ENGR10004 Engineering Systems Design 1 2016 - Project Description

1 Introduction

The document provides a summary description for the design project for Engineering Systems Design 1. This project involves the planning, design, construction, testing and reporting of a solution to a real-world design problem involving the pumping, storage and delivery of water to a remote community using renewable energy resources. Note that this document is a summary of the design project and supplementary infomation and further resources will be provided during the course of the semester in workshops, lectures and online via the Learning Management System (LMS).

2 Project Description

2.1 Overview

The proposed project involves the planning, modelling, design and testing of a small wind-powered pumping station to supply drinking water to a remote community from an underground well - see Figure 1 for a systems diagram of the station. The inhabitants have been using a system of buckets and ropes to retrieve drinking water from the underground well but this system is proving more and more cumbersome as the population continues to grow and has caused several safety issues. Your engineering firm has decided to take on a humanitarian design challenge and improve the water storage and delivery process for the local people with the help from donations from several non-governmental and not-for-profit organisations.

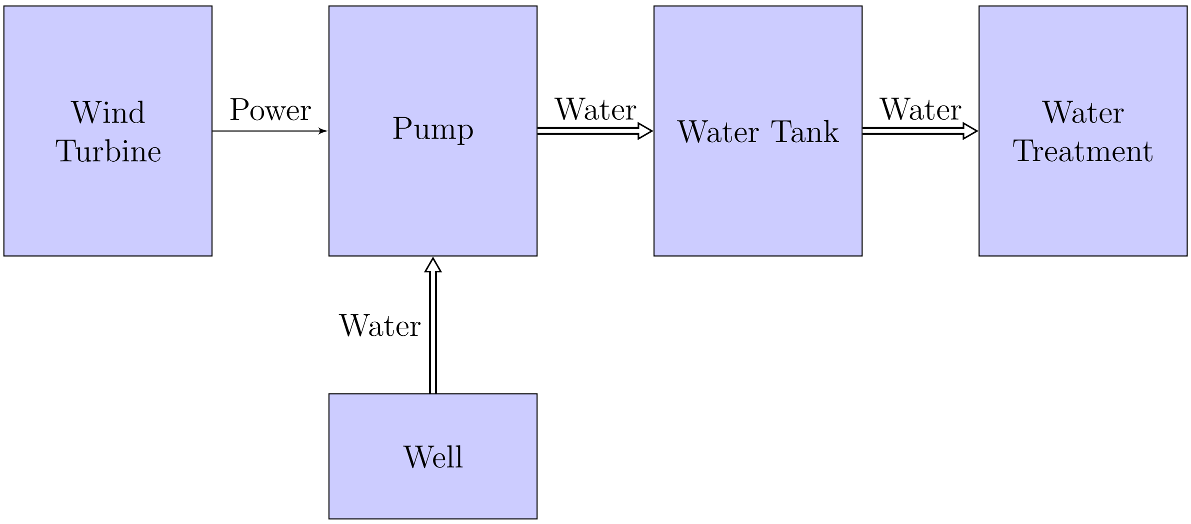

Figure 1: Wind Powered Pumping Station Systems Diagram

Wind energy will be harnessed via a wind turbine, which converts the mechanical energy provided by the wind into electrical energy to drive the pump in the underground well. The water is pumped through a pipe and stored in an above-ground tank that has a spout and tap on the bottom to allow people to obtain water via gravity-driven flow into their own buckets. This configuration with an above-ground tank is important because if a pump fails or no power is available, water can still be obtained for some time simply via gravity. There are periods when there is little or no wind power and energy storage system will be employed, but this is being designed and sized by an external engineering firm that specialises in this area. To improve the quality of the drinking water, the water will be treated by a small ozone generation and disinfection system.

The design project will consist of devising a real-world solution to several sub-systems of the water pumping and delivery process, each involving several major phases including experimentation, modelling, design and testing. In order to learn the relevant theory, measure important parameters and prototype designs, much of the design and testing will be performed on a small-scale test rig. Your team will gain familiarity with the operation of this rig over the course of the workshops for this subject and are required to show sufficient proficiency and obtain an acceptable level of performance in its operation. This rig will also feature as the centrepiece of your team's final presentation and demonstration.

