, hydropower accounts about 17% of global generation capacity for electricity while around 20% for energy produced every year [6].

The selection of wastewater treatment facilities for implementation of hydroelectricity plant has been assessed from several researches. It is viewed that wastewater treatment facilities usually consumes a lot of power for its operation where around 25% - 40% of the budget are spent for payment to utility company [7]. Besides, it has been shown that there is the potential to generate power in wastewater treatment facilities. The flow rates of water within the treatment plant contributes significantly to the power generation capacity where an increase in flow rate (m^3/s) usually causes an increase in the power generation potential (kW) [14]. There are however various parameters that set the flow rates of water within the facilities such as peak hour operation and seasons or times of the day [14].

Low-head hydropower from wastewater has been implemented in various wastewater treatment plant especially in United States. The Massachusetts Water Resource Authority (MWRA) has been generating power from the Deer Island Wastewater

Treatment Facility since operation started in 2001 [15]. The facilities utilized the reaction turbines which are 2 Kaplan units that have the rating of 1000 kW capacity of power and flow velocity of approximately 320 mgd (7303.8 m^3/s). Overall construction cost related to the hydropower facilities is approximately around $7.4 million [15].

2.1 Hydropower

The term hydropower in general constitutes the generation of energy from moving water where the potential energy is later converted into electricity. The first hydroelectric power plant was constructed in Fox River, Wisconsin which began its operation in 1882 [8]. Hydropower can be classified dependent on several measures such as from the source of water, type of construction as well as the turbine in operation [8]. The two main types of hydropower are either river power plants or storage power plants. The river power plants or known as run-of-river power plants uses natural flow and elevation drop of a river to generate electricity. Basically, the water channel or river are directed towards the hydro system or in certain case it is fed by diversion canal [8]. The other type is known as storage power plants in which dam is built around the water reservoir where high point of reservoir is channelled through pipes towards the turbine at lower point. The water gained potential energy from the higher elevation and directed towards the propelled turbines within the powerhouse that converts the kinetic energy into electricity.

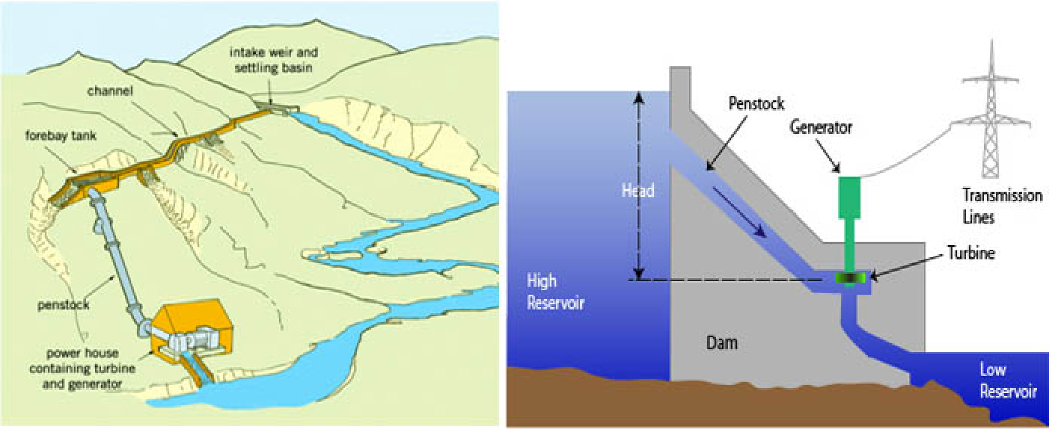


Figure 2.2: Run-of-river hydropower plant and Storage hydropower plant

Further the hydropower plants can also be classified from the power generation which are summarizes as follow:

Table 2.1: Category of hydro power plant based on power generation [8]

Category	Capacity
Large	> 10 MW
Small	< 10 MW
Mini	< 1MW
Micro	< 100 kW
Pico	< 5 kW

2.1.1 Pico-hydro System

The pico-hydro system in particular is established in rural parts of certain countries such as Zimbabwe and Zambia within the Africa region [10]. This hydro system provides an alternative to the high costs of extending the electricity grids. Basically, the pico-hydro system is used to supply power for local community in terms of residential [4].

The power from the pico-hydro system can be expressed from the following relation [10]:

$$P_{gross} = \rho_{water} \times Q \times g \times h_{gross}$$

where; P_{gross} is the theoretical power produced (kW)
ρ_{water} is the density of water (1000 kg/m^3)
Q is the flow rate in penstock pipe (m^3/s)
g is the acceleration due to gravitational force (9.81 m/s^2)
h_{gross} is the total vertical drop from intake to turbine (m)

However considering the losses within the system such as friction, and noise while calculating the power generated by the system, it is recommended to include the overall efficiency of the system where equipment is used to convert energy from one to another. Table as follow summarizes the typical component efficiencies [10]:

Table 2.2: Efficiency of components in the pico-hydro system

System Component	Efficiency
Canal	95%
Penstock	90%
Turbine	60 - 80%
Generator	85 %
Step-up and down transformers	96 %
Transmission	90%

Therefore, the actual power from the pico-hydro system is expressed from the relation as follow [10]:

$$P_{actual} = \rho_{water} \times Q \times g \times h_{gross} \times \eta_{total}$$

where; P_{actual} is the actual power produced (kW)

η_{total} is the total efficiency of all components within the system

$\eta_{total} = \eta_{canal} \times \eta_{penstock} \times \eta_{manifold} \times \eta_{turbine} \times \eta_{drive} \times \eta_{generator}$

The main components of pico-hydro system generally consists of the following [4]:

1. Intake water diversion (forebay tank) - includes diversion gate valve and settling basin
2. Penstock - known as water conveyance which channel the water from forebay tank to the powerhouse. Designed based on pressure exerted from the water.
3. Hydro turbine - based on impulse or reaction principles where utilized according to power output expected.
4. Generator - common types used include synchronous or induction.

2.2 Water Turbines

In a hydropower plants, the turbine is one of the main component of the system which converts rotational or mechanical energy into electricity through the usage of generator. Classification of water turbines is generally done based on direction of flow, pressure of water and shape or orientation of the turbine [3]. Generally, hydraulic turbines can be classified from the change of pressure occurring within the rotor of these turbines [8]. The classification can be identified as impulse turbines or reaction turbines.

2.2.1 Impulse Turbine

Also considered as the most common form of water turbine, it operates based on jets of pressurised water which are directed against vanes or cups placed on the perimeter of the wheel [3]. This causes the force acting on the wheel to be impulsive. There is no apparent change in the pressure of water while flowing through the rotor of the turbine. The operation starts with water directed from nozzle at high speed which then impinges on the buckets at rotating shaft. This causes rotational motion that produces kinetic energy. The most commonly utilized impulse turbine in industry is called Pelton turbine, in which several cup-shaped buckets are installed at the runner of the turbine [8]. However, several types of impulse turbine are also available such as Turgo turbines which is variation of Pelton turbine that is equipped with half-cup shaped buckets and also crossflow water turbine which is designed with trough-shaped blades in radial arrangement around a cylinder-shaped runner [8].

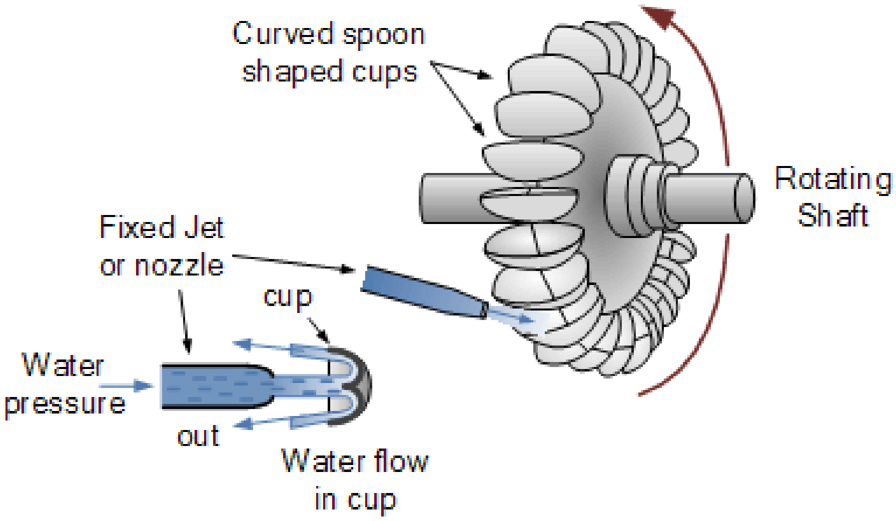


Figure 3.2: Design and operation of Impulse Turbine

2.2.2 Reaction Turbine

Reaction turbine operates based on changes in the pressure of the water causes by the variation in the profile of flow path as water passes through the rotor blades. [8] This change in fluid velocity as well as reduction in pressure, hence causes a reaction within the turbine blades. Basically, the turbine casing of these turbines would ensure a continuous flow of water within the turbine rotor that allow pressure to be exerted onto these blades. Commonly used reaction turbines include Francis turbine that operates based on water flowing above the rotor blade and is located between high pressure water source and the low pressure water exit. Another type of reaction turbine is Kaplan turbine or known as propeller turbine due to the shape of its rotor which resemble ordinary propeller of a ship. Kaplan turbine is usually feasible where there is high water flow with low height of fall [8].

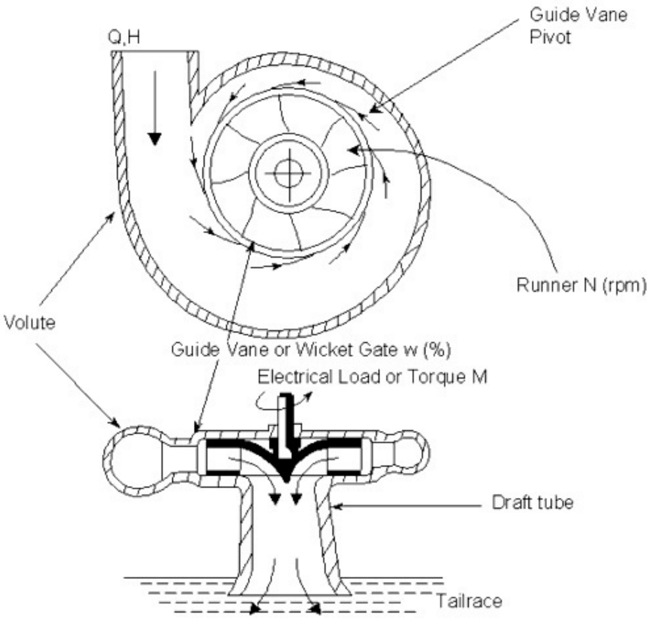


Figure 2.4: Design and operation of Reaction Turbine

2.2.3 Selection of Hydraulic Turbines

The selection of hydraulic turbine can be done when several parameters are known such as head and flow of water. The Figure 2.4 as follow shows how the selection criteria proceed based on flow rate as well head or drop in height (m): [8]

