



FloMov

CO₂ Stripping Performance

Technology Evaluation Report

Introduction

Over the last few decades, global fish food consumption has been increasing at an average annual rate of 3.1 percent, producing about 179 million tonnes in 2018 [1]. Due to this high demand for marine foods, aquaculture has become heavily relied on to meet this need, accounting for 46% of the total production [1]. The growth of the aquaculture industry has been facilitated by the implementation of recirculating aquaculture systems (RAS) because they provide a fully controlled and stable environment for the fish [2]. In these aquaculture systems, the two main limiting factors that need constant monitoring and adjustments are the levels of dissolved oxygen and carbon dioxide [3]. Dissolved CO₂ originates from the metabolism of the aquatic organisms being farmed and can therefore accumulate within these closed systems, causing physiological harm and affect the overall growth of the fish [4]. There are currently no set guidelines on safe levels of CO₂ in aquaculture systems given that sensitivity to dissolved CO₂ varies for each species. However, in a study conducted by Colt [5], it was proposed that the threshold for CO₂ can be divided between cold and warm water fish, where cold water species have a tolerance between 10-20 mg/L, and warm water species 20-40mg/L. From this, a threshold of 20mg/L was decided on for the experiments conducted in this report.

There are very few studies to date evaluating the CO₂ stripping capabilities of airlift pumps. The baseline research that is typically referenced on this topic is that of Loyless and Malone [6]. This study examined the rate at which an airlift pump could remove co₂ from a freshwater tank. Their experiments were conducted by first injecting co₂ into the water until the desired pH level was reached, then the airlift pump was operated, and pH readings were recorded every 30 seconds for up to one hour [6]. Equations to calculate the standard carbon dioxide transfer rate (SCTR) and the standard stripping efficiency (SSE) were derived [6]. Results indicated that the co₂ stripping rate increased as the airflow rate was increased whereas the degasification efficiency decreased [6]. Overall, these results suggested that if the oxygenation needs were met using an airlift pump, then co₂ stripping requirements would also be met. A study conducted in 2010 by Moran [7] continued the work of Loyless and Malone [6] utilizing an identical airlift system to measure the co₂ stripping performance. In this study however, the co₂

degassing efficiency was compared between fresh water (0‰) and saline water (35‰ NaCl) [7]. Results found that the CO₂ stripping efficiency did not differ with salinity [7]. A similar study by Barrut et al. in 2012 [8], tested salinity effects using a vacuum airlift pump and testing various injector types and pressures. This study also concluded that salinity did not effect the mass transfer of the system, but the presence of a vacuum was found to reduce the gas solubility in water and facilitate CO₂ stripping [8].

Methodology

The carbon dioxide stripping experiments were conducted in a 47"x37"x45" tank with a capacity to hold up to 1249 L as seen in Figure 1. This enclosed system utilized a 4inch FloMov pump by FloNergia ©, allowing the pump to recirculate the water into the same tank. This provides ample mixing to avoid CO₂ dead zones throughout the tank during testing. The airlift pump was attached to a structural frame that secured it to the tank and minimized movement and vibration during testing. The airlift was placed at a length of one diameter from the inlet of the pump to the bottom of the tank for proper operation and consistency during testing. The tank was filled with clean tap water and adjusted to the correct testing submergence for each trial. In order to operate the airlift pump, a pneumatic system was used where the injected air was supplied through a regenerative blower. The supplied air passes through a relief valve, a pressure gauge, and a check valve. The air flow rates of the axial and the radial injection geometries were controlled separately with the use of two rotameters reading up to 21 000 LPM and adjusted using control valves. From the rotameters, 1" tubing was used to supply the injected air to the injection ports of the FloMov pump.

