ENGR10004 Engineering Systems Design 1

Semester 2, 2018 - Project Description

Introduction

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

1 Project Description

1.1 Overview

The proposed project involves the planning, modelling, design and testing of a pumping station to disinfect and supply drinking water to a remote community from an underground well. A systems diagram of the station showing how the sub-systems of water delivery system are interconnected is shown in Figure 1. 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 delivery process for the local people with the help from donations from several non-governmental and not-for-profit organisations.

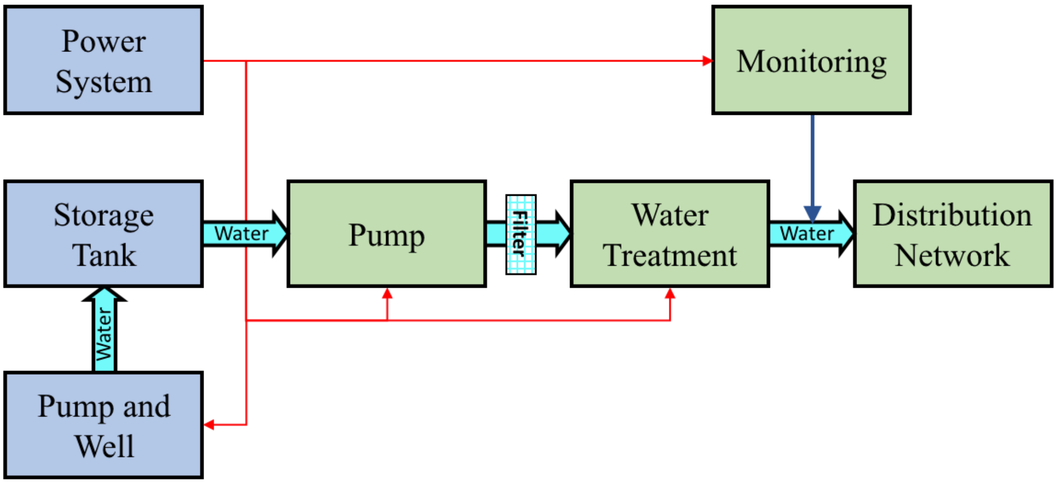

Figure 1. Pumping and water storage system, green blocks the subsystems in the design project.

The water is pumped from the well and stored in a tank that holds a seven day supply of drinking water for the town. This feeds the pump for the water treatment and distribution network. To improve the quality of the drinking water, the water will be treated using a small ozone generation and membrane disinfection system. Membrane and filter failure will be monitored via real-time tracking for particle contamination of the water after at a point in the flow circuit after the membrane. The power system was designed and donated by a separate engineering firm and is a combination of a wind turbine using battery storage with back up diesel generators. The electrical energy from the power system is converted into mechanical energy to drive the pump. The pump then does work on the water, creating pressure to drive the water through the water treatment process and the water distribution network.

The design project will consist of devising a real-world solution to several sub-systems including the (1) impeller and pump design, (2) the water treatment disinfection process using a membrane unit, (3) image capture and real-time analysis system to monitor for particle contamination should the filter or membrane fail and (4) the water distribution network. The solution for each subs-system will involve 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.

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 100m from the centre of the community. The tower structure holding the storage tank must be exactly 1m high, with the tank sitting on top of this. The pumping system and water treatment processing will must be located at the tank site. The distribution network must deliver treated water to a number of key distribution points in the community including both floors of a two-story medical clinic.

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 as well as a small medical clinic. 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 is the water consumption of the clinic?
- How much water must be treated in a day?
- What is the best geometry for the pipe network for distribution?
- What diameter should the pipes be?
- What size should the pump be?
- How large does the membrane system need to be?
- What are the risks to the membrane failing?
- How will a membrane failure be detected?
- What are the safety mechanisms in the event of a membrane failure?

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.

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

- Will the pipes need to be insulated from sun?
- Will distribution network be above or below ground?
- How does temperature affect membrane performance?

1.4 Materials

The pump and pipe distribution network and membrane units 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

- Which material should the pipe distribution network be made from?
- If the network is above or below ground, what materials should the supporting structure be made of?
- 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 process using ozone affect the type of materials used in the distribution network?
- Are there environmental issues that need to be considered?

