ENGR10004 Engineering Systems Design 1 Design Project
Water Treatment Specifications

1 Summary

This document presents the detailed specifications for the water disinfection process as part of the chemical engineering module of the semester long team 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 and delivery of water to a remote community using renewable energy resources.

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. 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. 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 process for completing the water disinfection section of the design project will consist of:

- Data Analysis
- Model Development
- Design
- Operating Parameters

Note that this document is a only a sub-module of the complete water-pumping design project. Refer to the complete project specifications for an overview of the project and description of the overall subject requirements.

A check list of the tasks to be completed for this module of the design project are summarised at the end of this document.

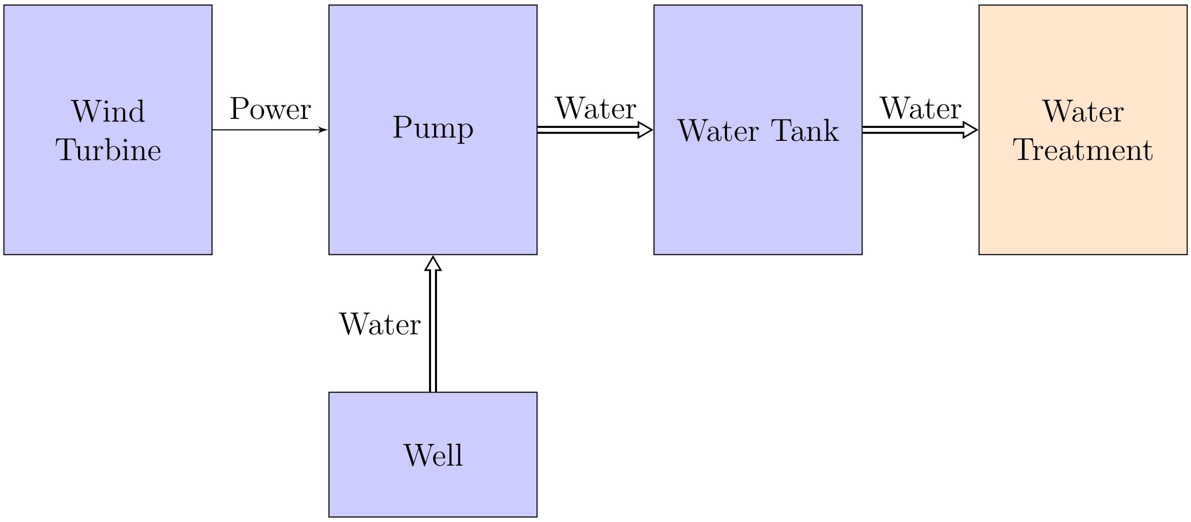

Figure 1: Wind Powered Pumping Station Systems Diagram

2 Introduction

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. 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 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, rain water run off or 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 primary 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 to be treated in a reactor (*i.e.* the CFSTR) very quickly after being generated. The ozone can be introduced into the water via bubbling gas through the water or by using a 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 systems 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 rig, instead using the chemical reaction data on ozone decay in solution from Part A of workshop 10 to design an ozone Venturi injection system feeding into a CFSTR. 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 1-4 hours), the time required for the ozone to react with the pathogens in water, and the time required for the ozone itself to break down. A more detailed block flow diagram of the ozone treatment system is given below in Figure 2