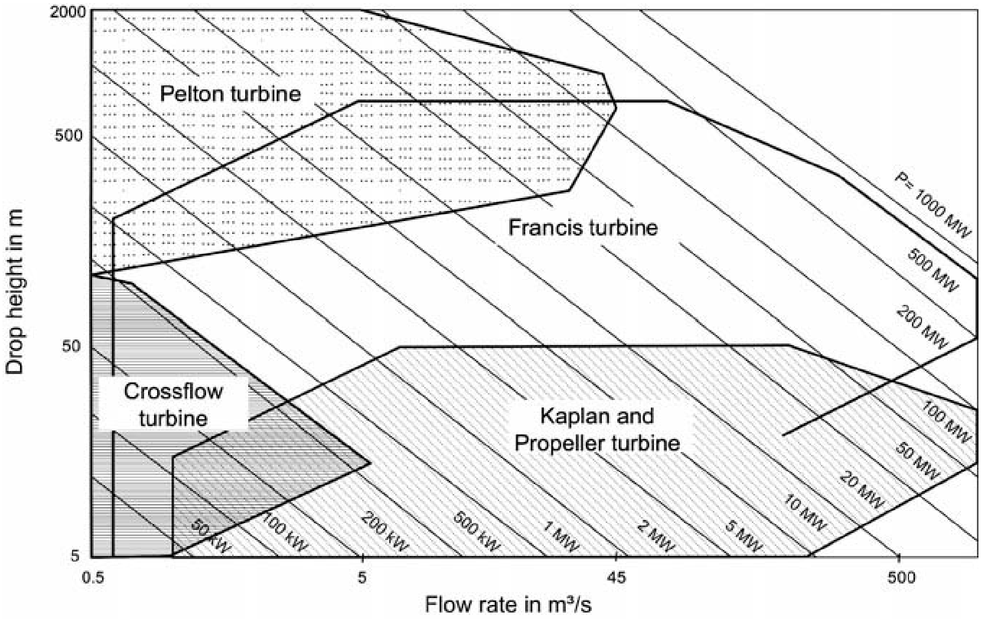


Figure 2.5: Operation areas of hydraulic turbines and their power

2.2.4 Pelton Turbine

Pelton turbine basically has one or more nozzles which direct the water jets toward the buckets mounted on the turbine runner (periphery disc). This turbine is usually utilized for medium to high head sites [4]. However for micro-hydro system with lower heads, the Pelton turbine will has smaller diameter of runner which needs to be rotating at high speed [4]. In this case, the velocity of jet which impinges the buckets will be calculated to be integrated in the design of the system.

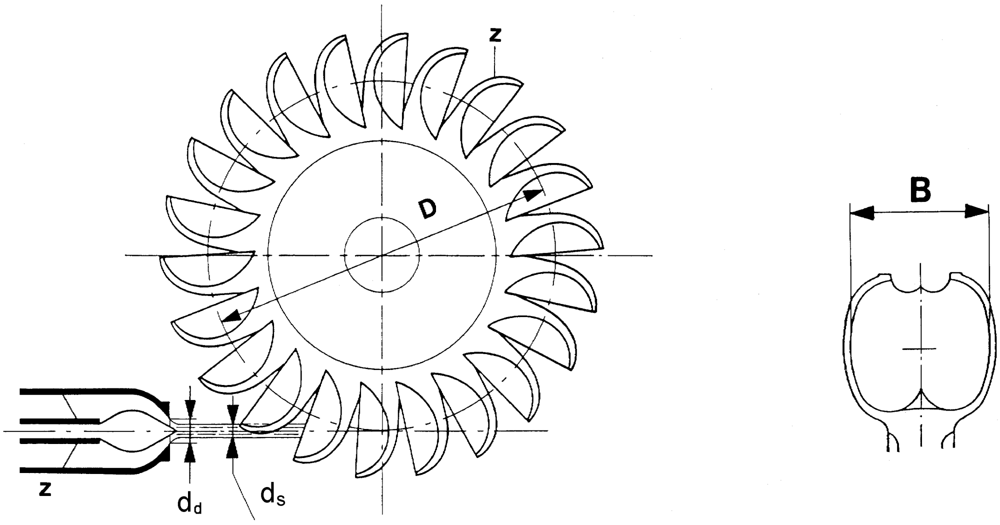


Figure 2.6: Parameters for design of Pelton Turbine including runner diameter and bucket dimension

Velocity of jet for the Pelton turbine is given from the equation [9]:

$$v_{jet} = C_v \times \sqrt{2gH_n}$$

where; v_{jet} is the jet velocity

C_v is the coefficient of velocity for the nozzle

g is the acceleration due to gravity (9.81 m/s^2)

H_n is the net head at the nozzle (m)

The flow of water within the turbine is given as [9]:

$$Q = A_{jet} \times v_{jet} \times n_{jet} = \frac{\pi\, d_{jet}^{\ 2}}{4} \times v_{jet} \times n_{jet}$$

where; Q is flow in m^3/s

A_{jet} is the cross sectional area of each jet (m^3)

n_{jet} is the number of jets

d_{jet} is the diameter of jets (m)

While assuming the coefficient of velocity, C_v is 0.97, the diameter of the jet is [9]:

$$d_{jet} = \frac{0.54}{\sqrt[4]{H_n}} \times \sqrt{\frac{Q}{n_{jet}}}$$

The basic speed for a Pelton turbine is given by [9]:

$$2\pi \frac{N}{60} \times \frac{D}{2} = \frac{\pi N D}{60} = x v_{jet}$$

where; N is the speed of the runner

D is the pitch circle diameter (m)

v_{jet} is the jet speed (m/s)

x is the ratio of runner speed at the pitch circle diameter to the jet speed (x is taken at 0.46)

2.3 Generators

In micro-hydro electric project, there are two types of AC generator suitable for usage which allows conversion of electrical energy from rotating shaft. Both types are either called synchronous generators (alternators) and induction generators. For synchronous generators, the frequency is directly dependent to the shaft speed [4]. Whereas induction generators does not have frequency changes according to speed or load variation.

2.3.1 Synchronous Generators with Permanent Magnet

The design of the generator is such that stator and rotors are made in the form of ring. The rotors are usually made from steel plate while the stator is created from electrical sheet steel strip. The winding coil is wrapped around the stator ring which is called as toroidal or "torus". There will be air gap in-between the two rotors and stator [13].

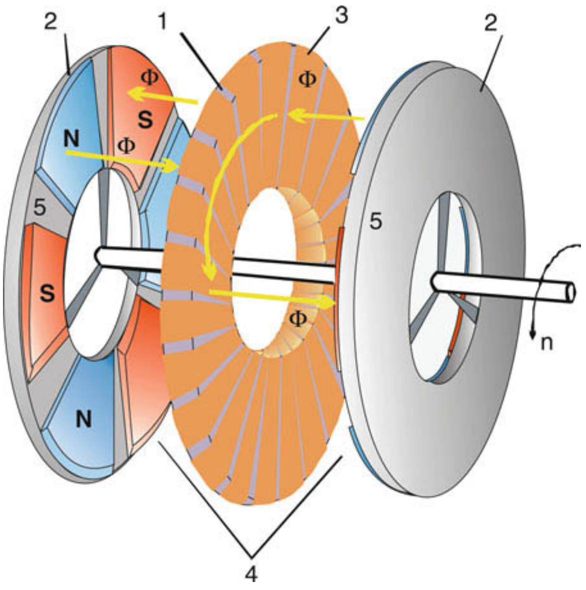


Figure 2.6: PMG with axial gap and longitudinal flux: 1 - Stator; 2 - permanent magnet; 3 - toroidal winding; 4 - air gaps; 5 - rotor yoke

2.4 Conservation of Mass - The Continuity Equation

The law of conservation of mass is generally describing that within any closed system where transfers of energy and matter took place, the mass of system remains constant at any given time considering there is no addition or removal to the initial mass. Therefore, the quantity of mass remains unaffected over time in the system. The conservation of mass is generally used for fluid flow within a system and the mass flow rate can be described as follow [19]:

$$\dot{m} = \rho Q = \rho AV$$

where; ρ is the density of the fluid

Q is the volumetric flow rate (m^3/s)

A is the area of the system (m^2)

V is the velocity of fluid flow (m/s)

For a fixed, nondeforming control volume involving one stream of a type of fluid flowing through the system, the mass flow rate is equivalent to [19]:

$$\dot{m} = \rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

As for incompressible flow (where density is constant):

$$Q = A_1 V_1 = A_2 V_2$$

Thus, the general law of conservation of mass can be shown as follow [19]:

$$\Sigma \dot{m}_{in} = \Sigma \dot{m}_{out}$$

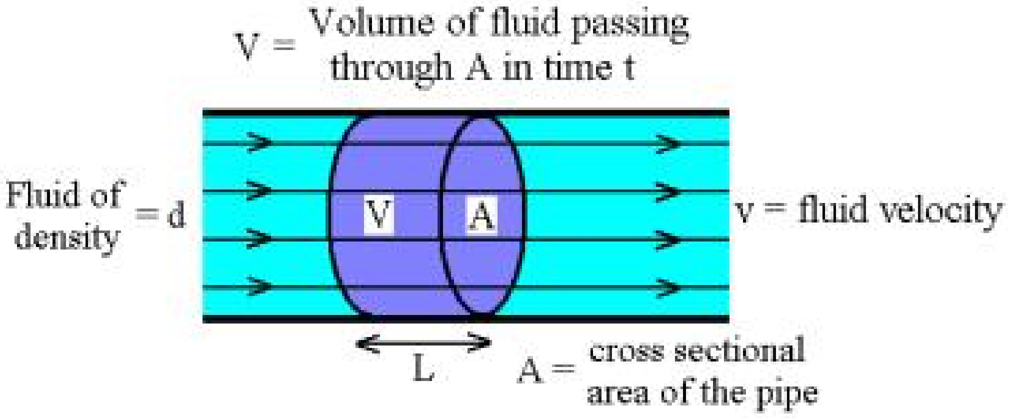


Figure 2.7: The Law of Conservation of Mass, denotes the mass of the fluid remains constant regardless of other parameters

2.5 Past Works

2.5.1 Off-grid electrification from Pico-hydro System in Kenya

Pico-hydro scheme based on Pelton Turbine has been designed and studied by researchers from Nottingham Trent University, United Kingdom. The system was installed in rural residential of Kathamba, Kenya. The overall scheme was able to generate up to 1.1 kW during operation with 8.41 m^3/s flow rate using Pelton Turbine with 200 mm pitch circle diameter [20].

Figure 2.8: Pico-hydro scheme using Pelton Turbine in Kathamba, Kenya

2.4.2 Micro-hydro scheme in Bondo, Kenya

A micro-hydro scheme with Pelton Turbine is designed and installed at the river located in Bondo, Kenya by a team of researchers from University of Zimbabwe. They assessed that the system has a capacity of 88 kW during operation with 0.325 m^3/s flow rate. The overall efficiency of the turbine is measured at 60% [10].

Figure 2.9: Pelton Turbine used in micro-hydro scheme in Bondo, Kenya

CHAPTER 3

METHODOLOGY

3.0 Project Phases

The overall project implementation and completion is expected for 28 weeks. According to the course timeline which is divided for Final Year Project I and II, each phase for the realization of project is taken into consideration.