2 System Modules

2.1 Overview

A flowchart representing the process for completing the design project is shown 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.

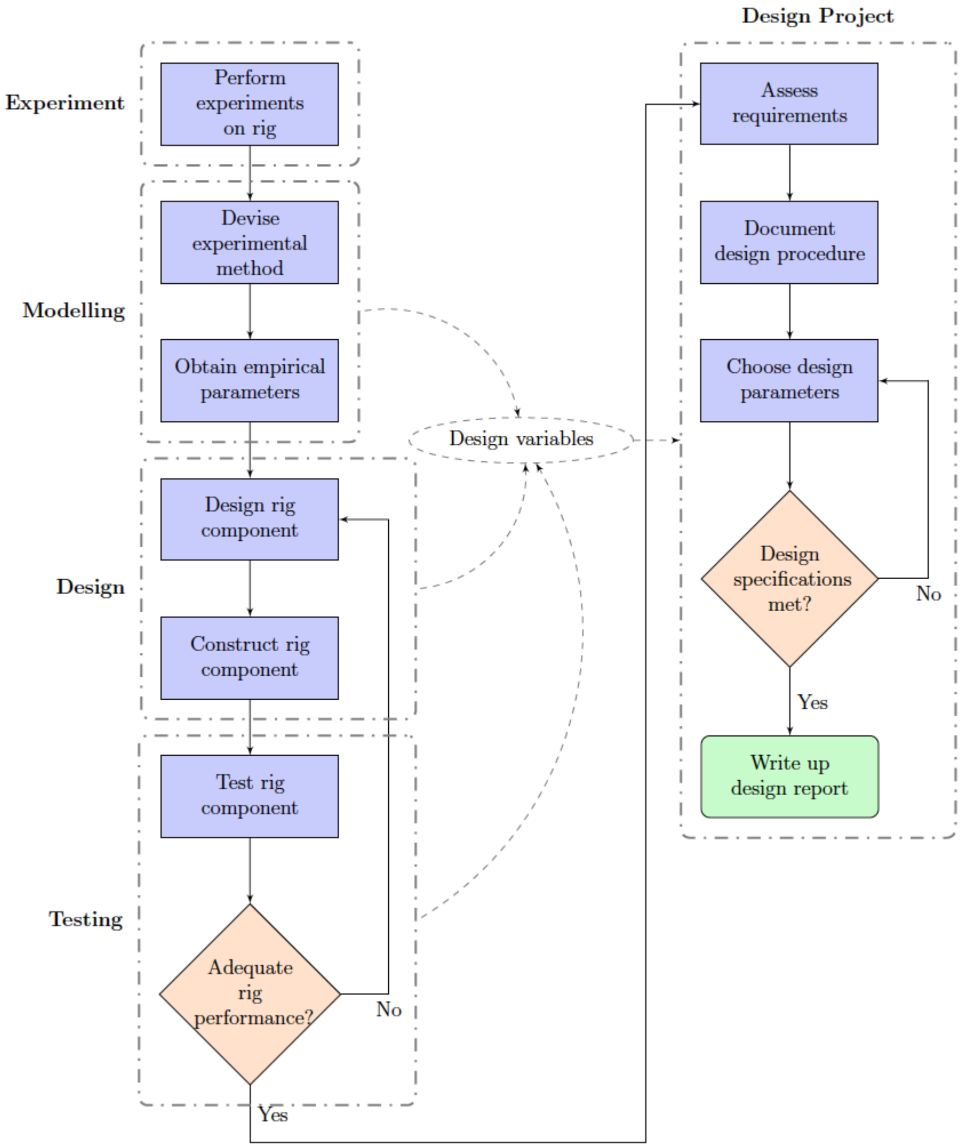

Figure 2. Flowchart for the completion of the design project

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 (1) impeller and pump design, (2) the water treatment disinfection process using a membrane unit, (3) the image capture and real-time analysis system to monitor for particle contamination should the membrane fail and (4) the water distribution network.

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.

2.2 Impeller and Pump Design

Pumps come in a number of different configurations and designs, but at this scale for this project, pumps typically have some type of housing surrounding an impeller that is able to rotate. The rotation of the impeller is driven by a motor. As the impeller rotates it creates a region of low pressure that draws water in and region of high pressure that "pushes" the water out of the pump. Thus, the pump's core job is to convert the mechanical energy from the rotation of the motor to impart energy into the water, called "doing work on the fluid", to increase the pressure in the water so it can move through the pipe network.