Documentation and up-to-date reporting of your team's progress, design process and final engineering solution is critical for the successful completion of this project.

This is an open-ended design project, and as such will have many possible engineering solutions. Design solutions will require assumptions about the equipment, location, usage or environmental conditions of the proposed station.

You MUST clearly state any assumptions that you have made as part of the design process.

2.1.1 Location

The entire pumping system is to be located in a relatively flat, semi-arid area close to the location of the underground well, which is situated approximately 200m from the centre of the community. The well is approximately 35m deep. The only limitation on the height or land area that can be occupied by the complete pumping system is that the tower structure must be exactly 10m high, with the tank sitting on top of this. It is desired to keep the system relatively small so as not to disturb the environment and allow for any future growth of the town.

Residential power to the community is provided by several existing wind turbines that are outdated and already overloaded. Backup power, when the turbines cannot meet the load requirements, is provided by diesel generators that are used sparingly as they are prone to breakdowns and the transportation of diesel is extremely costly. Note that the existing power infrastructure also delivers Alternating Current (AC) and is therefore not compatible with the system to be designed, which uses Direct Current (DC).

Questions to consider

- How much land area will the entire system cover?
- Are there any landscape features that may impact on the operation of the turbine?
- What height does the wind turbine need to be?
- How will the turbine impact on its surrounding environment?
- What shape and profile should the turbine blades be?
- How much power will be generated by the wind turbine?
- How much power does the pump require?
- How heavy will the tank be? Can the ground support it?

2.1.2 Community

The remote community contains approximately 2,000 people who survive on an economy of local ocean fishing. The average annual growth rate of the population is 1.2%. There is no airstrip and the distance to the nearest town of any significance is 2,000km. The system must supply the drinking water requirements of the total population and more so it is expected that the system to be designed should last a minimum of 10 years. Water required for other tasks such as laundry and domestic cleaning can be obtained via a nearby river that is unsafe for drinking.

The simplicity and inherent safety of the system is also an important consideration as ordinary people must be able to obtain water without needing to know the technical details of the entire system. Several people can be selected to be trained as basic technicians and supplied with simple serviceable parts in the event of a problem with the pumping system.

Questions to consider

- What is the average daily need of drinking water for a person?
- What dimensions should the tank be?
- What size should the pump and piping be?
- What size should the nozzle be on the bottom of the tank?
- What risks to the community does the system pose?
- What are the safety mechanisms in the event of a failure?
- How much reserve water should be kept in the tank?

2.1.3 Weather

Day time temperatures in the region are fairly stable throughout the year, with a yearly average high of 31°C and a variation of only several degrees between average winter and summer highs. The yearly average low is 21°C and can vary from monthly low averages of 12°C in winter to 26°C in summer. The lowest temperature ever recorded was 4°C, almost 75 years ago. The area receives a lot of cloudy days due to the presence of the ocean nearby, hence solar power systems were deemed infeasible for the pumping system.

The prevailing wind is from the north but you can assume that the wind turbine will always be able to rotate to face the direction of the wind to achieve the maximum wind speed. Note that while the area is relatively free from inclement weather it can be susceptible to occasional tropical cyclones, the most recent one occurring 15 years ago and destroying several structures in the community.

Rainfall peaks in summer, with an average monthly rainfall of 110mm, while winter and spring are very dry and only average a few mm per month.

Questions to consider

- How does the wind turbine design depend on the wind speed?
- Will the tank have to be insulated from the sun?
- Is there a minimum wind speed needed for charging?
- Is there a maximum wind speed that can be captured?
- Is there an optimum wind speed?
- How much additional force should the tank tower structure be able to withstand due to weather conditions?
- Should rain water be collected from the tank structure?

2.1.4 Materials

While the type of wind turbine to be used is fixed, the other structures, including the turbine blades, storage tank, tank support structure, and water treatment tank can be made from any material deemed feasible. Of course, it is an objective to keep material costs down, while remaining safe and reliable. Should a breakdown occur, spare parts should be readily available and able to be installed quickly.