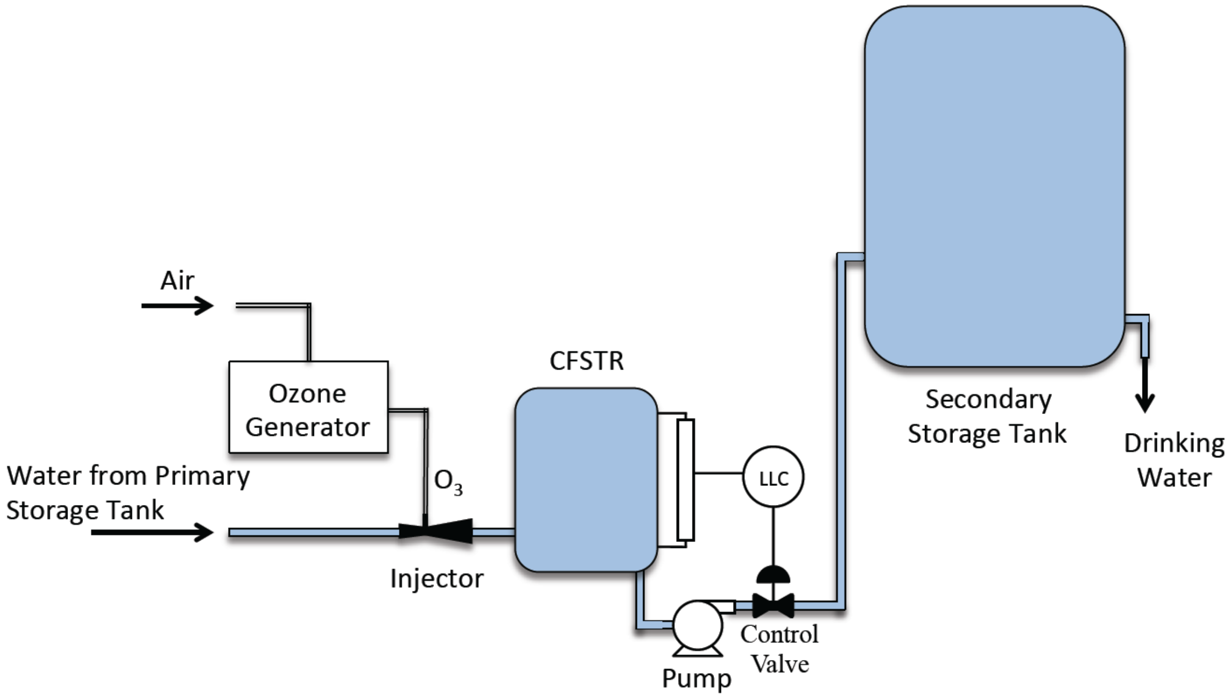

Figure 2: An ozone water disinfection system using a Venturi injector, CFSTR and secondary storage tank.

3 Specifications

The specifications and constraints for this design are listed below with a reasonable amount of justification. It is important to make a list of all the constraints as they are grouped by topics where the same process variable may have several constraints.

3.1 Log Inactivation Credit Requirements

There is no other water treatment process other than disinfection, thus the inactivation credits for viruses and Giardia of 4 log and 3 log, respectively, must be achieved by the design based on the log activation credit model and CFSTR mass balance equations used in lecture. (Note: the example in the water treatment lecture is a good starting point.)

3.2 Operational Temperature

Assume the process must be able to meet the log inactivation criteria for temperatures from 15 to 35°C. (Note: pathogen inactivation rate constants as a function of temperature are available from lecture and ozone decay rate constants for the 15 to 35°C temperature range are available from Part A in workshop 10.)

3.3 Volume of Water to be Disinfected, Secondary Storage Tank and Water Flow Rates

- Regardless of the volume of the primary storage tank volume, the disinfection system should be run once a day and treat enough drinking water to supply everyone in the village for one day.
- The process time needs to be less than 4 hours for reasons of both energy needs and the labor within the community to operate the disinfection cycle.
- The CFSTR system will have a pump and a liquid level controller to ensure the output flow matches the input flow.
- The input flow can be varied based on the tap from the primary water storage tank which is under gravity flow. Provided the flow rate results in a sufficiently small change to the overall tank volume, the flow rate from the primary storage tank can be treated as constant. Depending on the size and dimensions of the the primary water storage tank this may not be true in practice, but as a first estimate of the design of the disinfection process, this is acceptable.
- Obviously, the outlet of the the primary storage tank was not designed to feed into a pumping system. You may assume a separate pipe will be added to your primary storage tank to feed the pump on the water disinfection process. You do not need to design this pipe or pump. Your existing primary tank design and outlet is critical, should the water treatment system break down . Thus, the addition of this water treatment section should not affect your current or existing designs for the primary water tank or turbine system. If you feel compelled to comment on any pitfalls in this omission you are welcome to in your report, but you are not required to.

3.4 Ozone Generator and Injection System

Ozone generation can vary greatly depending on the oxygen gas feed concentration and the type of generator where medium and high frequency generators can get to very high concentrations, 3% for and air feed and 10 % for a oxygen feed. Unfortunately due to their power consumption, the unit employed here is a low frequency coronal discharge unit that operates at concentrations as low as 0.5% using an air feed as pure oxygen (normally as liquid oxygen) is not available. This results in very low concentrations of ozone in the water. As the operation of the Venturi is complicated and scales with liquid and gas flow rates, you may assume that the inlet concentration of ozone is 0.11 mg/lire. You are welcome to learn more about Venturi injection systems as there are a great deal of commercial systems available, but this inlet concentration is within the range of typical values for low concentration ozone gas streams.