The key design parameters for a pump are based around the flow rate the pump must operate at, the increases in pressure required and the efficiency of the impeller in converting the rotational energy from the motor to energy in the water increasing the pressure, *i.e.,* doing work on the fluid. In this design, the flow rates are defined by the design specifications around how much water people need in a day. The pressure required from the pump will depend on the resistance to flow caused by parts of the flow circuit after the pump, including the membrane unit, see Figure 3. The efficiency of the impeller depends on the physical shape of the impeller, *e.g.* the number and curvature of the impeller blades.

In this module of the project you will be investigating the pump performance by measuring the efficiency of the pump impeller as a function of flow rate, called a pump curve. Using the lab scale rig, you will first use a base impeller model and then design and 3D print and test your own pump impeller design. You will use the pump curve in the design of the full-scale pumping system to satisfy the goals of the project.

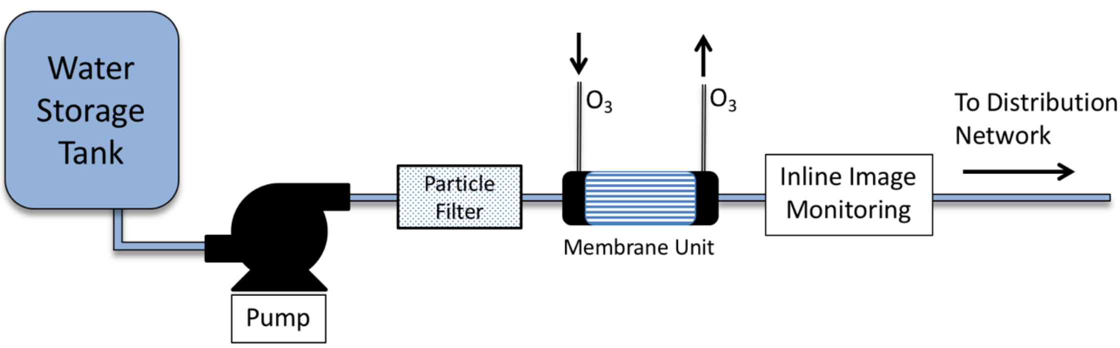

Figure 3. Pumping subsystem: The pump is feed from the water storage tank and provides the work to transport the water through the membrane unit to the distribution network.

2.3 Water Treatment Disinfection System

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 or 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.*). Yet, 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 harmful 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 coronal discharge method using oxygen, is a gas and must be transferred into the water very quickly after being generated. 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 unit as a gas liquid contactor or by using venturi (a special type of valve) injection. Each method has different advantages where this project will be using a membrane unit as a gas-liquid contactor. This type of process unit is robust in the range of flow rates and pressures that can be used and is simple to operative and maintain.

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 ozone with the experimental rig, so the experimental component will focus on the fluid flow through the membrane. The full-scale design will account for the transfer of the ozone from the gas stream into the water via the membrane using empirical engineering correlations. The size of the membrane unit required will depend on the specified concentration of ozone in the water exiting the unit based on water quality requirements. The membrane unit size will also depend on the volume of water to be treated in a set time period (*e.g.* 2-6 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 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 pipe to the town. A block flow diagram of the ozone treatment system is given below in Figure 4.

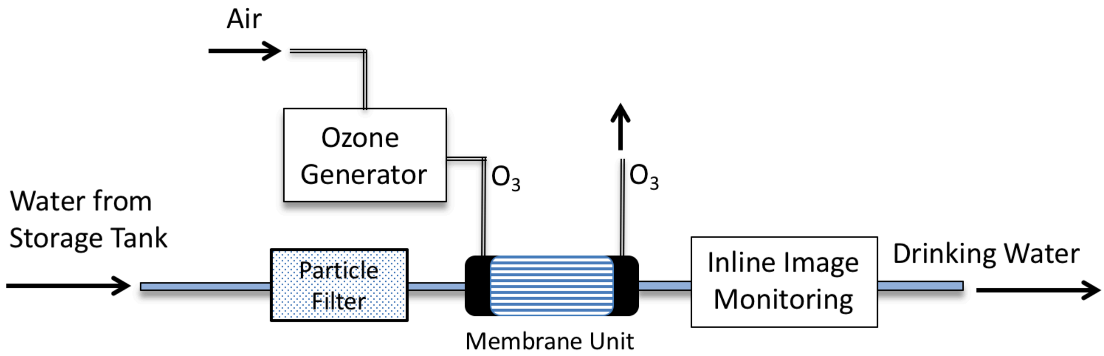

Figure 4. Water Treatment Subsystem: An ozone water treatment system using membrane unit as a gas-liquid contactor.