Questions to consider

- How strong does the tower need to be?
- Which material should the tank and its support structure be made out of?
- What shape should the tank be?
- Which components are at the greatest risk of failure?
- How much will the system cost to build? How much to run and maintain?
- Does the water treatment tank need to be a different material than the storage tank?
- Are there environmental issues that need to be considered?

2.2 System Modules

A flowchart representing the process for completing the design project is shown in Figure 2. There are several stages to this process that will take you through experimenting, modelling, design and testing phases and finally being able to tackle the large-scale design project itself. You will be gathering data from the small-scale experimental rig and learning about the relevant theory over the course of several workshops which will aid you in the selection of some *design variables*. This process is not a one-way process, in that there are loops in the flowchart representing the process of *iterative design*. Using iterative design, you design, implement and test an engineering solution as part of an iterative loop. If the observed system behaviour matches the desired system behaviour, you have solved the design problem. If the observed system behaviour doesn't match the desired system behaviour, then you have to go back to the design step and modify your design or model.

As you progress through the design project phases, you will be given less detailed instruction and need to rely more on your own initiative and application of the engineering method that you will be learning about in the lectures and workshops. There are four major subsystems to be considered in the overall system - the wind turbine, the pump, the piping and water storage system and the water treatment system.

It is suggested that your team is organised into various sub-teams to split up the design tasks. If your team chooses to do this, it is important that you regularly communicate between the sub-teams to ensure that the project is progressing successfully.

