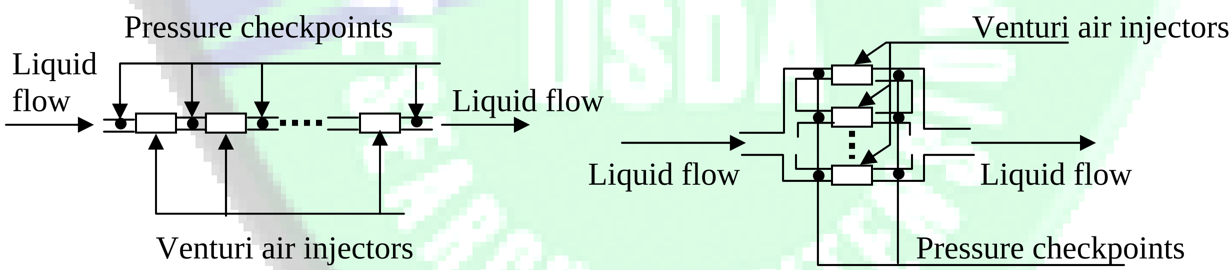
CHAPTER 2. SURFACE AERATION SYSTEM DEVELOPMENT

The key component of any aeration system is the aerator. Therefore, the majority of work in this project is to develop a cost-efficient aerator module that can be used for field application to drive the aeration structure. In the following sections, details on the design and test of the developed aerator module will be presented.

1. Design of the venturi air injection module

A new air injection module consisting of more than one venturi air injectors was developed aiming at improving aeration efficiency. The reason for using venturi air injectors is based on literature information that venturi aerators perform best in transferring oxygen into liquid as compared to other aerators such as perforated small-bore aerators, mechanical surface aerators, and diffuser pipe aerators.

Two configurations of the air injection module were evaluated, each containing a number of venturi aerators connected either in series or in parallel (Figure 1a and 1b). Both configurations are considered to be able to add more oxygen into liquid than that with a single injector. The actual number of aerators to be used in each configuration was determined by water tests according to the maximal aeration efficiency achieved (kg O_2 transferred into water per kWh) under the respective conditions. The equations used to calculate k_La and aeration efficiencies can be found in Chapter 1.



(a) (b)

Figure 1. Schematic of the two configurations of the air injector module design

1). Venturi air injectors used

All venturi air injectors used in this project were purchased from the Mazzei Injector Corporation (Cat#: 1583, 500 Rooster Drive, Bakersfield, CA 93307).

2). Water tests results for both modules

Water tests for both modules (series and parallel) were conducted to determine the performance of these aerator modules in terms of oxygen transfer and aeration efficiency. For both designs, up to three venturi air injectors were used to build the modules (Figure 2 and 3) that were subject to water tests according to the test procedure described previously. The test system consisted of a

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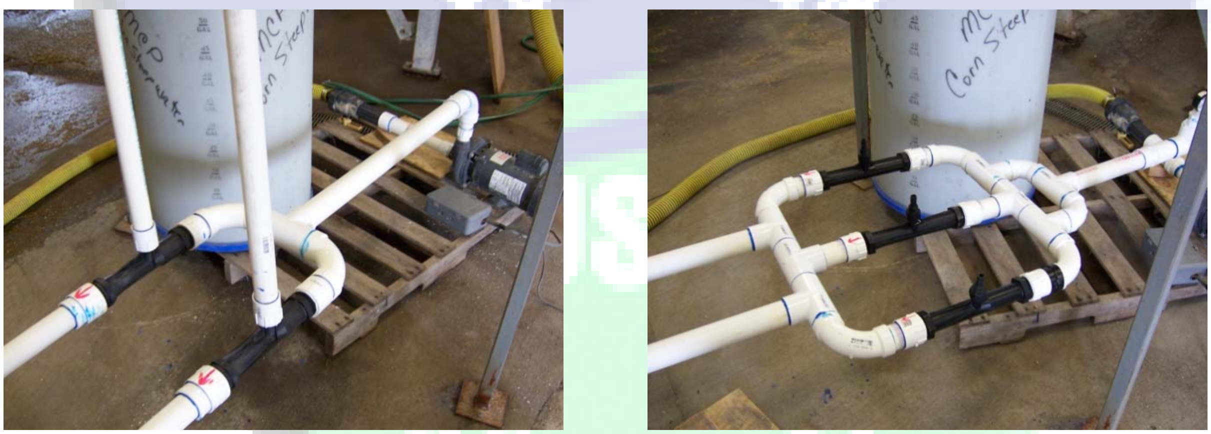
water tank containing 600 gallons of water and a 1.5 horsepower centrifugal water pump. The liquid pressure and flow rate in the pipe were also monitored. The dissolved oxygen level in the aerated water was recorded at one minute intervals until it approached saturation under the test condition. The water temperature was also recorded. For each module, the test was run three times and only the means of three measurements were presented.