2.4 Inline Image Monitoring

The field of online or integrated sensing is becoming the prevalent in diverse areas such as controlling and monitoring a chemical processing plant, real-time face recognition software (*e.g.*, Facebook, Google, photo(mac)), personal health and bio-monitors (*e.g.*, Apple watch, Fitbit), air quality monitoring in buildings, and complex, automated image analysis in medical imaging. Any engineer, regardless of discipline, will need to become familiar with some aspects of real time monitoring or sensing.

In the context of water treatment, a membrane process must have monitoring systems to determine if the treatment system is working reliably. This can include offline water quality analysis and testing as well as online or inline monitoring systems. One of the main risks in using membrane processes is membrane failure, which will cause the membrane may not operate properly. In the water treatment system for this project, a pre-filer is included to prevent particle or sediment from going through the membrane, which can clog or damage the membrane if particles run through the membrane for an extended period of time.

An inline image monitoring system includes an online optical monitoring system using a camera linked to a real time image analysis processing system to detect particle contamination using automated image analysis system, see Figure 5. If the presence of particles in the treated water exceeds a critical value, a control valve is automatically triggered to recycle water to the main storage tank and sound an alarm to change the membrane filter.

In this module of the project you will develop and test your own real time image analysis processing system. You will iteratively develop this image processing algorithm through testing your image processing program using a high-speed camera as part of the experimental rig with a flowing system with different levels particle contamination in real-time. The refined and tested image processing system will be included in your final design of the full-scale water treatment and distribution system.

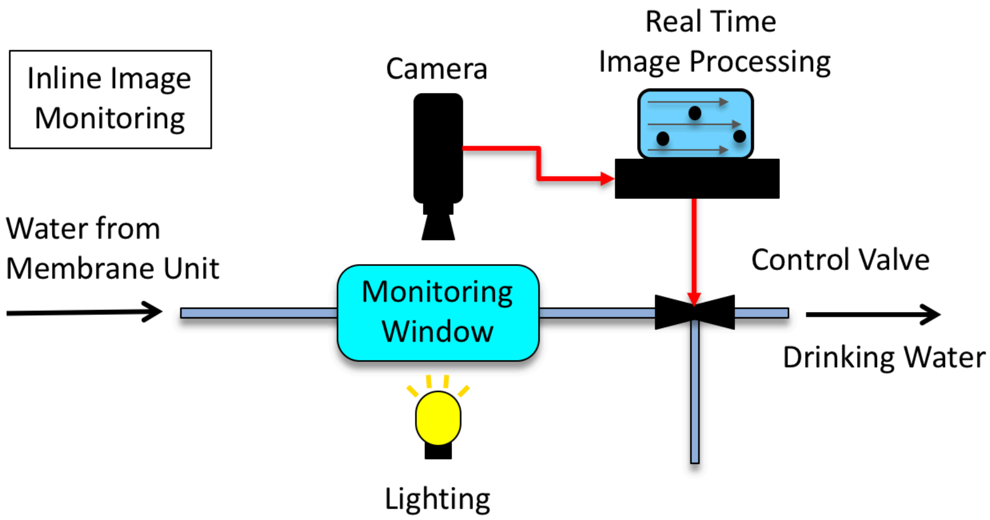

Figure 5. Inline image monitoring system to detect particle contamination using a camera and an automated imaging processing system operating in real-time.

2.5 Water Pipe Distribution Network

The pipe distribution network is in two sections with different purposes. As shown in Figure 6, in the first section, the water must be transferred from the storage tank and pumped through the filter and membrane disinfection unit. The water must then travel to the town and be feed into a short-term water tower. The second section, is the pipe distribution network within the town. Using the water tower to provide hydrostatic pressure, water is delivered at specified pressures and flow rates at four distribution points in the town, two within the clinic, See Figure 7.