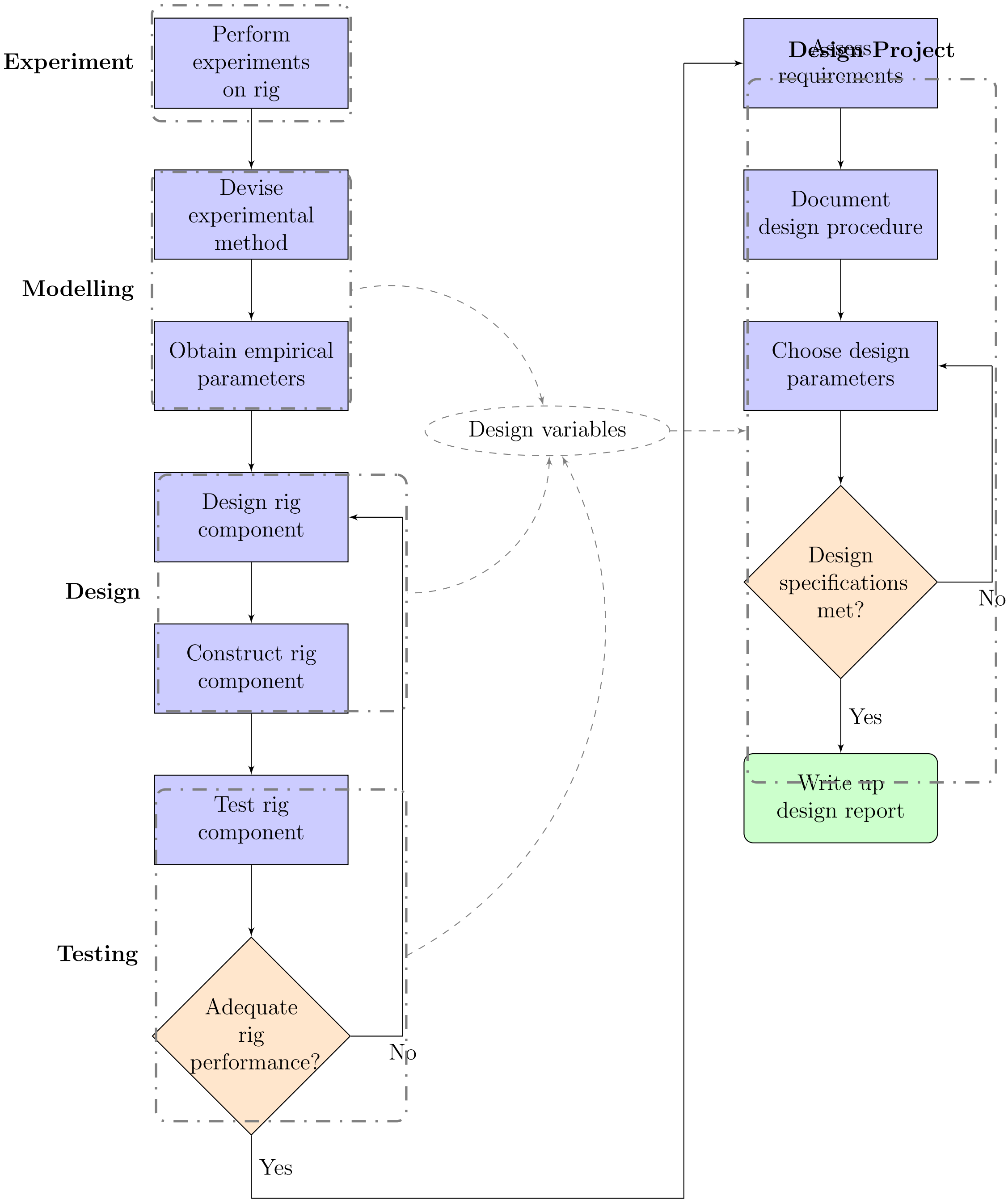

Figure 2: Flowchart for the completion of the design project

2.2.1 Wind turbine system

The main principle behind wind turbines is very simple: the energy in the wind turns two, three or more blades around a rotor. The rotor is connected to a shaft, which spins a generator to create electricity. Wind turbines are mounted on a tower to capture the energy from the wind. The higher the blades are, the more they can take advantage of faster and less turbulent wind. A simple wind turbine consists of three main parts, the blades, shaft and generator, as shown in Figure 3.

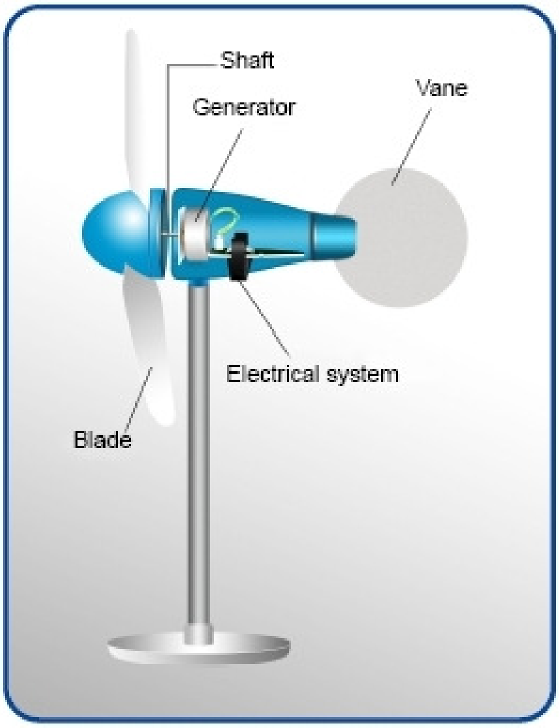

Figure 3: Internals of the wind trubine

Blades: The blade acts as barriers to the wind. When the wind forces the blade to move, some of the wind energy is transferred to the rotor.

Shaft: When the rotor spins, the shaft also spins, and transfers the mechanical energy into rotational energy.

Generator: A generator uses the difference in electrical charge (electromagnetic induction) to produce a change in voltage. Voltage can be thought of as a form of 'electrical pressure', the force that moves an electrical current. The voltage drives the electrical current (AC power) through power lines for distribution. In the case of this design project, the wind turbine is only powering the pumping system and the generator outputs Direct Current (DC) power.