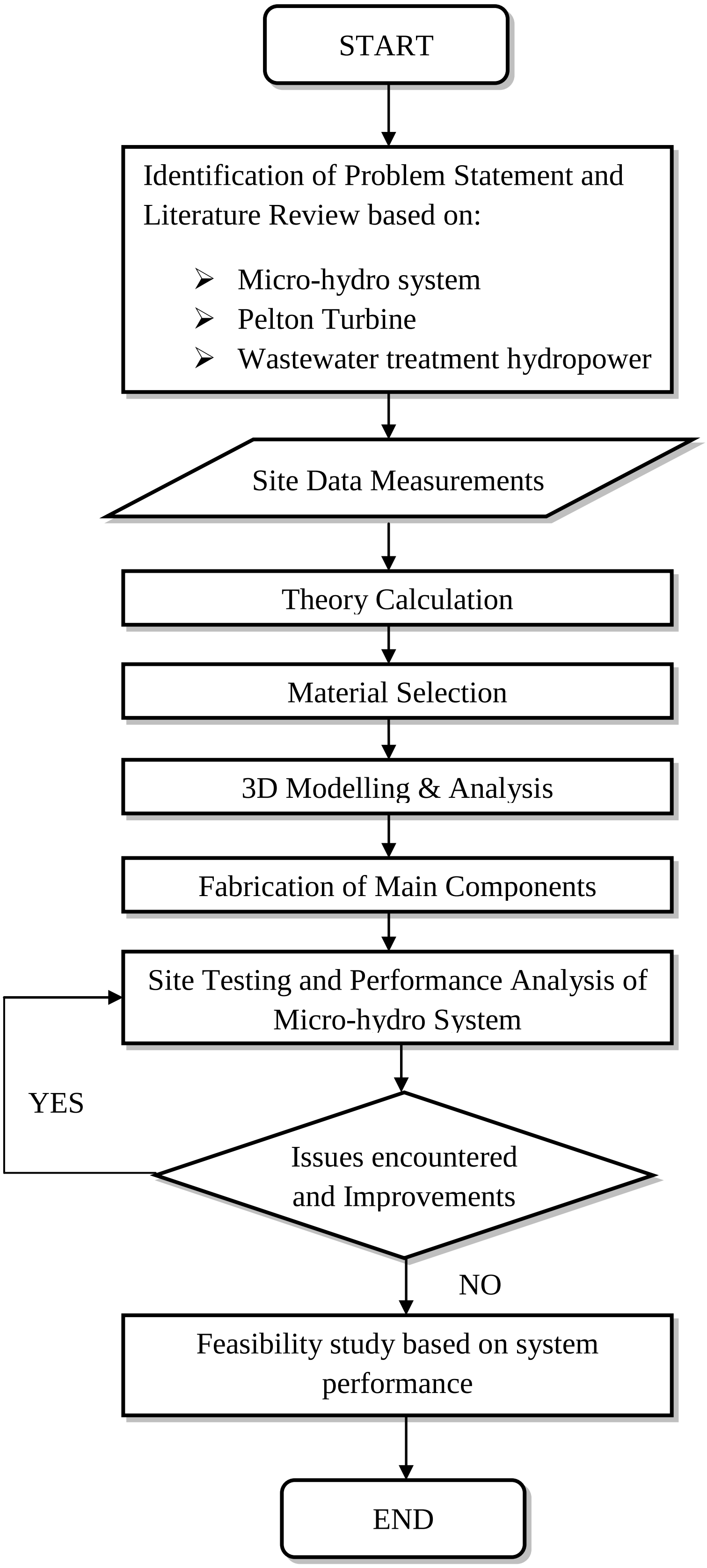
3.0.1 First Phase

For the first phase occurring in the initial 14 weeks, the inception and conceptual stage takes place. Within this phase, several researches will be reviewed which deemed appropriate for the project as well as identifying the problem statement for current objectives. Afterwards, measurement and data gathering will be starting at the control site and this may include the dimension of the water channel (m), flow rate (m^3/s) and also velocity of water (m/s). From hand sketches to using Solidworks software, the overall design of the components for the system are modelled in 3D. The ANSYS Fluent software is used to visualize the flow of water occurring within the forebay tank to the penstock.

3.0.2 Second Phase

The second phase of the project commences at the final 14 weeks of the course timeline. This phase involves the implementation and analyse stage. The fabrication will involves manual labour in terms of metalworking processes such as welding, bending and lathing. After fabrication, site testing will proceed with the produced system model. Several measurements will be taken on site such as power output from the turbine (W), torque produced (rpm) as well as velocity of water flow and jet flow (m/s) which are important to study the effect of this parameters on turbine performance. Afterwards, a feasibility study will be done to assess the impact of this project towards the water treatment facilities.

3.1 Project Flowchart



3.2 Project Timeline

			Final Year Project (FYP 1)													
No.	**Project Activities**	**Allocation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Discussion on Project Title	2 weeks	■	■												
2	Literature Review & Research	3 weeks			■	■	■									
3	Information Gathering - Parameters, Design	2 weeks					■	■								
4	Theory Calculation of the Project	2 weeks					■	■								
5	Preparation of Extended Proposal	1 week							■							
6	Submission of Extended Proposal	22/2/2015								▲						
7	Visit to Control Site for Measurements	1 week									■					
8	Discussion on Findings & Issues	1 week									■					
9	Proposal Defence Evaluation	19/3/2015										▲				
10	Design of Conveyance System (Penstock)	2 weeks										■	■			
11	Design of Pelton Turbine - 3D Model	3 weeks										■	■	■		
12	Material Selection and Price Quotation	3 weeks											■	■	■	
13	Flow Analysis of Penstock Design - ANSYS Fluent	1 week												■		
14	Design of Synchronous Generator	3 weeks												■	■	■
15	Submission of Draft Interim Report	1 week													■	
16	Submission of Interim Report	20/4/2015														▲

			Final Year Project (FYP 2)													
No.	**Project Activities**	**Allocation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Fabrication of Hydro System - Phase I (Penstock)	2 weeks	■	■												
2	Fabrication of Hydro System - Phase II (Turbine)	3 weeks		■	■	■										
3	Fabrication of Hydro System - Phase III (Elec. Sys)	3 weeks			■	■	■									
4	Testing of Hydro System Performance	2 weeks						▲	■							
5	Gathering and Analysis of Data from Testing	3 weeks						■	■	■						
6	Submission of Progress Report	1 week							▲							
7	Evaluation on Results and Performance of System	2 weeks								■	■					
8	Overall Design Improvements	1 week									■					
9	Pre-SEDEX Evaluation	1 week										▲				
10	Cost Evaluation for the Hydro System	1 week										■				
11	Preparation of Final Report	4 weeks										■	■	■	■	
12	Submission of Draft Final Report	1 week												■		
13	Preparation of Technical Poster	2 weeks												■	■	
14	Submission of Technical Paper	1 week												▲		
15	Submission of Dissertation (Soft Bound)	1 week													▲	
16	Viva Presentation (Ext. Examiners, SV)	-														▲
17	Submission of Dissertation (Hard Bound)	2 weeks														▲

3.3 Project Activities

3.3.1 Fabrication of Hydro System Components

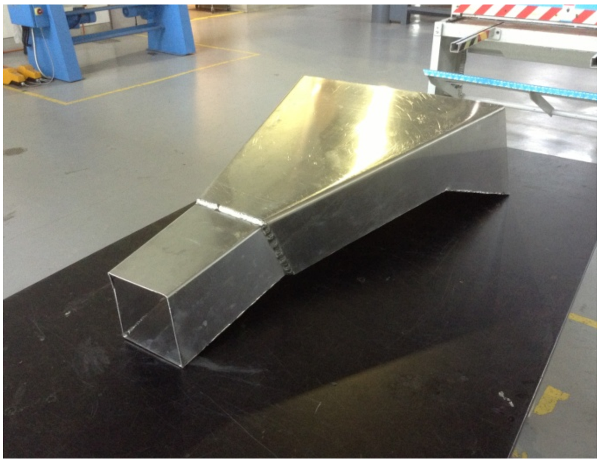


Figure 3.1: Fabrication of Penstock from Aluminium Sheet

1. Fabrication of Penstock

The penstock is modelled based on design done through Solidworks software. The dimension and shape of the penstock is based on the water drain in the treatment facilities.

Fabrication of penstock continues until 2 weeks. The material which is used is Aluminium with varying thickness (2mm - 3mm).

Figure 3.2: Penstock and Piping Joints at Testing Site

2. Penstock Joint & Piping

The pipes which are connected on the penstock is selected based on calculations done.

The main purpose of choosing pipes which gradually reduced through the whole connection is due to lessening the water pressure which can initiate surge force when area is reduced dramatically.

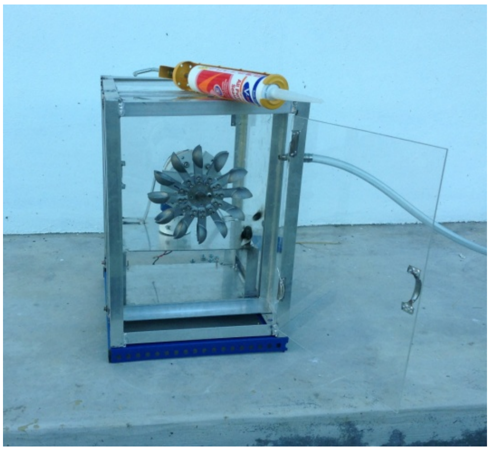


Figure 3.3: Turbine & Generator Casing after completion

3. Turbine and Generator Casing

The casing is done based on the size of the turbine and generator itself.

The construction of the casing took approximately 6 weeks due to various issues encountered. The main structure is fabricated using Aluminium while Perspex is used as glass-like exterior for the casing.

3.3.2 Site Testing & Performance Evaluation

Figure 3.4: Hydropower system at the Sewage Drain

1. Testing at the Drainage

The hydropower system is tested at the drainage of treatment facilities. The penstock is placed where the highest potential of water can be obtained through full immersion.

After placing the system at site, it is viewed that the flow of water from the drainage is not feasible for this hydropower system. Thus, selection of other method is considered.

Figure 3.5: Testing of Hydropower system by using Tap Water

2. Testing using Tap Water.

The tap water allows full control of water velocity flowing through the pipe. It assessed in which velocity of water the turbine starts to rotate at full rotation.

Measurements are taken using multimeter for voltage & current. The data is recorded and analysed as intended. 5 different readings are taken for the following site.