(a) (b)

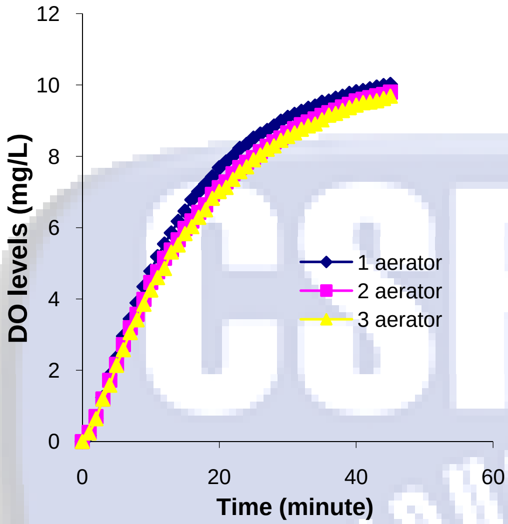
Figure 2. Aerator module in series (a – one injector; b – two injectors)



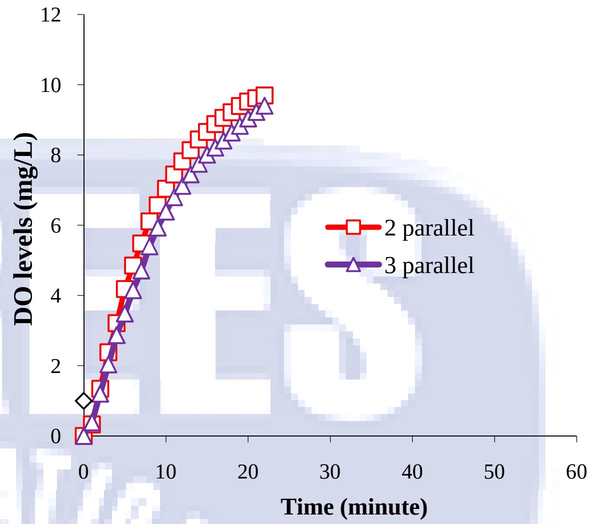
(a) (b)

Figure 3. Aerator module in parallel (a – two injectors; b – three injectors)

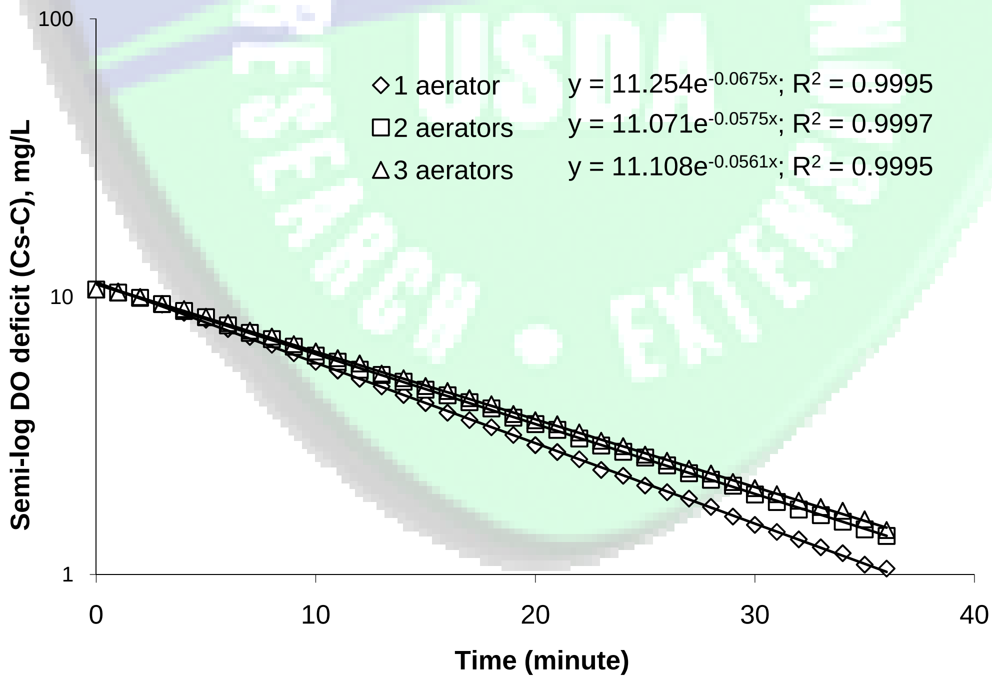
Figure 4 shows the water test results for both designs, i.e., series and parallel. Obviously, the parallel with 2 injectors performed the best in terms of oxygen transfer coefficient. Both parallel modules with either 2 or 3 air injectors beat all the series modules, and the oxygen transfer coefficients, k_La, from high to low are 0.13/min (2 parallel), 0.093/min (3 parallel), 0.068/min (1 series), 0.058/min (2 series), and 0.056/min (3 series). Therefore, the parallel module with two injectors was used for later development of the aerator module for field experiments.