Traditional windmills (drag type) have used flat blades or sails that would catch the wind and turn a drive shaft. Mechanical energy from the drive shaft would be transmitted through 90 degree gear arrangements and transferred to a point where the mechanical energy was desired, such as a grinding mill. Low wind forces are the choice for this flat-blade design, since grinding wheels and other mechanical parts would be (and have been) destroyed in higher winds. But for higher wind speeds drag is something to be avoided. Drag is defined as the force on an object that resists its motion through a fluid. When this fluid is a gas such as air, the force is called aerodynamic drag, or air resistance. Aerodynamics are an important consideration when studying wind turbines, as aerodynamic drag will decrease the efficiency of wind turbines. As turbine blades rotate with the wind and spin the motor drive shaft, the mechanical force that slows down the system can reduce the amount of power generated. Therefore, increasing the efficiency and reducing the drag on the moving blades is key to generating the maximum amount of power from wind turbines. These are the main ways to reduce drag in wind turbine systems:

- changing the pitch or angle of the blades
- using fewer blades
- employing light weight materials to reduce the mass of the blades
- using smooth surfaces on the blades as rough surfaces create more friction with the air
- optimising the shape of the blades to be more aerodynamic.

This last point is important since designing a blade that has lift rather than drag as its main component for turning a rotor will produce much more power in higher winds. In this module of the project you will be investigating all of these factors in order to accurately model blades of different profiles, and design a full-scale wind turbine to satisfy the goals of the project.

2.2.2 Water pumping and storage system

An above-ground gravity driven storage system is to be employed in order to deliver drinking water to the remote community as shown in Figure 4. In this scheme, an underground pump pumps clean water from the underground well into an above-ground tank. The tank is housed on a sturdy but simple support structure 10 m off the ground. An outlet on the bottom of the tank then supplies water via a basic tap valve. In this system, the water flows out of the tank due to gravity, which keeps the system relatively simple and has the benefit of offering a limited water supply in the case of a pump failure or power outage. Housing the tank some distance above the ground also prevents it from being contaminated or interfered with by humans.

The tank comprises of an inlet at the top, an outlet on the bottom and a couple of sensors that detect when the fluid level in the tank is high or low as shown in Figure 5. The sensors connect or disconnect the pump from the power supply (*i.e.* wind turbine) through a control module depending on the level of the water as shown in Figure!6. Note that this is not a one-to-one mapping, but employs *hysteresis*, where the state of the pump (*i.e.* OFF or ON) depends not only on the current water level but also on if the level is decreasing or increasing. Hysteresis is intentionally added to the pump system to prevent unwanted rapid switching if only a full sensor was used and regular but low volume amounts of water were taken from the tank.

Modelling the tank requires an accurate knowledge of the geometry of the tank and a value