3.5 CFSTR Design

The CFSTR design has a number of constraints for a variety of reasons:

- Only the volume of the CFSTR must be specified, shape does not need to be defined at this stage. In any case, a minimum reactor volume is required to ensure that vessel is well mixed and baffled, the the CFSTR volume must be at least 100 litres.
- The materials of construction of the tank should be specified and be appropriate for both drinking water and ozone exposure.
- As an additional engineered safety feature, and common in practice, there is a minimum exposure time for an ozone contractor. This is often concentration dependent, but in this case it can be set that the residence time can not be less than 10 minutes.
- Obviously, capital and operational costs come into play in the design and while a detailed cost function is not required, provided the above specification can be met, the reactor volume should be minimised as much as technically feasible.
- The CFSTR will be operated at steady state. The minimum operation time for the process must be greater than 1 hour to assume that the CFSTR can reach steady state and not impact negatively on the process. It is not required to verify this assumption, but it can be done using the CFSTR MATLAB program from lecture if you are curious. (Note: If you do explore this, what would the initial concentration in the tank be? The Venturi injection may effect this.)

3.6 Omissions

A number of aspects of the process do not need to be included in your design at this stage.

- The design of the secondary storage water tank
- The pump, piping, liquid level controller or control valve in the disinfection process.
- The pipe connecting the primary storage tank to the water treatment reactor pump. See section 3.3 for more detail.
- The Venturi injection system.
- The ozone generator

4 Designing the Disinfection Process

Below is a list of process variables and other issue that should be considered in the development of your model and design.

4.1 Process Variables

Identify what process variables you can set and what variables are then calculated from these. These variable should include:

- The amount of water that must be processed each day. It is up to you how you account for population growth.
- How long the process will operate each day.
- The inlet flow rate (which is equal to the outlet flow rate).
- The volume of the CFSTR
- The residence time
- The concentration of ozone at the outlet, determined from your mass balance model for the CFSTR

4.2 Temperature

The disinfection system must be able to operate in a range of temperatures, which will affect both types of rate constants. It is suggested you set the temperature, get a technically feasible design and then verify this design meets the specifications across the entire temperature range. Thus, for the entire temperature range (at the increments of 15, 20, 25, 30 and 35°C) you will need to calculate:

- Ozone decay rate constants
- Pathogen inactivation rate constants
- Log inaction values for viruses and Giardia inactivation rate constants (this must use the CFSTR model outputs)

4.3 Scope and References

Even a quick internet search will yield a large amount of information on ozone disinfection of drinking water. Most material is consistent with these design specifications here, but there is a large amount of variation to these processes. It will also become apparent that there are many ways to design a disinfection system and even some common heuristics found on manufacturer websites. For example, it is commonly stated for an ozone contractor, it is required to have a concentration of 0.4 mg/litre with a holding time of 4 minutes (You should not use this!!!). For this specific concentration and operating condition, this is reasonable in many circumstance where the origins of this heuristic are much more complicated and grounded in the pathogen inactivation rate constants and the ozone decay constants discussed in lecture and workshop 10. If you wish to design your disinfection system differently to what has been suggested in sections 3 and 4.1 to 4.2, you may do so, but you must then adhere to all of the details and information outlined in the references below, you may not design your entire system on a simple heuristic from the internet like the one mentioned above and you must meet the checklist in the next section. These are good references for your information as well. (Note, information on how to access knovel is on LMS.)

- US EPA: LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE TOOLBOX GUIDANCE MANUAL, follow the link at: (`http://www.epa.gov/dwreginfo/long-term-2-enhanced-surface-water-treatment-rule-documents`)
- US EPA: Alternative Disinfectants and Oxidants Guidance Manual, follow the link at: (`http://www.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules`)
- Basic Water Treatment, ISBN 978-0-7277-5816-3, available on Knovel, Chapters 3 and 11 very useful.
- Ozone in Drinking Water Treatment - Process Design, Operation, and Optimization, available on Knovel, Chapters 1-4 very useful.

5 Checklist

Use Table 1 to ensure that you have completed the necessary tasks for each part of the experiment and design process. Once you have completed these tasks, you should have enough information to compile your final group project report for the water disinfection module.

Phase	**Task**	**Completed**
Data Analysis	Determine the ozone decay first order rate constants over the operating temperature range at increments of 15, 20, 25, 30 and 35°C	☐
	Determine the pathogen inactivation rate constants over the same temperature range	☐
CFSTR Design	Model CFSTR steady state operation at the above temperatures in MATLAB or Excell	☐
	Select volume of reactor	☐
	Select material of reactor	☐
CFSTR Operation Specifics	Select appropriate flow rate and residence time for each operating temperature	☐
	Calculate exit concentration of ozone at each operating temperature.	☐
	Calculate the log inactivation credits for viruses and Giardia at each operating temperature.	☐
	Confirm that all of the design and operation parameters meet the constraints and specification of the design brief.	☐

Table 1: Checklist of required tasks in order to complete the water disinfection process module of the design project