For the initial set of CO₂ stripping experiments, a 4-inch FloMov pump was tested operating at 50% axial/50% radial dual injection at a submergence ratio of 0.9. In order to test the stripping capabilities of the airlift pump, CO₂ gas must first be injected using air stones to better diffuse the gas into the water. The CO₂ gas was diffused for an hour for each test to

achieve a consistent initial CO₂ reading of 625 mg/L. The CO₂ concentrations were measured with a drop count titration method using the HACH CO₂ titration kit with reagents of phenolphthalein and sodium hydroxide to measure the concentration levels within each collected water sample. The temperature of the water was also recorded prior to each test. At this point, the airlift pump is operated at the airflow rate being tested for each trial and allowed to run until the CO₂ levels reach below 20mg/L as dictated in literature as a safe amount of CO₂ in aquaculture applications. As the airlift is operating, a timer is set to record the time it takes for the water to be stripped of CO₂ below the designated concentration levels. CO₂ readings are measured and recorded every 5-10min throughout the trial in order to accurately observe the pumps' stripping capabilities throughout each test. With this data, further analysis can be conducted to fully understand the pumps stripping capabilities.

The airflow rates chosen for testing for the first set of experiments using the 4inch pump, were based on the pumps performance curve. As seen in Figure 2, the three airflow rates were taken at 100LPM, 800LPM and 1400 LPM. This was dictated to encompass the pumps best efficiency point (100LPM), the maximum liquid flow rate at 800 LPM as well as the maximum operating airflow rate available withing the setup's operating air flow range. Additional airflow rates may be tested in future trials; however, these three points cover the basic operating range of the 4inch pump.