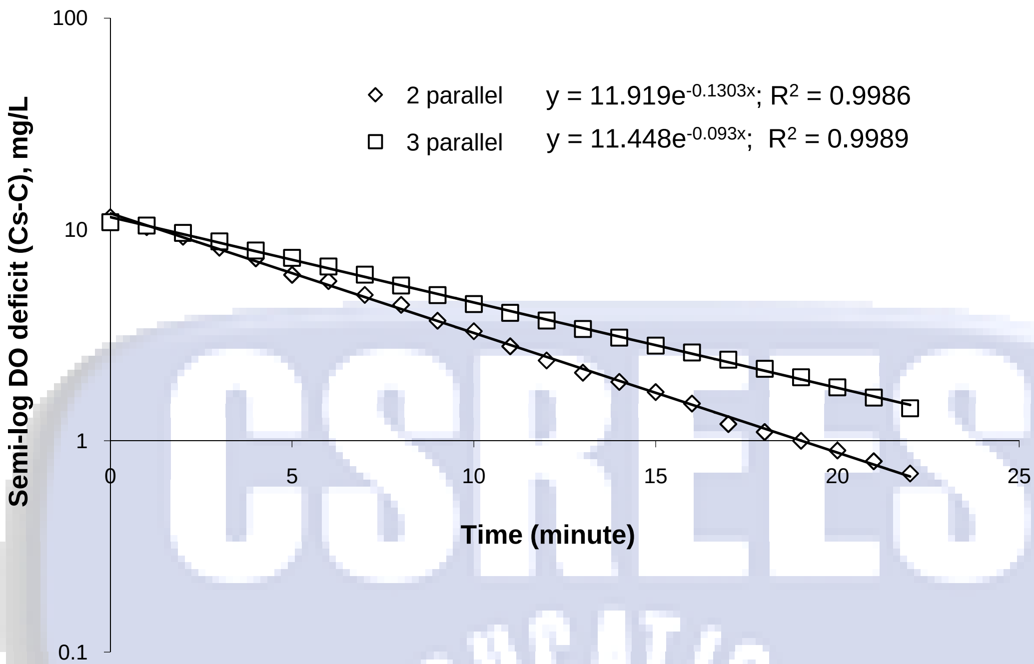
(a)



(b)



(c)



(d)

Figure 4. Water tests results, (a) and (b) – DO measurements for 3 series and 2 parallel modules; (c) and (d) – calculations to determine the oxygen transfer coefficients for series and parallel modules.