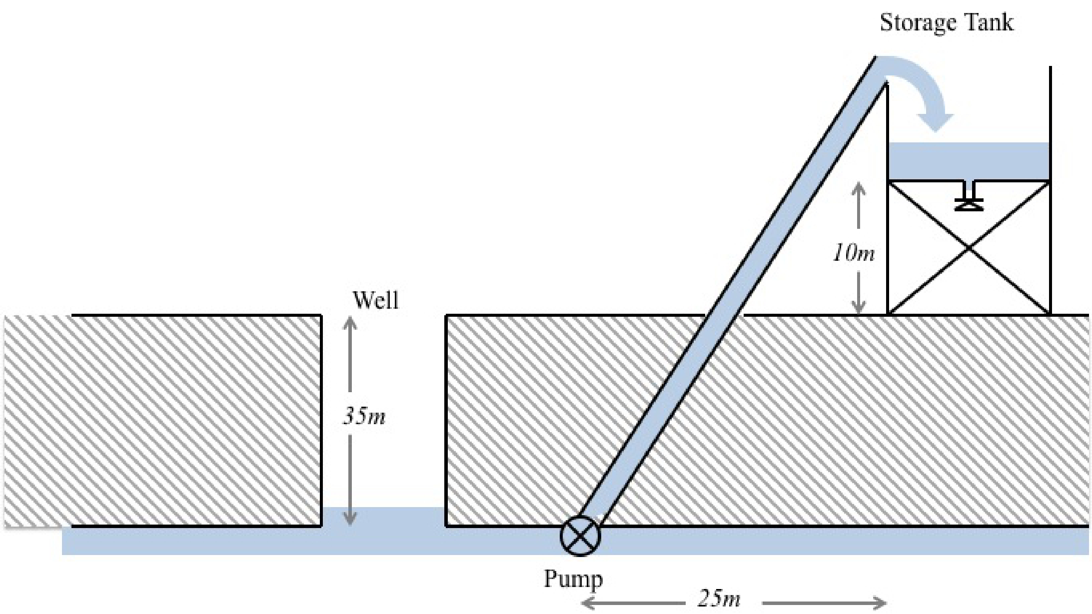

Figure 4: Pumping and water storage system

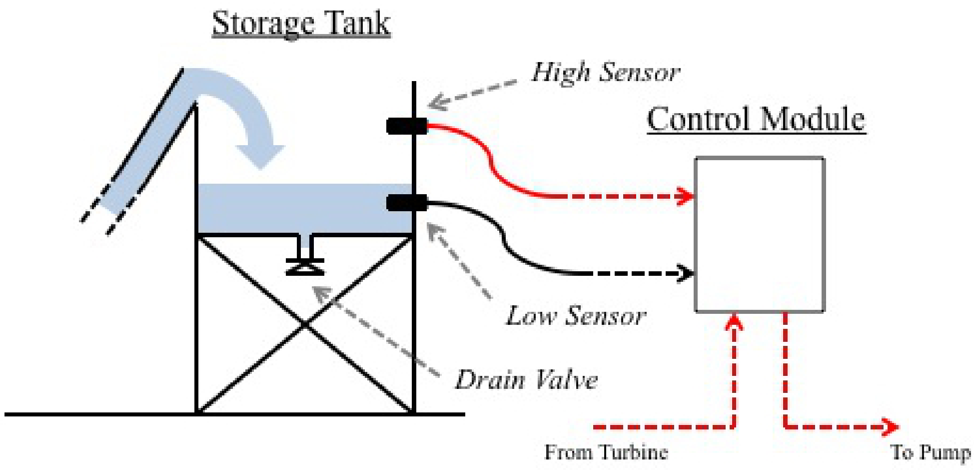

Figure 5: Tank system showing sensors and control system

for the *orifice coefficient*, denoted as C_D, which models the behaviour of fluid through the outlet. This value is usually determined empirically, that is from experiment, due to it being highly dependent on the geometry of the tank outlet and thus difficult to calculate from theory.

The pump is a submerged unit and sits well below the ground surface. Knowing the pump's power characteristics is vital in coupling it to the wind turbine unit. Both of these units must be able to generate enough power to run the pump, which must also have enough power to pump the water to height of the tank on the support structure. The flow rate the pump can deliver is also important and must take into account the size of the tank, the drainage characteristics of the tank, and the expected need for drinking

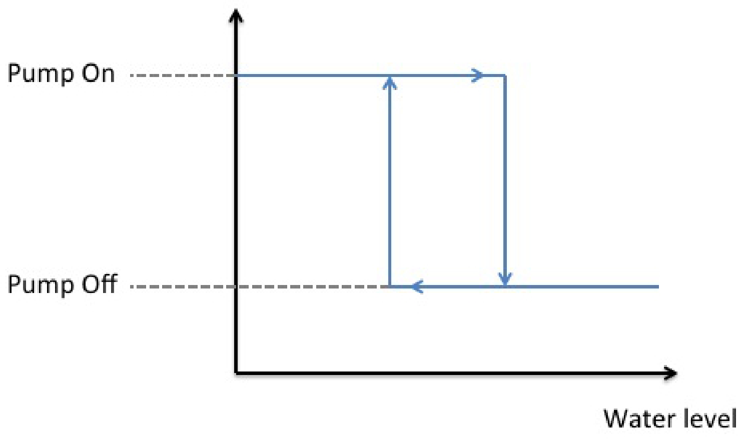

Figure 6: Operation of the pump for different water levels

water for the community.

In this module of the project you will be investigating the pump and water storage system in order to accurately model the tank, construct your own scale model of the tank support structure and design a full-scale pumping and storage system to satisfy the goals of the project.