3.4 Selected Model for Hydro System

The major equipments which have been used in the hydro system include:

1. Pelton Turbine
2. Wind Turbine based Generator
3. Mechanical Coupling

Model Specifications:

Pelton Turbine

- Turbine Runner Diameter: 198mm / 0.198m
- Turbine Buckets: 6
- Bucket Radius: 95mm / 0.095m
- Nozzle Area: 3.14×10^{-4} m^2

Generator

- Model: Hyacinth P-300W
- Rated Power: 300 W
- Rated DC Voltage: DC 12V/24V
- Rated Current: 25A/12.5A
- Rated Speed: 900 rpm
- Type: Three-phase permanent magnet generator

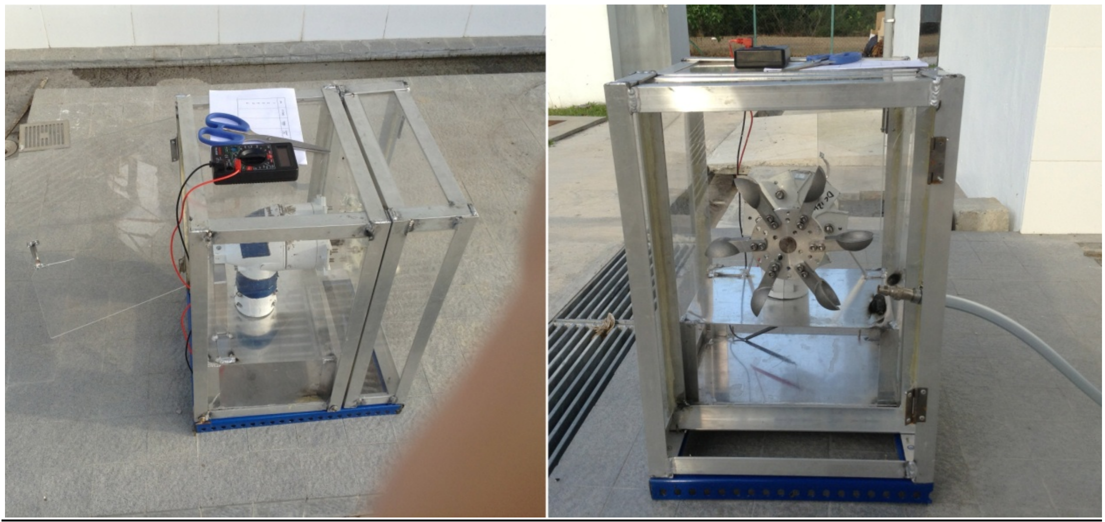


Figure 3.7: Generator Mounted on the Casing (Left); Pelton Turbine with 6 Buckets used for the Experiment (Right)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Gathering & Analysis

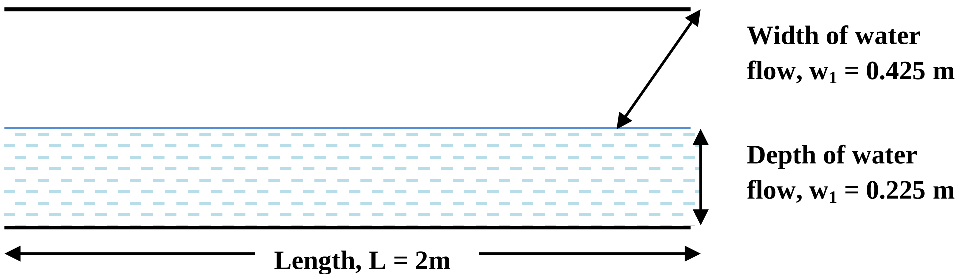


Figure 4.1: The site where measurements are taken for the hydro system project

Average stream flow velocity, V_r:

1. First reading: 2m/4.0s = 0.5 m/s
2. Second reading: 2m/3.89s = 0.514 m/s
3. Third reading: 2m/4.01s = 0.498 m/s

$$\text{Average velocity} = \frac{0.5 + 0.514 + 0.498}{3} = 0.504 \text{ m/s}$$

By using floating method, it is recommended to apply correction factor which shows the actual mean velocity of stream in relative to the condition or depth of the channel. For the effluent discharge stream, a correction factor of 0.45 is taken [18]:

$$V_m = V_{avg} \times 0.45$$

$$V_m = 0.227 \text{ m/s}$$

Cross-sectional area of the channel, A_r (m^2) [17]:

$$A_r = w \times d = 0.425 \times 0.225 = 0.0956 m^2$$

The water flow rate, Q (m^3/s):

$$Q = V_m \times A_r = 0.227 \times 0.0956 = 0.0217 m^3 s^{-1}$$

4.2 Theoretical Calculation for Pelton Turbines

Input power to the turbine (W) [18]:

(the gross net head, H_n is taken at 1 m)

$$P_{ti} = \rho g C_v^2 H_n Q_t$$

$$P_{ti} = (1000)(9.81)(0.97)^2(1)(0.0217)$$

$$P_{ti} = 200.29 \text{ W}$$

Calculation of turbine speed (N) [18]:

1. Specific speed, N_s; (where n_j is number of turbine nozzles (jets) taken at 1)

$$N_s = 85.49 \times \frac{\sqrt{n_j}}{H_n^{0.243}} = 85.49 \times \frac{\sqrt{1}}{(1m)^{0.243}}$$

$$N_s = 85.49 \text{ rpm}$$

2. Turbine speed, N [9];

$$N = N_s \times \frac{H_n^{\frac{5}{4}}}{\sqrt{P_{ti}}}$$

$$N = 85.49 \times \frac{(1m)^{\frac{5}{4}}}{\sqrt{0.20029\ kW}}$$

$$N = 191.02\ rpm$$

Calculation of the runner circle diameter, D_r (m):

1. The velocity of water jet through nozzle, v_j [9];

$$v_j = C_v \times \sqrt{2gH_n}$$

$$v_j = 0.97 \times \sqrt{(2)(9.81)(1)} = 4.29ms^{-1}$$

2. The runner tangential velocity, V_{tr} [18]:

$$V_{tr} = w \times R_r = \frac{\pi N D_r}{60}$$

$$V_{tr} = x \times v_j$$

Rearrange; $D_r = \frac{60 \times x}{\pi N} \times v_j$

$$D_r = 38.6 \times \frac{\sqrt{H_n}}{N} = 38.6 \times \frac{\sqrt{1}}{191.02\ rpm}$$

$$D_r = 0.202m$$

Given that the equation has been employed when taking value of x to be around 0.46 to 0.47. This can yields turbines with maximum efficiency.

Calculation of nozzle dimension, (m):

1. The diameter of the jet, d_j [18]:

$$d_j = \sqrt{\frac{4 \times Q_t}{(\pi \times n_j \times v_j)}}$$

$$d_j = \sqrt{\frac{4 \times 0.00339}{(\pi \times 1 \times 4.29)}} = 0.0318\ m$$

2. The nozzle area, A_j [18]:

$$A_j = \frac{\pi {d_j}^2}{4}$$

$$A_j = 7.942 \times 10^{-4} m^2$$

3. The water flow rate through each nozzle, Q_n [18]:

$$Q_n = v_j \times A_j$$

$$Q_n = 0.00341 \text{ m}^3\text{s}^{-1}$$

4. The distance between nozzle and bucket taking into account the minimum clearance between the nozzle and bucket, X_{nb} [18]:

$$X_{nb} = 0.625 \times D_r = 0.126\text{m}$$

Calculation of bucket dimensions (m):

1. The number of buckets on the runner, n_b [18]:

$$n_b = 15 + \frac{D_r}{(2 \times d_j)} = 15 + \left(\frac{0.202}{2 \times 0.08}\right)$$

$$n_b = 16.26 \approx 17$$

2. The length of moment arm of bucket [18]:

$$L_{ab} = 0.195 \times D_r = 0.04\text{m}$$

3. The radius of bucket center of mass to center of runner, R_{br} [18]:

$$R_{br} = 0.47 \times D_r = 0.095\text{m}$$

4.3 Penstock Design & Analysis

Area of the Penstock

From the Continuity Equation - conservation of mass [19]:

$$\dot{Q}_{\substack{net\\in}} = \dot{Q}_{\substack{net\\out}}$$

$$A_{in}V_{in} = A_{out}V_{out}$$

For the first section, the *diameter of the pipe (m)*: (selection of pipe diameter is 3 " which is equivalent to 0.0762m)

$$A_j v_j = A_{pipe}V_{pipe}$$

$$V_{pipe} = \frac{A_j v_j}{A_{pipe}} = \frac{0.0215\text{m}^3\text{s}^{-1}}{\frac{\pi d_{pipe}^{\ 2}}{4}} = 4.71 \text{ m/s}$$

For the second section, the width of the socket connection with *forebay tank and the pipe (m)*:

$$A_{tank}V_{avg} = A_{socket}V_{pipe}$$

$$(0.0956m^2)(0.504 \text{ m/s}) = A_{socket}(4.71 \text{ ms})$$

$$A_{socket} = 0.0102 \text{ m}^2$$

Given that: A = width × length

$$\therefore w_{socket} = \sqrt{0.0102 \text{ m}^2} = 0.101 \text{ m} = 10.1 \text{ cm}$$

The socket connection is square in area, so the length is equal to the width of the connection.

To reduce the effect of water turbulence caused by sudden change in area, the penstock diameter is further reduced to 1 1/4" or approximately 0.03175 m. The speed calculated at the end of the nozzle is related to the axial force acting on the buckets.

$$A_{penstock\ 1}V_j = A_{penstock\ 2}V_a$$

$$V_a = \frac{0.01956}{7.917 \times 10^{-4}}$$

$$V_a = 24.71 \text{ m/s}$$

The force exerted by the jet of water is given by [18]:

$$F = \rho A_{penstock\ 2}V_a\left[v_j + V_{a1}\right]$$

$$F = (1000)\left(7.917 \times 10^{-4}\right)(24.71)[4.29 + 2.27\cos 30^{o}]$$

$$F = 122.38 \text{ N}$$

The power given by the runner jet is [10]:

$$P = 122.38 \times \frac{\pi(0.202)(191.02)}{60}$$

$$P = 247.25 \text{ W}$$

4.3.1 Penstock Analysis

Simulation for the velocity and pressure contours are done by using ANSYS Fluent software. The boundary conditions for the inlet, connector and outlet wall are set using the velocity values calculated prior (e.g. V_{avg}, V_{pipe}, v_{jet}). The main purpose of doing the CFD analysis is to assess the pressure occurring within the penstock which allow proper measures to be taken during fabrication.

Velocity Contour of the Penstock

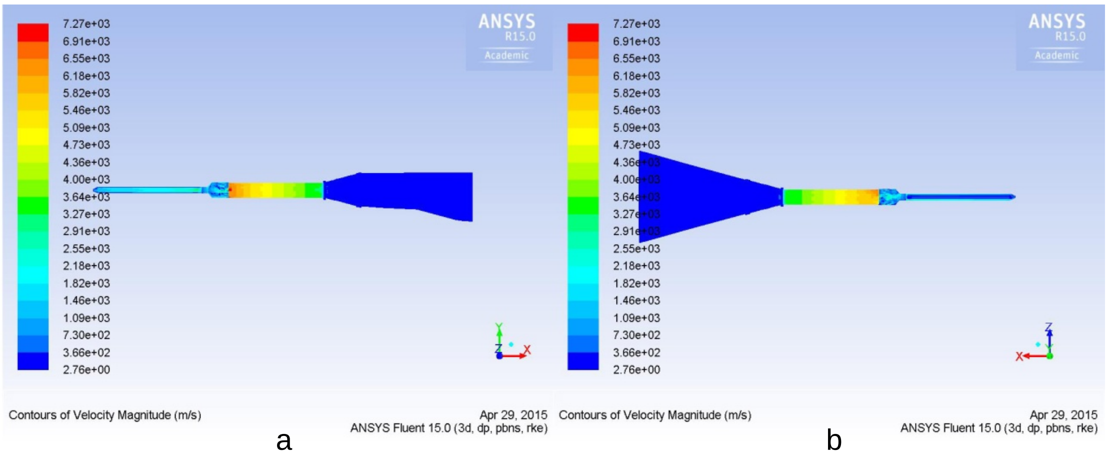


Figure 4.2: a) The right hand view of the velocity contour for the penstock; b) the upper view of the velocity contour for the penstock.