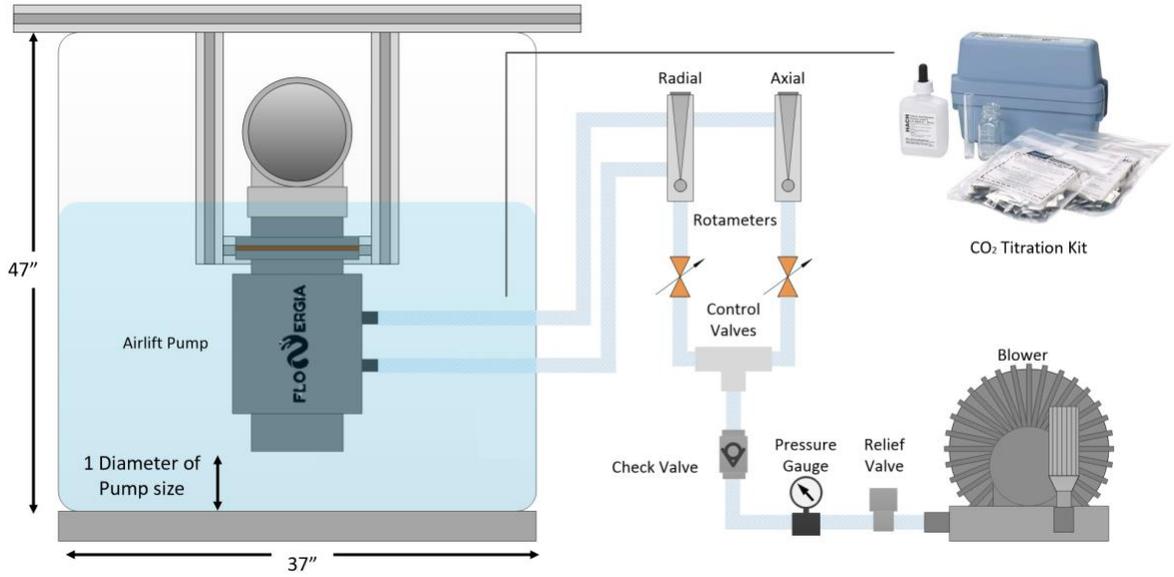


Figure 1: CO2 stripping experimental setup

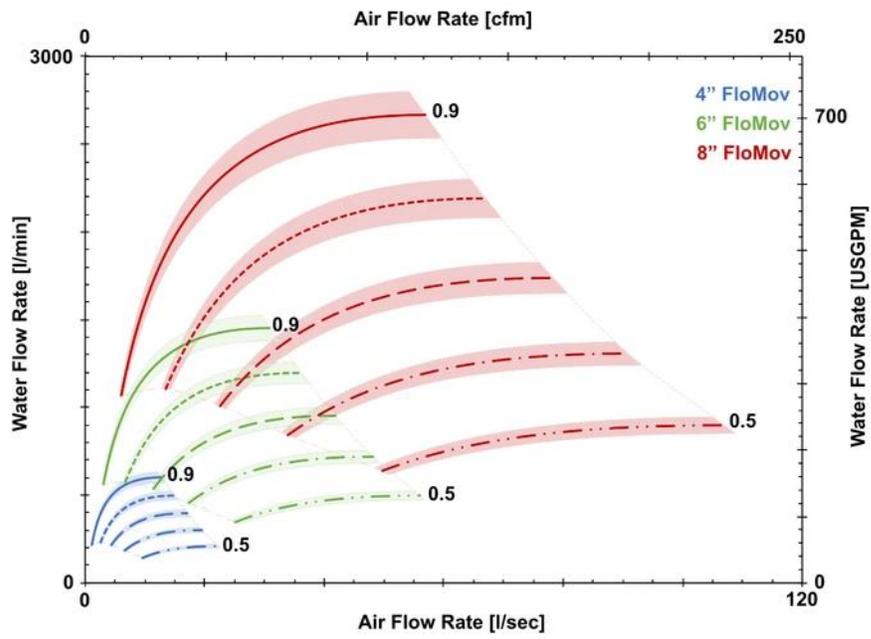


Figure 2: FloMov pump performance curves

Analysis

To analyse the collected data, the co2 stripping rate was calculated using the following equations derived by Loyless and Malone [6]. Firstly, the gas transfer coefficient K_{LaCO_2} was calculated using linear regression of the following equation:

$$-\ln\left(\frac{C_t - C_s}{C_o - C_s}\right) = K_{LaCO_2} t$$

where t is the time in minutes, and C_o , C_t , C_s are initial, temporal, and saturation carbon dioxide concentrations in mg/L. The saturation concentration was assumed to be 0.5 mg/L due to various reasons stated by Loyless and Malone [6]. The gas transfer coefficient was then corrected to a temperature of 20°C ($(K_{LaCO_2})_{20}$) using an Arrhenius type relationship where θ is equal to 1.024, and temperature is in Celsius.

$$(K_{LaCO_2})_{20} = \frac{K_{LaCO_2}}{\theta^{(T-20^\circ C)}}$$

To calculate the standard carbon dioxide transfer rate (SCTR) in gO₂/h, the following relationships adapted from ASCE 2-91 (1992) where used:

$$SCTR = (K_{LaCO_2})_{20} [C_m - (C_s)_{20}] V \cdot 60 \cdot 10^{-3}$$

where $(C_s)_{20}$ is the saturation concentration corrected to 20°C, set at 0.5 mg/L, and C_m is the standard measured concentration, arbitrarily defined by Loyless and Malone to be 1 mg/L [6]. The volume of the water, V , is measured in liters, and a conversion from minutes to hours and from milligrams to grams is added to the equation. In the present study, the total volume of fresh water is 800 L is used to carry out the experiments. To find the standard stripping efficiency (SSE) in gO₂/kWh, the power of injection is first calculated using the following equation:

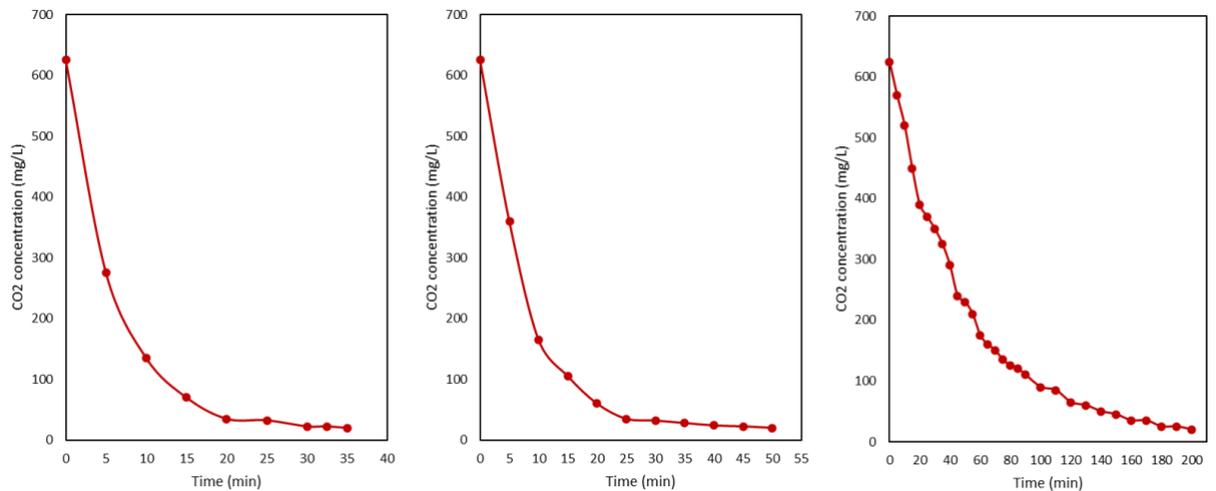
$$Power = \frac{\rho \times g \times H_s \times Q_G}{1000}$$

The power is defined using the water density ρ in kg/m^3 , the acceleration due to gravity g in m/s^2 , the static head H_s at 0.9 submergence in meters, and the air flow rate Q_G in m^3/s , divided by 1000 to convert from W to kW. From this, the SSE can then be calculated by dividing the transfer rate by the delivered power.

$$SSE = \frac{SCTR}{kW_{ad}}$$

Results

The three initial tests recorded at airflow rates of 1400LPM, 800LPM and 100LPM were graphed in Figure a) b) and c) depicting the CO_2 concentrations in mg/L over time (in minutes). The analysis was performed to calculate the SCTR and SSE values at each tested airflow rate. Figure 4 depicts the SCTR curve where an increase in SCTR is exhibited as the airflow rate is increased, which increased the amount of mass transfer that can occur.

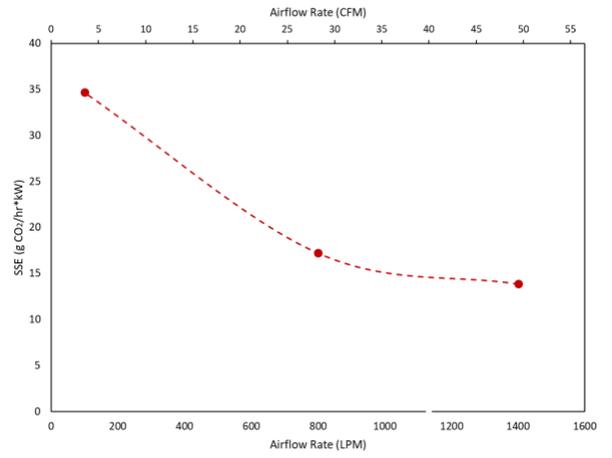
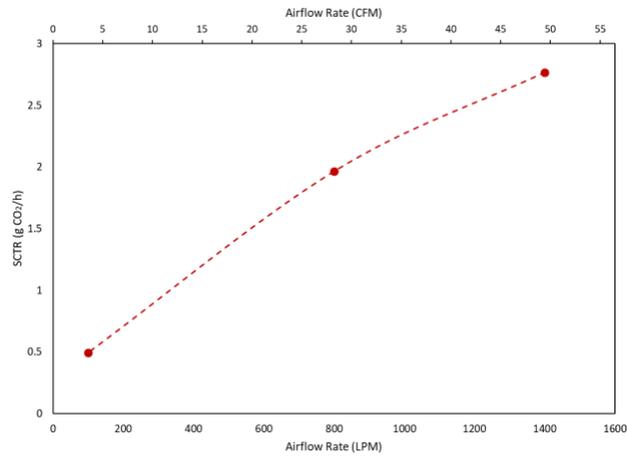


a) Airflow rate: 1400 LPM

b) Airflow rate: 800 LPM

c) Airflow rate: 100 LPM

Figure 3: CO_2 degassing curves at 3 airflow rates and dual injection



a) Standard carbon dioxide transfer rate

b) Standard stripping efficiency

Figure 4: SCTR and SSE graphs

Results (1-inch FloMov)