2.2.3 Water Treatment

Water treatment is comprised of the processes that make water suitable for an end-use, may it be for industry or drinking by reducing or removing contaminants. For drinking water these processes may include separating solids using filtration of settling tanks and chemical treatments including disinfection or coagulation. In theory, well water is safe to drink provided the well source has no naturally occurring contaminants in high levels (*i.e.* heavy metals, chemical contaminants, *etc.*). In addition, shallow wells may run the risk of biological contamination (*e.g.* bacteria, viruses, parasites and other microorganisms) originating from anthroprogenic (human made) sources or rain water run off as well as from short to medium term storage of the water, which is the case in this design. Therefore, the water will be treated with a disinfection process when released from the water storage tank.

There are a number of methods to disinfect water including boiling water, which can be energy intensive and time consuming, but very reliable, as well as chemical treatments such as chlorination. A technology that has become more common within the last 40 years is treating water with ozone to disinfect water against biological contaminants. Ozone, comprised of three oxygen molecules, O_3, is well known for being in the earth's atmosphere with a higher concentration in the stratosphere and helps block some portion of hamrful ultraviolet radiation. Ozone, when not in the atmosphere, can be used as a highly reactive oxidising agent that is very effective in breaking down even the most difficult biological contaminants in drinking water.

Ozone, commonly generated by a cornonal discharge method using oxygen, is a gas and must be transferred into the water to be treated in a reactor (*i.e.* the water treatment tank) very quickly after being generated. Thus the water treatment section will contain an ozone generator using air as the source of oxygen. The ozone can be introduced into the water via bubbling gas through the water, using a membrane contactor or by using venturi (a special type of valve) injection. Each method has different advantages where the venturi inject method is common for small scale ozone water treatment system commercially.

Even at low levels in the air, ozone can be harmful to be in contact with, thus this section of the design project will not use the experimental rig, but a virtual reactor simulator to assist in the design of the ozone venturi injection and reactor system. The size of the reactor will be dependent on the concentration of ozone in water, the volume of water to be treated in a set time period (for example 6-8 hours), the minimum time required for the ozone to react with the contaminated water, and the time required for the ozone itself to break down so that the water is safe to drink. This will require an analysis of data on ozone reaction rates with biological containments as well as the the interplay between the time required for ozone to react with biological contaminants and the time that is required for the water to flow through the reactor tank. A block flow diagram of the ozone treatment system is given below in Figure 7

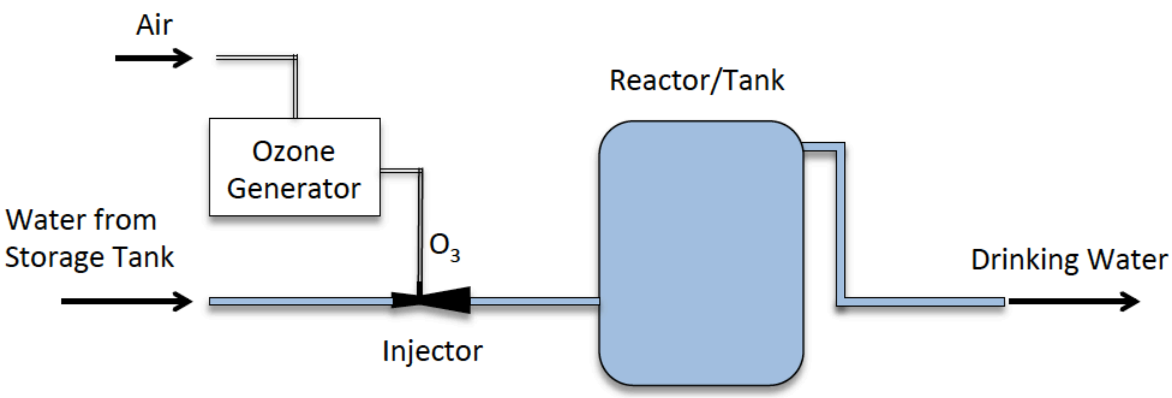

Figure 7: An ozone water treatment system using a venturi injector and reactor/tank.

2.3 Constants

For this design project, the constants in Table 1 may be assumed. There are further constraints and objectives for each system module as detailed in the module design documents that you will receive soon.