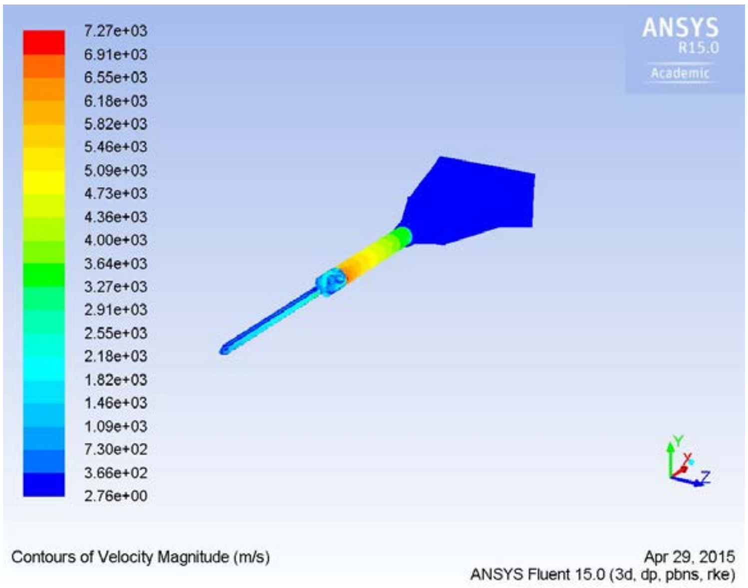


Figure 4.3: Isometric projection of the penstock showing the velocity contour (dark blue indicates the lowest velocity, red indicates the highest velocity).

Pressure Contour of the Penstock

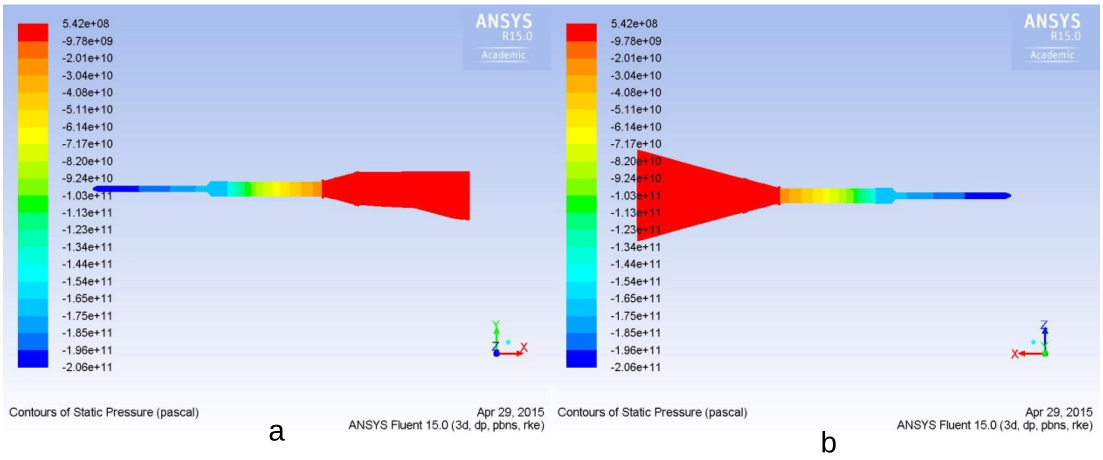


Figure 4.4: a) Right-hand view of the pressure contour for penstock; b) Upper view of the pressure contour for penstock.

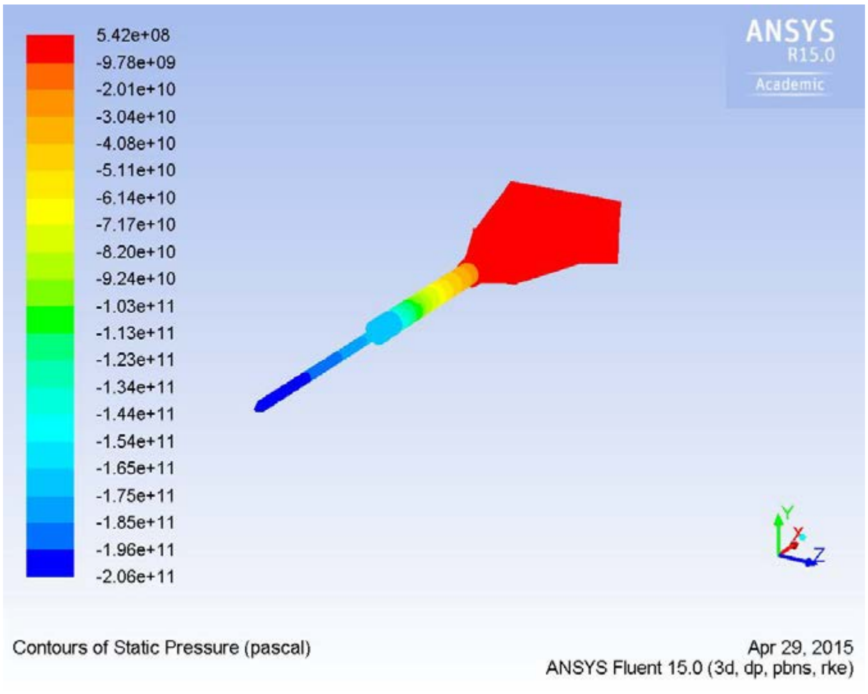


Figure 4.5: Isometric view of pressure contour for the penstock design; the highest pressure of water is inlet of penstock while the lowest pressure is reduced piping which has diameter of $1^{1/4}$ inch.

4.4 Design of Hydrosystem Components

4.4.1 Penstock with Piping Joints

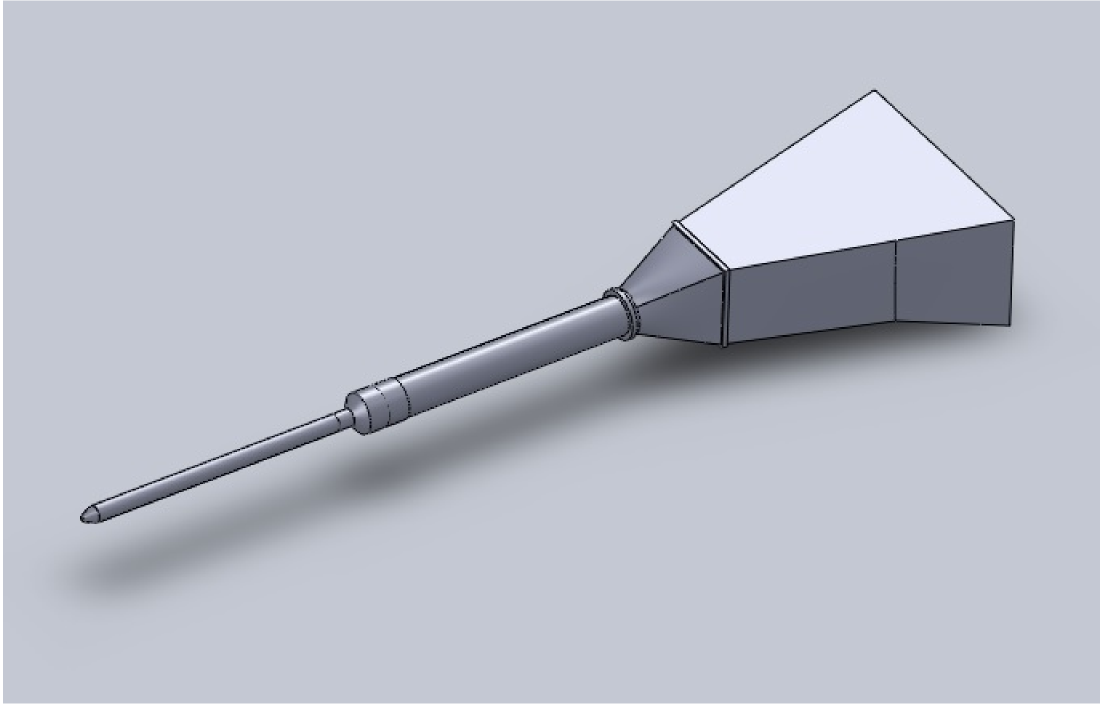


Figure 4.6: Penstock Design with Piping and Nozzle

The penstock design is based on the water catchment tank in real-life hydrosystem application. From the inlet of the penstock, there is a silt basin which will allow the sediments e.g. sand and small rocks to be collected at the inlet. Gradual reduction in area throughout the penstock will allow increase in velocity towards the end of penstock at nozzle. This will in turn leads to water jet which will impinges the buckets of Pelton Turbine which rotates the generator. The variation of power produced will be dependent of the water velocity from the source, v_r.

4.4.2 Pelton Turbine

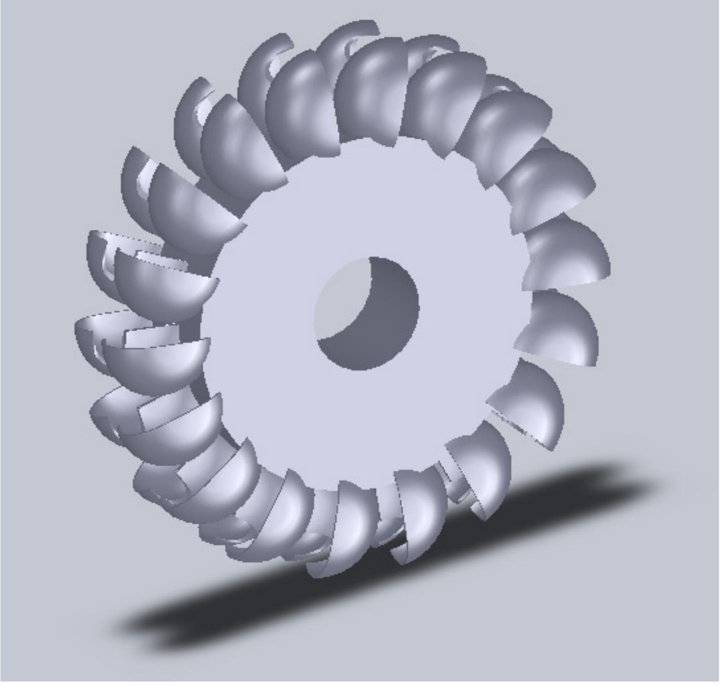


Figure 4.7: Initial Pelton Turbine Design

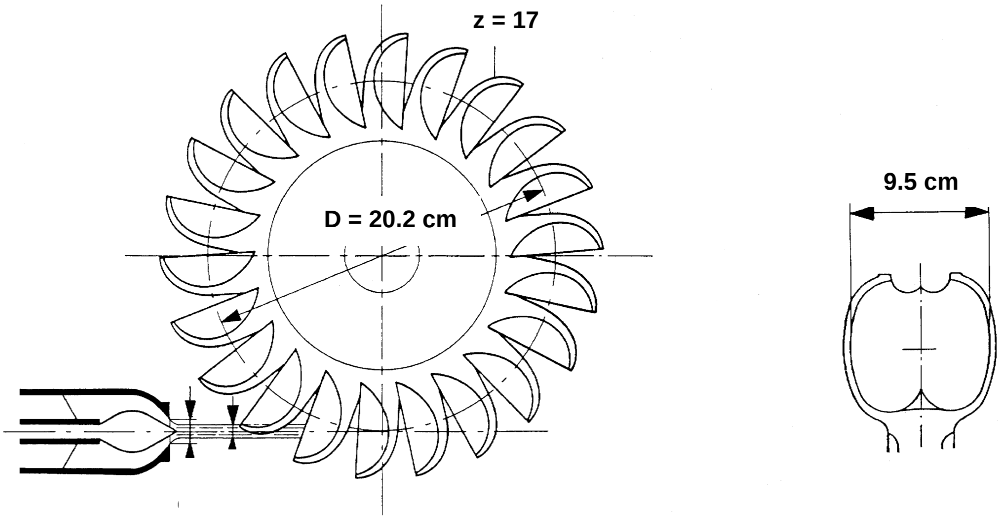


Figure 4.8: Pelton Turbine Dimensions from Calculations

The Pelton Turbine design was completed using Solidworks software. The initial design consists of 17 buckets on the periphery disc. In small pico-hydro system application, the maximum number of buckets is proposed to be 17 where the runner is smaller in diameter compared to larger hydro system application [9]. The overall diameter of the turbine is calculated as 0.202 m or 20.2 cm which has 17 buckets with moment arm of bucket at 4 cm and radius of bucket around 9.5 cm.