The size of diameters of the pipes within the network are dependent on the required flow rates, set by design specifications around the water needs of the community. In both sections of the network, the water will flow from high to low pressure. In section 1, the pump provides the pressure as the water flows through the pipes and membrane. The resistances to flow come from both the changes in height of the water as it is pumped into the water tower and from the energy lost through friction as the water moves through the pipes. In section 2, the height of the water tower provides most of the necessary pressure to drive flow.

In this module of the project you will be investigating the interplay between the pressure in the pipes from pumps and the losses that occur from friction of the water with the pipe. Using the lab scale rig, you will measure the frictional losses in a flow circuit for different types of fittings relevant to the pipe network and membrane unit. The measured frictional loss correlations with flow will be used in combination with a conservation of energy approach to design the fluid network, specifying the length and diameters of the pipes, changes in elevation of the pipe, and the number of bends, T-junctions and valves required to transport the water through section1 and to the four distribution points in section 2.

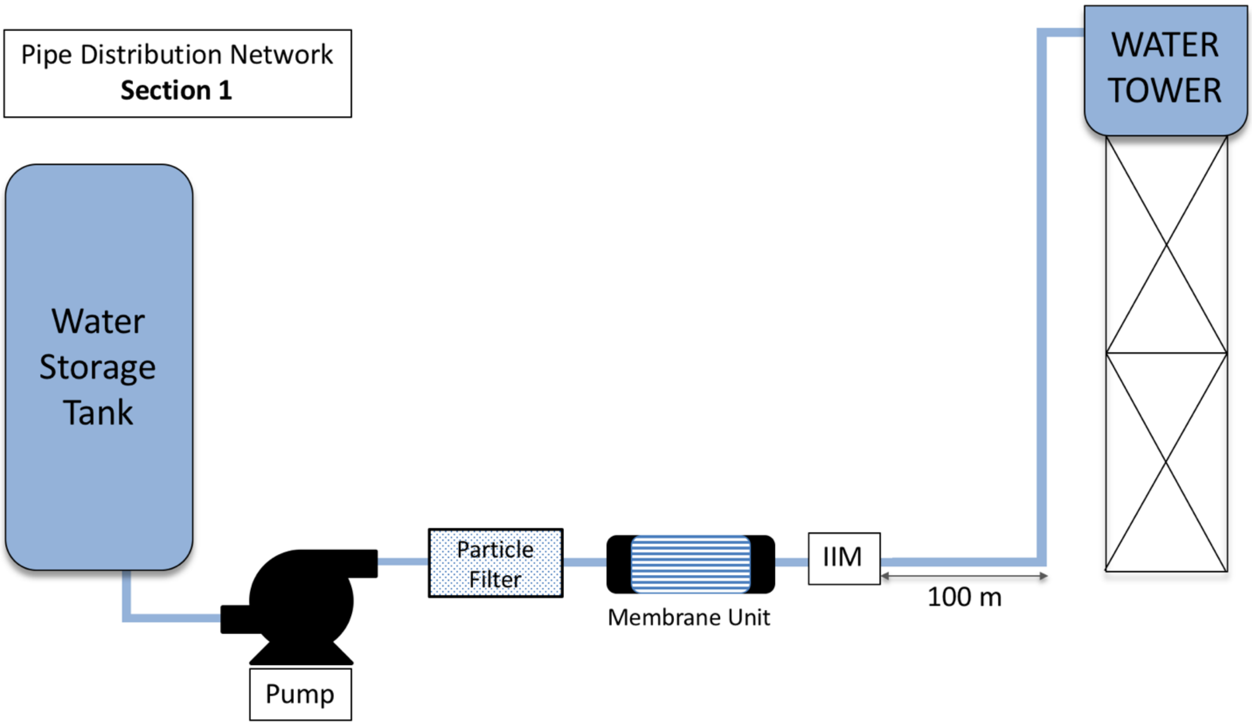

Figure 6. Water pipe distribution network, section 1.