Parameter description	**Symbol**	**Value**
Density	ρ	$1000\,kg/m^3$
Viscosity	μ	$10^{-3}\,Pa.s$
Gravitational constant	g	$9.8\,m/s^2$

Table 1: Physical constants for all parts of the design problem

3 Workshop Schedule

The schedule for the workshops is given in Table 2. Note that a more detailed schedule of lectures, workshops and assessments for the subject as a whole is available on LMS.

Workshop	Description
1	Team Formation
2	Modelling with MATLAB
3	Modelling Tank Drainage
4	Modelling Pumping
5	Modelling Turbine
6	Turbine Design
7	Presentations
8	Mass Balances
9	Reactor Game
10	Reactor Design
11	Complete Project

Table 2: Workshop Schedule

4 Project Deliverables (Assessment)

This subject employs a mix of team-based assessment, individual assessment and peer assessment. Marking schemes for most of the assessments will be made available through the LMS in order to guide you as to what is required.

4.1 Team contract (5%)

One of the first things to do once you have formed your team is to decide on the ground rules for the team. What tasks need to be performed? How can labour be fairly divided? Are there specified roles for each team member? What is the schedule or plan for making deadlines? These are the sorts of questions your team will need to think about and agree upon answers for. This *team contract* will act as a contract between all team members.

You will complete the team contract in-class in Workshop 2 using a provided template. Items to think about will include

- Expectations

- Team tasks and roles
- Risks
- Schedules and deadlines
- Decision making process
- Ground rules for communication
- Actions to be taken in the event of issues

The team contract is worth 5% of your final ESD 1 mark and you will each receive the same mark as each member in your team.

4.2 Peer Assessment

One of the main distinctions of engineers over other professions is that they work in teams. As you are working in a team of six for this design project, you are expected to equally contribute to the goals of the project.

You will assess your team mates and yourself THREE times during semester - after Weeks 4, 10 and after the submission of the final report (during the exam period).

The Week 4 assessment is only for feedback purposes, with Week 10 and the exam period moderating your team project assessment.

4.3 Team Presentation (10%)

An important part of being an engineer is being able to communicate effectively. Towards the end of semester, your team will be giving a short *presentation* to your workshop class on your design solution. In this presentation your group will demonstrate to the class your approach to the design problem, understanding of the topic and proposed solution.

Your team will have access to a computer for your presentation and will need to bring your work on a USB memory device (PDF, Microsoft Powerpoint 2003 or 2007 format only)

- Presentations are limited to 25 minutes per group, with a 5 minute question and answer period at the end.
- ALL group members must speak approximately EQUALLY as part of the presentation.
- As part of the presentation, your team is able to demonstrate the operation of the experimental rig with in order to aid explanations.

- Each team will review another team's presentation for feedback purposes.
- A demonstrator will review each team's presentation for feedback and assessment purposes (10%).
- Assessment will be based on :
  - Structure of content
  - Knowledge of content
  - Relevance of information presented
  - Quality of slides
  - Coordination of slides with speakers

You will receive both a team mark and some individual feedback for the presentation.

The team presentations will be in the workshop classes in Week 8 of semester.

The rubric for marking the presentations will be available on the LMS.

4.4 Draft team report (5%)

At the end of Week 10, your team will submit a *draft report* encompassing your design work to date and specifically covering the water pumping and storage system and the wind turbine system. The prupose of submitting a draft report is for your team to receive feedback to improve upon for your final team report.

The draft report is limited to 15 pages (excluding appendices) and is to be submitted via LMS.

The rubric for marking the draft report will be available on the LMS.

4.5 Final team report (35%)

You team must submit a *technical report* on your proposed solution to the design problem (maximum of 40 pages).

The report must include :

- Cover page
  - Team name, names and student numbers
- Abstract (200 words maximum)
  - A brief summary of what will be presented in the report
- The main body of the report

- Appendices
  - Include all MATLAB code you have written

The cover page and appendices do NOT count towards the total page count.

The final report will be due at 5pm on Tuesday, 6th June, in the first week of the exam period.

Further details on the final team report will be made available on the LMS during semester.