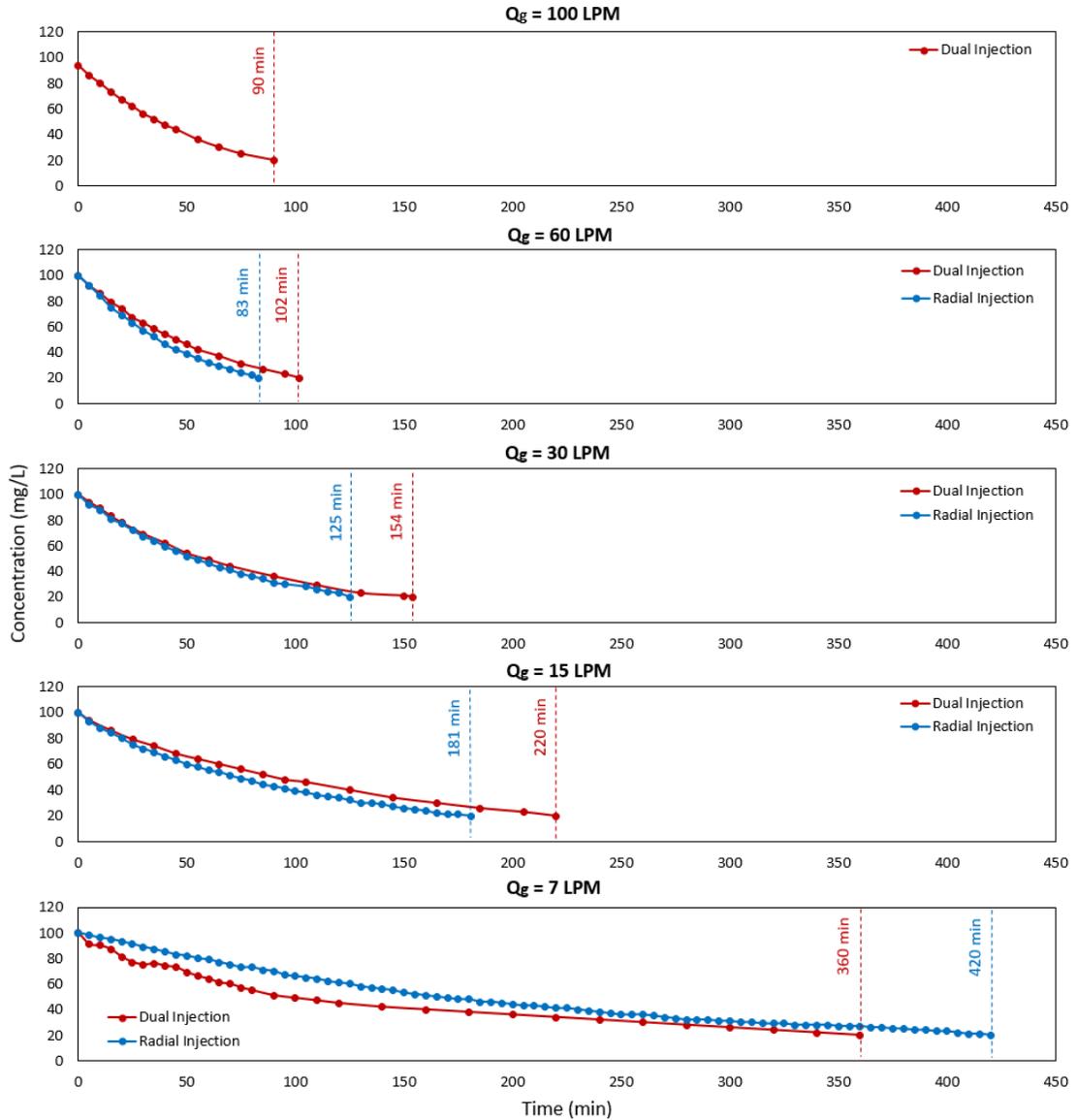


Figure 5: CO₂ degassing curves for 1 -inch FloMov pump