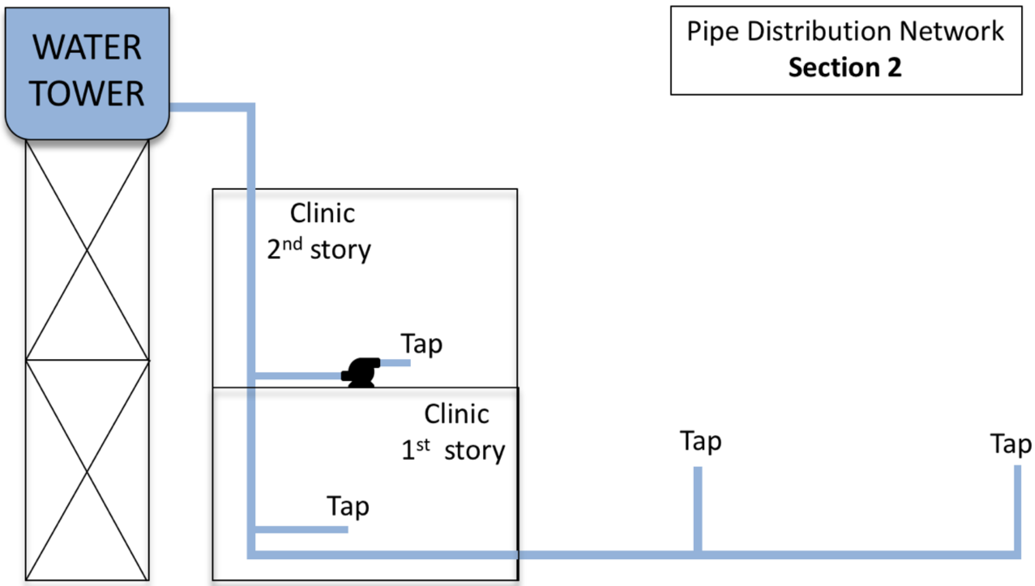

Figure 7. Water pipe distribution network, section 2.

2.6 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.

Table 1. Physical constants for water and gravity for all parts of the design problem

Parameter description	Symbol	Value
Water Density at 25°C	ρ	997 kg/m^3
Water Viscosity at 25°C	μ	8.90 x10^{-4} $Pa.s$
Kinematic Water Viscosity at 25°C	μ/ρ	8.92 x10^{-7} m^2/s
Gravitational constant	g	9.8 m/s^2

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.

Table 2. Workshops Schedule

Workshop	Description
1	Team Formation/MATLAB
2	Team Management Plan/Friction Loss Measurement
3	MATLAB Loss Analysis/ Peer Assessment/Pump Curve
4	EBE Problems/Pump Curve – Custom Designed Impeller
5	Mass balance/ Membrane pressure drop
6	Membrane problems/ Membrane design/ Continue impeller testing
7	Project Presentations
8	MATLAB (loops and functions)/Camera and image capture in MATLAB
-	Draft Report Work, use Design Studio for team meetings
9	Image processing using Matlab/ Particles in pipes I
10	Particles in pipes II

Workshop attendance and participation in each in workshop is 0.5% worth of your final mark as part of your individual assessment, totaling to 5% (0.5 % x 10 workshops). And additional 5% of your final mark will be based on individual assessment tasks that occur in the workshops or homework problems assigned in the workshops.

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 Project Team Management Plan (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. The Project Team Management Plan will act as the frame work for how your team will operate and you will work together.

You will work on the Project Team Management Plan in-class in Workshop 2. This will be submitted via lms on at the start of week 4, Monday August 13th by 5 pm.

The Project Team Management Plan will consist of 5 main themes.

- Project Goal & objectives
  - Students identify the main goal and objectives of the team, outlined based on SMART criteria
- Roles & Responsibilities
  - Students decide the role(s) and responsibilities of each team member
- Task Planning & Scheduling
  - Breakdown of tasks in the project along with deadlines and dedicated responsible member for each task.
  - A schedule of tentative project meetings for the semester
- Risk Planning & Management
  - Identify risks in the project, ways of monitoring and contingency plans
- Team Communication Plan
  - Outline how the team will manage communications, conflicts and intolerable behaviour.

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 5, 9 and after the submission of the final report (during the exam period).

The Week 5 assessment is only for feedback purposes and group health, with Week 9 is focused on the presentation and the exam period moderating is focused on the report of 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 pump, pipe network, and parts of the membrane systems. The purpose 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 17 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 Monday, 29th October, in the first week of the exam period.

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