4.5 Theoretical Experiment

Table 3.1: Theoretical Data for the Hydro system

H_g (m)	N (rpm)	A_r (m^2)	V_r (m/s)	V_j (m/s)	Q_t (m^3/s)	P_{el} (W)	P_{ti} (W)	P_{to} (W)
1	191.02	0.0956	0.227	4.29	0.0217	200.307	199.696	191.098
	191.02	0.0956	0.222	4.29	0.02122	195.895	195.297	186.889
	191.02	0.0956	0.217	4.29	0.02075	191.483	190.898	182.68
	191.02	0.0956	0.212	4.29	0.02027	187.071	186.5	178.471
	191.02	0.0956	0.207	4.29	0.01979	182.659	182.101	174.261

The data is obtained through calculation from the measurement obtained at site and the equation provided as mentioned. The variation of flow rate is taken from difference of 0.005 m^3/s where the water velocity flowing to the penstock is initially at 0.227 m/s. The power obtained theoretically is around 200 W but due to losses in the components the overall power output to turbine is 191 W.

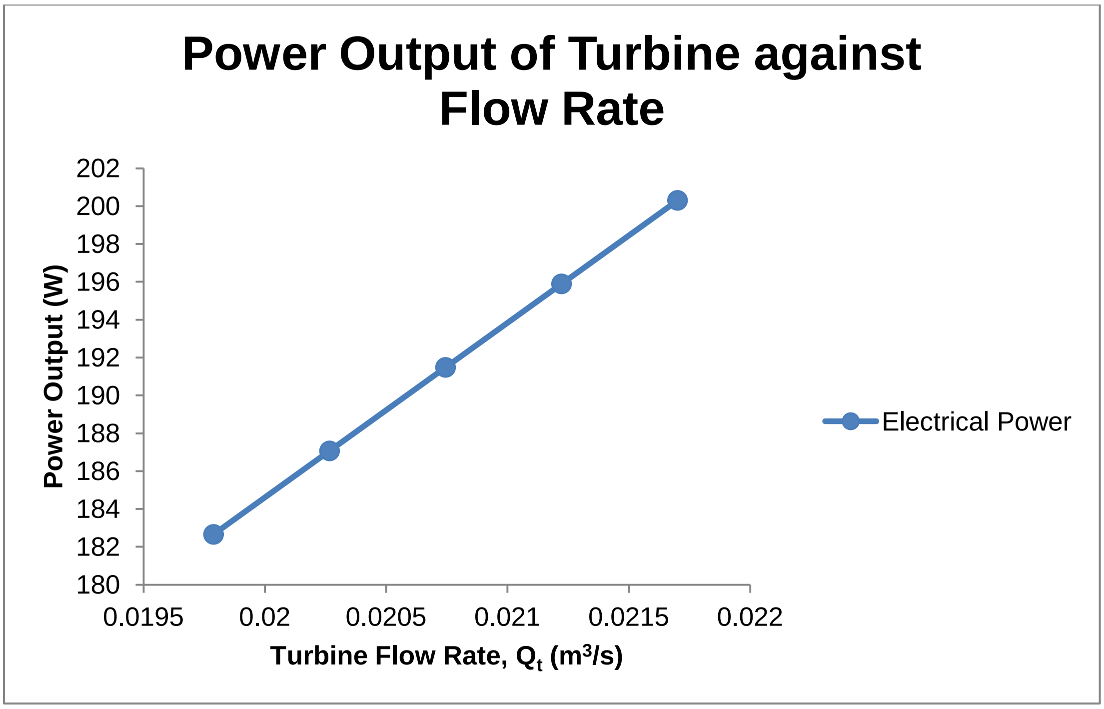


Figure 4.9: Relationship between Power Output (W) and Flow Rate of Water into Turbine (m^3/s)

From Figure 4.9, it is assessed that the flow rate of water into turbine, Q_t is directly proportional to the power output of the turbine, P_{to}. With increment in the flow rate, the power into the turbine also increases.

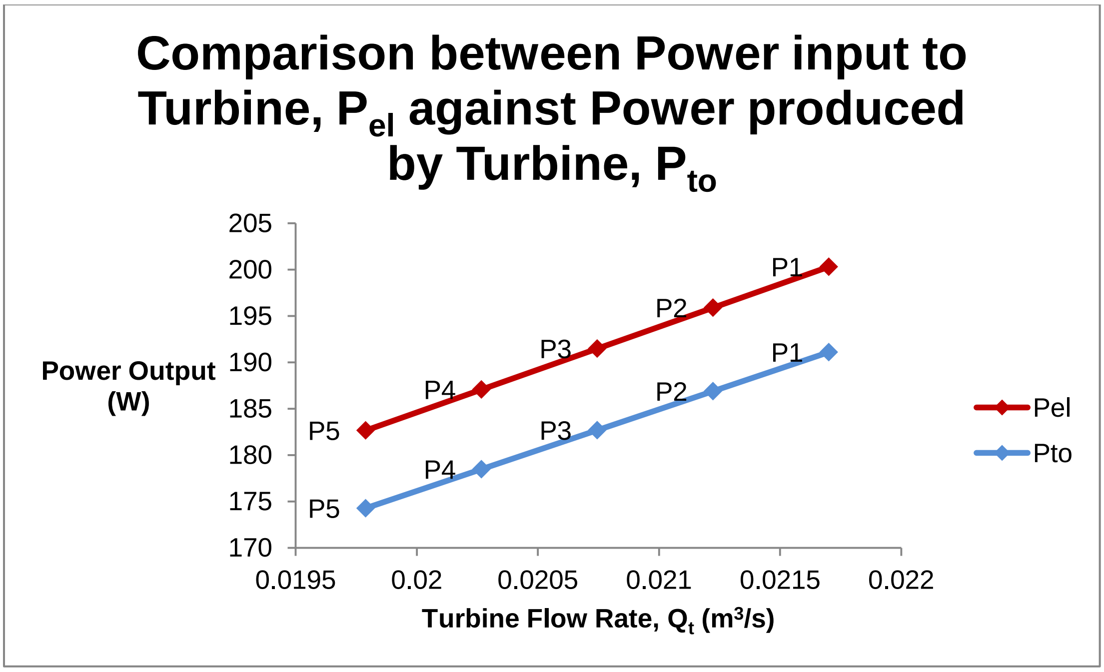


Figure 4.10: Comparison of Power into Turbine and Actual Power Output against Flow Rate into Turbine

Based on Figure 4.10, the theoretical power produced by the turbine, P_{to} is generally smaller at varying flow rate than the theoretical power input into the turbine, P_{el}. Considering losses which is prevalent in the components such as mechanical and friction pipe losses, the power output produced by turbine is affected by such considerations.

Table 4.2: Theoretical Parameters including Turbine Efficiency and Torque

H_g (m)	N_s (rpm)	V_r (m/s)	V_j (m/s)	Q_t (m^3/s)	P_{ti} (W)	P_{to} (W)	η	T (Nm)
1	85.49	0.227	4.29	0.0217	199.696	191.098	0.65072	14.9175
	85.49	0.222	4.29	0.02122	195.297	186.889	0.65072	14.589
	85.49	0.217	4.29	0.02075	190.898	182.68	0.65073	14.2604
	85.49	0.212	4.29	0.02027	186.5	178.471	0.65073	13.9318
	85.49	0.207	4.29	0.01979	182.101	174.261	0.65072	13.6032

The hydraulic efficiency of turbine is given from the following equation;

$$\text{Turbine Hydraulic Efficiency, } \eta_{th} = \frac{P_{to}}{P_{ti}}$$

And the Turbine Mechanical Efficiency, η_{tm} considering generator and turbine is at 0.85 and 0.80 respectively [10]. The overall efficiency of the turbine can be expressed as follow:

$$\eta_t = \eta_{th} \times \eta_{tm}$$

The torque acting on the turbine is given from the equation as follow [18]:

$$T = Q_t \times D_r \times \rho_w \times \left(V_j - V_{tr}\right)$$

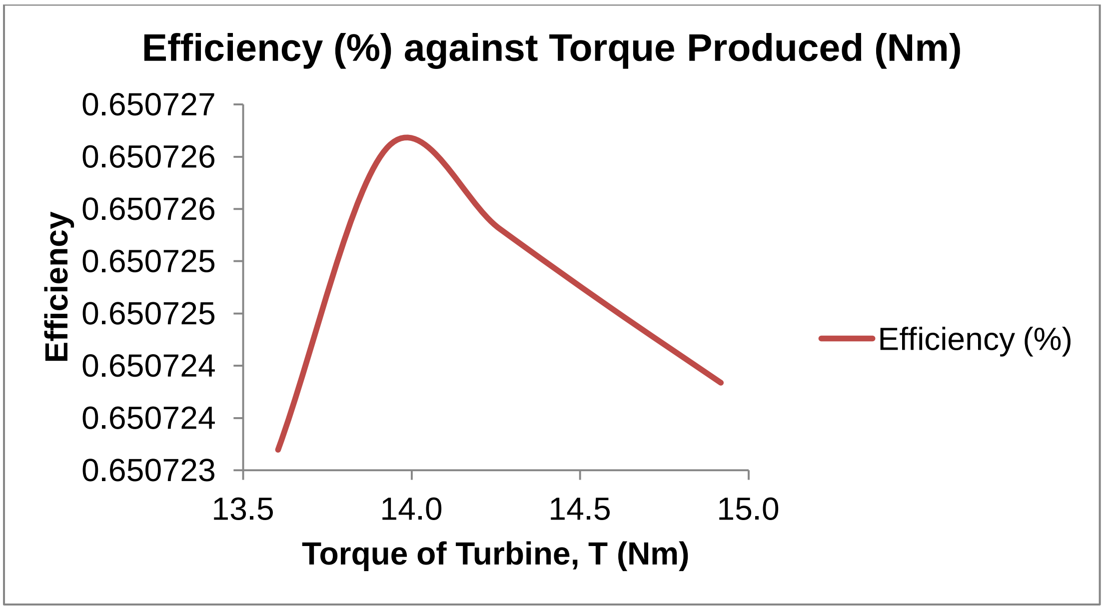


Figure 4.11: Efficiency of Turbine against Torque Produced by Turbine

The efficiency of the turbine increases until 14.2 Nm where it reaches the peak load of generator. Afterwards, there is a sharp decline in efficiency where the generator experiences underloaded (continuous duty) and lastly to overloaded (intermittent duty). It is recommended to operate the generator at the peak load stage in order to save on energy consumption for the system. Basically, the turbine efficiency is dependent on the electrical power produced by the motor or generator. Furthermore, the electrical power produced is highly dependent on the turbine speed during operation. In general, torque is related to the output power as increment in speed causes increase in torque.