3). The final aerator module design

The goal of this surface aeration system is to cover 1/3 acre of lagoon surface using the aerator module developed that is driven by a 1.5 hp pump (1.125 kW). Since the parallel module with two injectors scored the best result in oxygen transfer capability, the final module was thus designed as a combination of three parallel modules, each providing aeration to 1/9 acre of the lagoon surface. A picture of the field module is shown in Figure 5. In order to maintain equal liquid flow rate in all three branching pipes, the size of the pipes were not the same and determined by calculation based on fluid dynamics. Also, the angle that the two side pipes were branched out relative to the center pipe was determined using the same principle. Therefore, the field module is not something that everyone can build in his backyard. It is a pivotal piece of work in this project that enables us to develop a relatively efficient surface aeration system to control manure odor emission from open storages at an affordable cost to the majority of swine producers. Since the water tests were conducted at different times under different temperatures, in order to compare the performance of all aerators, the test results in terms of k_La were corrected for temperature using Eqn. 3 in Chapter 1 and the corrected k_La for the field module is 11.87/h, which is about 42% higher than the best individual module (2 parallel, 8.37/h). Considering that the same pump was used in both cases, the results have proved our hypothesis that aeration efficiency of an aeration system can be improved by better aerator module design without additional spending.

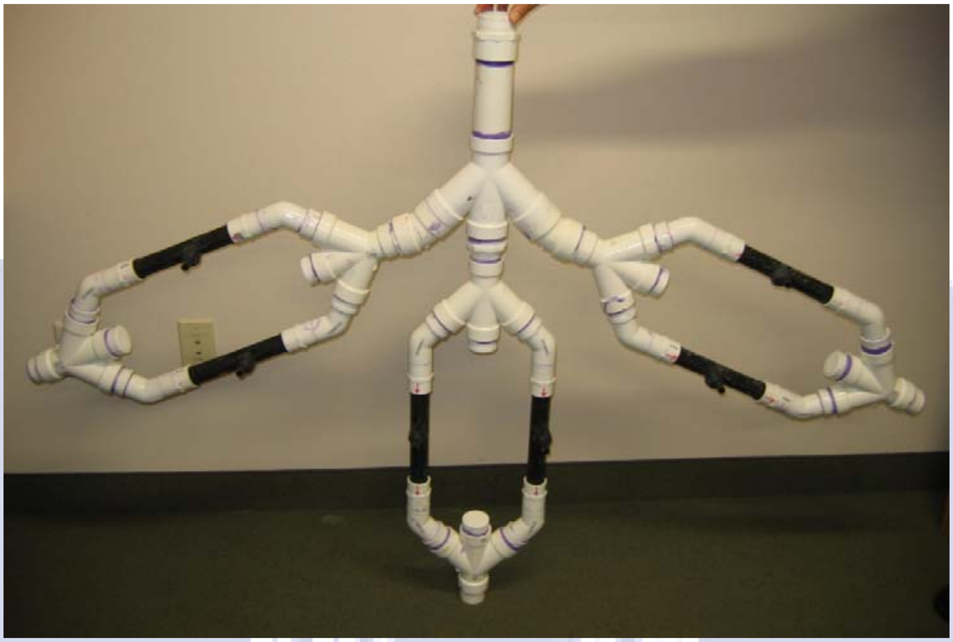


Figure 5. The final design of the aerator module for field experiments

2. Design of the aeration piping structure

The piping structure takes the responsibility of distributing the oxygenated water back into the lagoon so that an aerated surface layer can be created and maintained. In this study, one-inch diameter PVC pipe was used for constructing the distribution frame that was placed 12” below the liquid surface. The piping frame was sized to cover 1/3 acre of the lagoon during the field trials.

For even distribution of water, the liquid flow rate at each orifice (hole) along a pipe should be identical (see Figure 6 for illustrations). Due to friction loss as liquid moves farther down the pipe, the equal flow rate requirement can only be met by varying the orifice size, which can be determined methods commonly employed in irrigation system designs. For those who are interested in getting more information on this subject, they are encouraged to consult with any published book dealing with uniform distribution of water in pipes. Only a brief introduction of the methodology is presented herein.

When determining the size of each individual hole along the pipe, a number of variables are needed to be known first, i.e., friction loss, head loss, and liquid velocity. Figure 7 gives a brief description of those variables involved. The head loss increases (e_i) in each section between two holes can be determined as:

$$e_i = \frac{1}{2g}(v_{i+1}^2 - v_i^2) \tag{1}$$

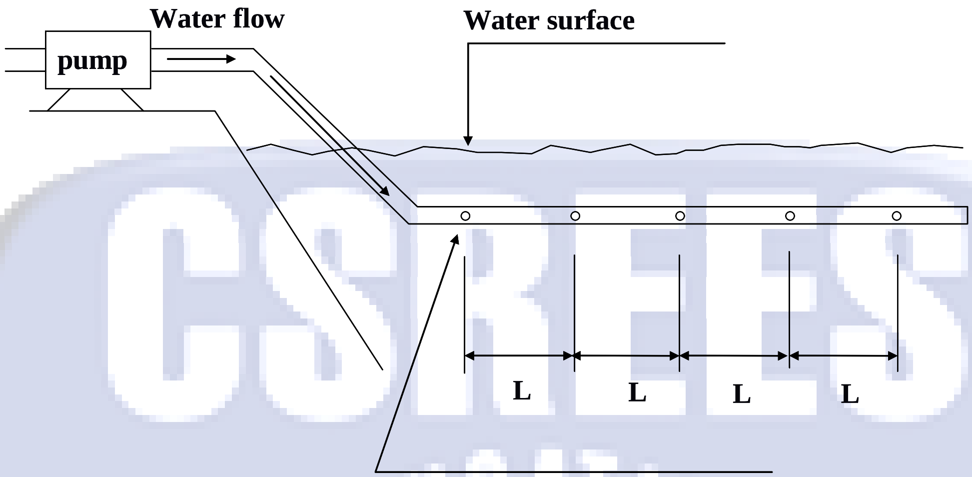


Figure 6. Schematic of the piping structure in lagoon water (not drawn to scale)

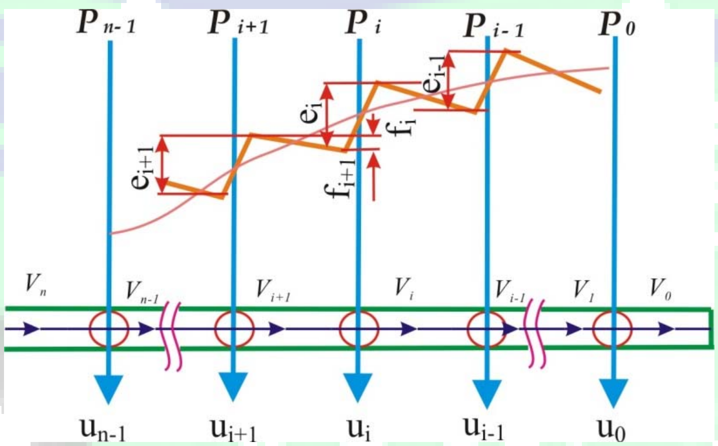


Figure 7. General description of all variables in connection to liquid movement inside a pipe

The friction loss in each section between two holes can be determined as:

$$f_i = \lambda \frac{L}{D} \frac{v_i^2}{2g} \tag{2}$$

where “L” is the distance between two adjacent holes and can be calculated based on the total number of perforations (“*n*”) and total length “*l*” as:

$$L = \frac{l}{n-1} \tag{3}$$

Based on energy conservation, for horizontally-placed pipes, the head pressure and velocity at the last hole before the end of the pipe can be calculated as:

$$H_0 = \left[\frac{4q}{\mu \pi d_0^{\ 2} \sqrt{2g}} \right]^2 \tag{4}$$

$$u_0 = \mu \sqrt{2gH_0} \tag{5}$$

Where:
q = the discharge rate from each perforation (m^3/s)
μ = orifice constant (0.61) which varies by type of orifice
d_0 = orifice diameter (m)
g = 9.8 m/s^2
H = head pressure on the orifice (m)

Please note that in Figure 7, P indicates “head loss” and is numbered backwards, i.e., P_0 is larger than P_1 and P_1 is larger than P_2…. By back calculations, the diameter of each hole can be determined.

The briefly described method above has led to the completion of our aeration system design that consists of three PVC pipes (1” in diameter and placed 50’ apart in parallel) with openings made on the pipes at 3.75 ft intervals (facing horizontally for liquid injection). Again, the pipe size and hole spacing were determined through hydraulic calculations based on the pump size, the lagoon area needed to be covered, the uniform liquid flow rate from each hole, and the flow rate in the pipe. Aeration was realized by the venturi air injector module presented early (Figure 5) and the entire system was driven by a 1.5 hp centrifugal water pump. The piping structure was placed 12” below the liquid surface and supported by floating barrels (the blue color objects shown in Figure 8) that allowed the structure to float with the liquid level. The performance of this aeration system on one swine and one poultry manure lagoon will be our topic in the next two chapters.

Figure 8. The actual placement of the aeration piping structure in a swine manure lagoon.