4.6 Actual Experiment

Table 4.3: Actual Parameters Obtained from Hydro System Testing

H_g (m)	n_b	N (rpm)	Voltage (V)	I (A)	V_r (m/s)	V_j (m/s)	Q_t (m^3/s)	P_{ti} (W)	P_{to} (W)
1	6	112.15	7.4	0.65	1.35	4.29	0.00083	7.68	4.81
	6	68.00	6.5	0.50	0.92	4.29	0.00056	5.19	3.25
	6	46.04	5.4	0.40	0.61	4.29	0.00037	3.45	2.16
	6	37.53	3.3	0.30	0.28	4.29	0.00017	1.58	0.99
	6	30.85	1.4	0.26	0.10	4.29	6.3E-05	0.58	0.364

The power produced from the actual experiment is exceptionally lower than the theoretical power calculated prior. There are several factor which determines this such as:

1. The Generator provided has an output of 12 VDC, where the maximum voltage obtained is 7.4 V. The overall power rating of the generator is 300 W in relative to turbine speed input of 900 rpm.
2. The buckets of the turbine has been reduced from 12 to 6 due to the weight of the overall Pelton Turbine in which the water jet velocity is not sufficient to rotate the turbine.
3. The flow rate of water into the turbine, Q_t is very small compared to the theoretical data obtained before. This is because the diameter of pipe from tap water is around 14 mm or 0.014 m. The area of the pipe is 6.16 x 10^{-6} m^2.
4. The actual runner diameter, D_r of the Pelton Turbine is 0.198 m or 19.8 cm. This causes the parameters which is dependent on the runner size e.g. torque produced to be lower than the theoretical values.

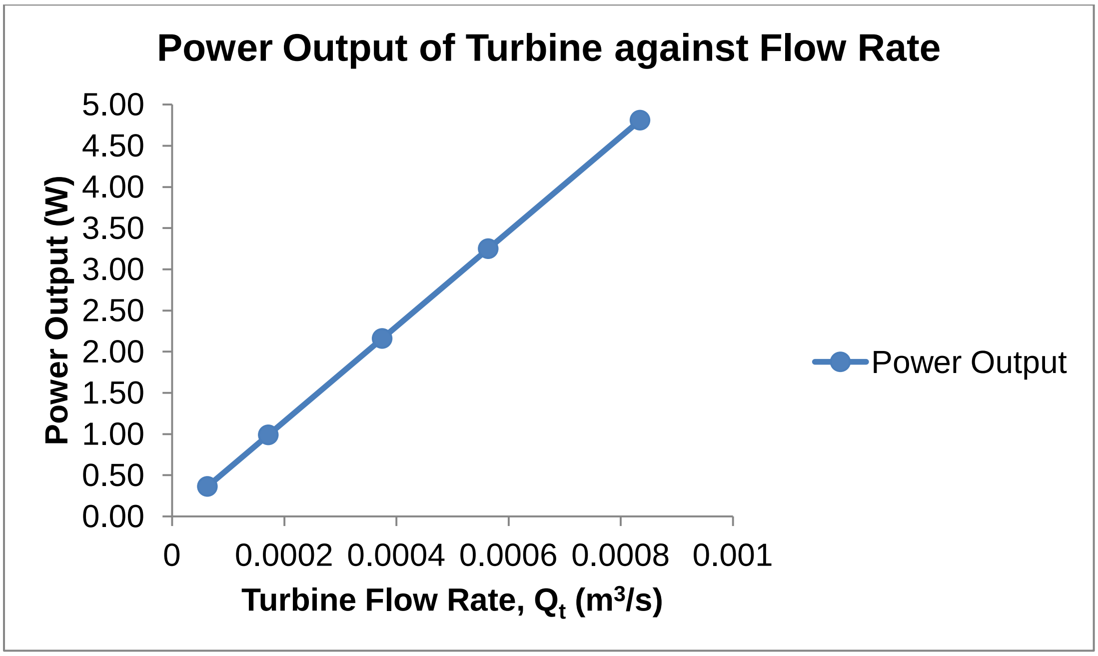


Figure 4.12: Relationship between Power Output and Turbine Flow Rate, Q_t

Power output of turbine is directly dependent on the water flow rate into the turbine as assessed from the theoretical values before. It is confirmed that the relationship between velocity of water from the source into the turbine affect the generation of power by the generator.

Table 4.4: Actual Parameters for the Hydro System Testing including Efficiency and Torque

H_g (m)	N (rpm)	V_j (m/s)	Q_t (m^3/s)	P_{ti} (W)	P_{to} (W)	η	T (Nm)
1	112.15	4.29	0.00083	7.68	4.81	0.42596	0.51672
	68.00	4.29	0.00056	5.19	3.25	0.42596	0.40022
	46.04	4.29	0.00037	3.45	2.16	0.42596	0.28289
	37.53	4.29	0.00017	1.58	0.99	0.42596	0.13266
	30.85	4.29	6.3E-05	0.58	0.364	0.42596	0.04964

The data calculated for efficiency and torque represent a variation from the values obtained theoretically. In the actual experiment, power output of the turbine (the values read through multimeter) is considerably smaller than the power input of the turbine. This shows an inefficient hydro power system where there are some losses in terms of mechanical components (e.g. shaft) or piping (due to friction). The overall efficiency of turbine however remains constant through the whole readings.

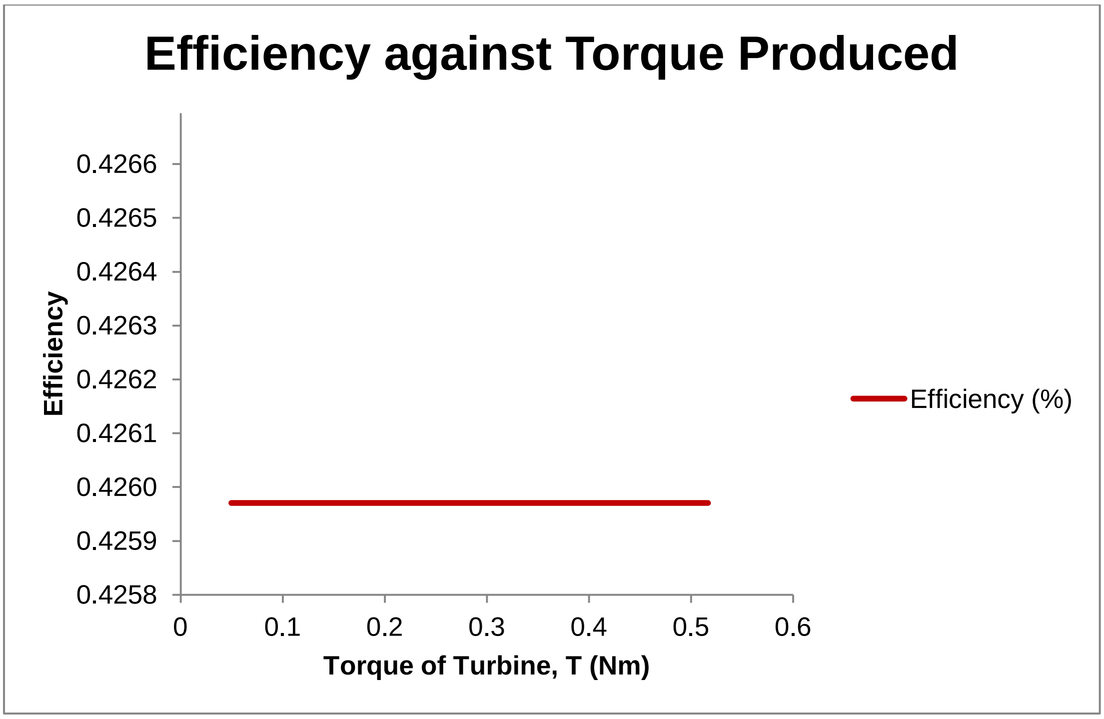


Figure 4.13: The Efficiency of Turbine against Torque Produced

There is no variation in graph when the torque increases as the efficiency remains the same. The difference in power output of the turbine, P_{to} from changing of water source flow rate (m3/s) is small which yield hydraulic efficiency, η_{th} with very small variation between each changes of flow rate. It is assumed that the generator is operating at peak load stage which corresponds to highest efficiency attainable for this type of generator. The highest efficiency obtained by the generator is 0.426 or 42.6% which relatively smaller than the theoretically obtained data.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The project mainly focuses on the implementation of pico-hydro system at wastewater treatment facilities in order to save on the operating expenses related to power consumption. Several design processes and calculations have been done to assess the feasibility. Based on the theoretical values, the hydro system is capable of producing up to 200 W of power. However, a feasibility study had been done which assess that the treatment facilities drainage does not has a suitable amount of flow rate (m^3/s) to cater the operation of impulse turbine (e.g. Pelton or Turgo).

It is shown that the power produced from operation of Pelton turbine is highly dependent on water source velocity,V_r (m/s). Considering a head gross of 1 m at site, it is proposed that the operation of the Pelton Turbine to be utilized in medium or high head situation. Therefore, the power produced by hydro system may have been higher if the head of body water is higher at project site.

In general, the hydro system is implementable at site with varying power output depending on the type of hydraulic turbine used e.g. Impulse or Reaction Turbines. However, based on the feasibility study done and improvements made to the project it is viewed that using Impulse Turbine is not suitable for the treatment facilities drain as the flow rate is too small due to water source velocity. Despite having varying flow rate (m^3/s) during different times of the day (e.g. peak hour operation and seasonal changes), a complex design using various components should be considered if using Impulse Turbine at site.

5.2 Recommendations

For the future works on this project, several recommendations and improvement are expected that can make the project more feasible and achievable for the pico-hydro system :

a) Fabrication and selection of material for the penstock. Selection of one material e.g. Aluminium for the whole body of the penstock to the piping is recommended due to avoiding attachment issues.
b) Using ANSYS features to simulate the turbine performance according to control site parameters.
c) Proper selection of hydraulic turbine to assess on the performance, where selections are made according to the flow rate and gross head at the site. Selection of the turbine can be made based on the graph available in the book.
d) Choosing a higher specification generator to produce greater capacity of power. Selection of generator can be made by knowing the turbine speed (rpm) through calculations which is relative to power output.
e) Utilizing various components e.g. water pump and control valve to study the effect of water velocity on the turbine performance. As the flow rate at site is too small, using water pump is expected to accommodate the operation of the Impulse Turbine thus producing water stream or jet capable of rotating the machinery.

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APPENDICES

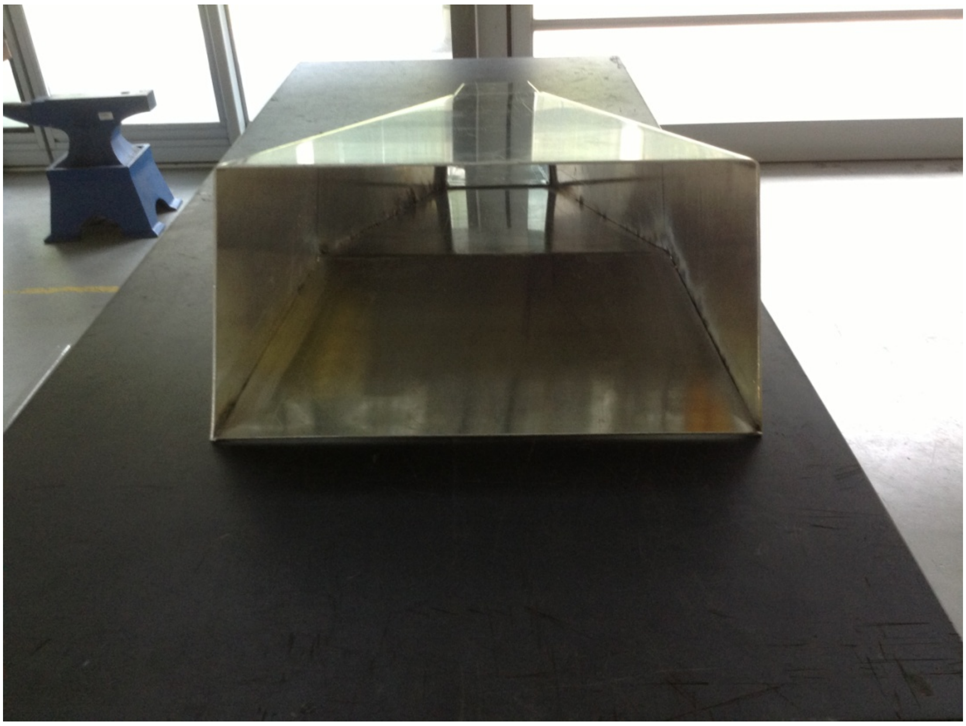


Figure A1: Penstock Fabrication in Common Engineering Lab, Block 21, UTP

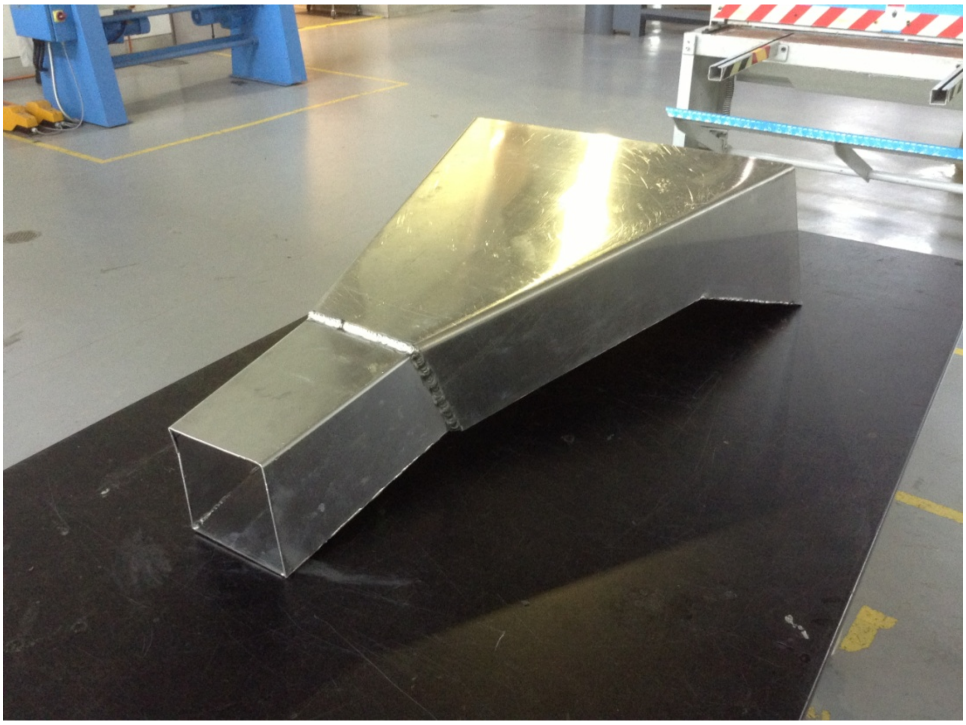


Figure A2: Completed Penstock Fabrication for the Hydro System

Figure A3: Velocity Measurements for Water Flowing in the Drain of Sewage Treatment Plant, UTP

Figure A4: Hydro-system Components in Place at the Drain of Sewage Treatment Plant, UTP

Figure A5: Water Flowing through the Penstock Component with Moderate Velocity

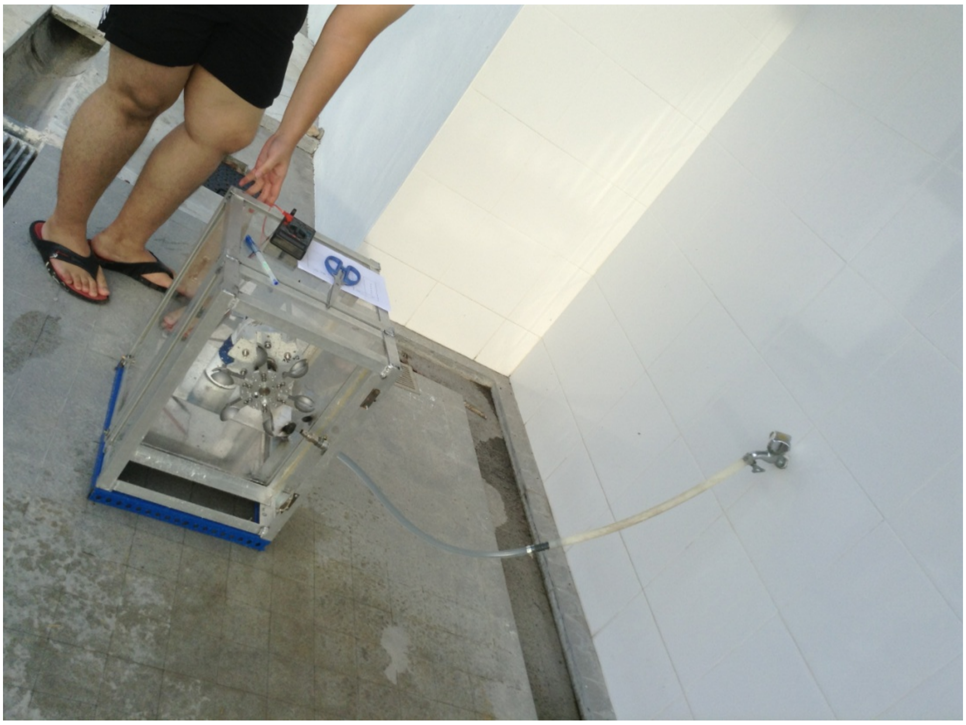
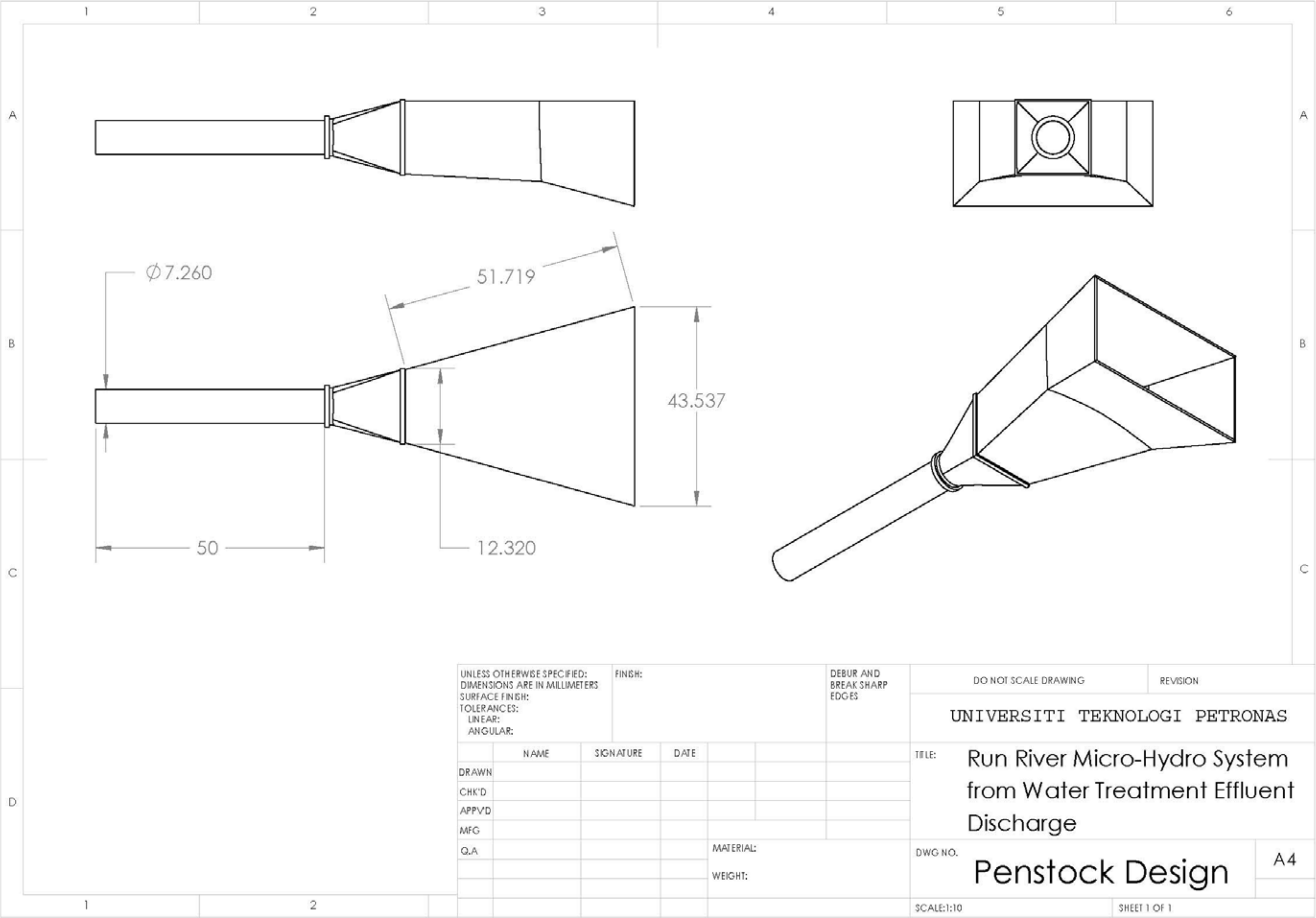


Figure A6: Preparation for Tap Water Testing for the Hydro-system

APPENDIX II: Drawing of Hydro-System Components



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

UNIVERSITI TEKNOLOGI PETRONAS

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Run River Micro-Hydro System from Water Treatment Effluent Discharge

MATERIAL:

WEIGHT:

DWG NO. Penstock Design

A4

SCALE:1:10

SHEET 1 OF 1