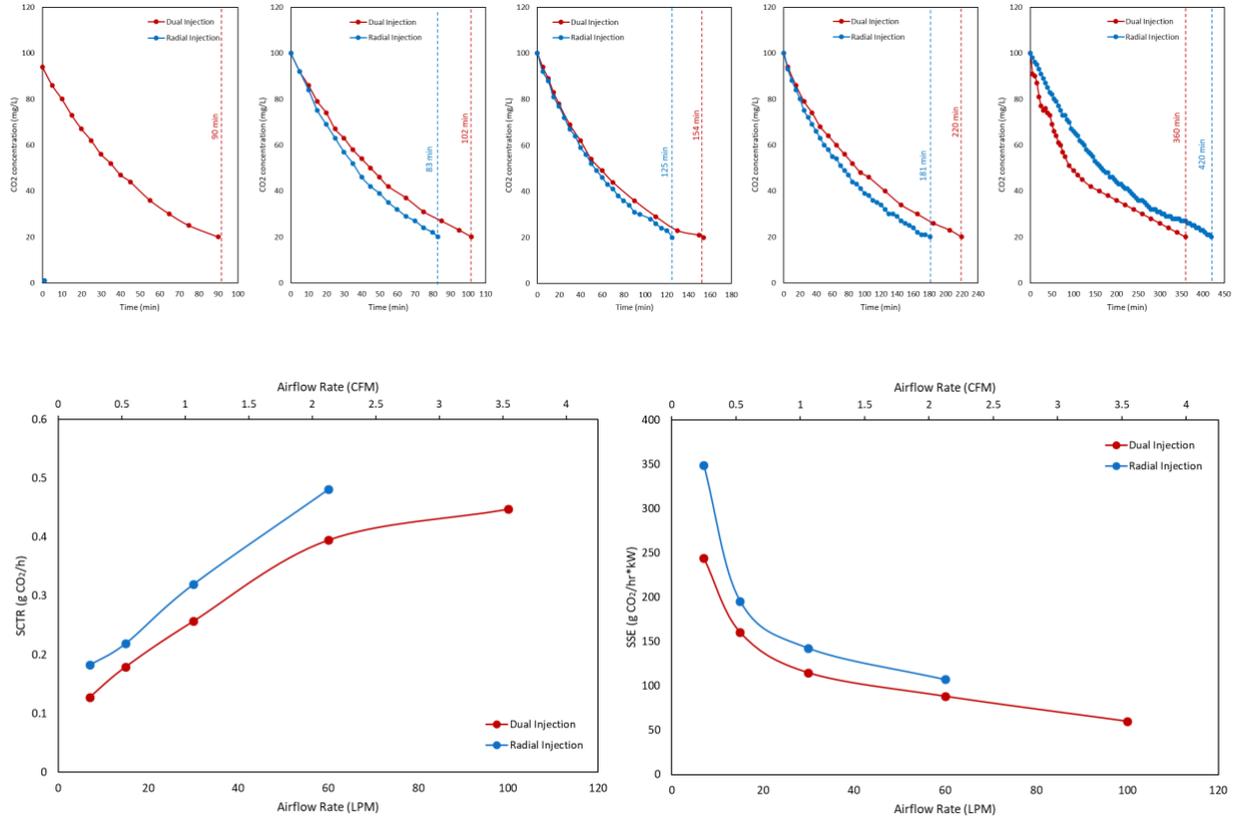


Figure 6: SCTR and SSE graphs (The values are per 1 liter of water)

Results (2-inch FloMov)

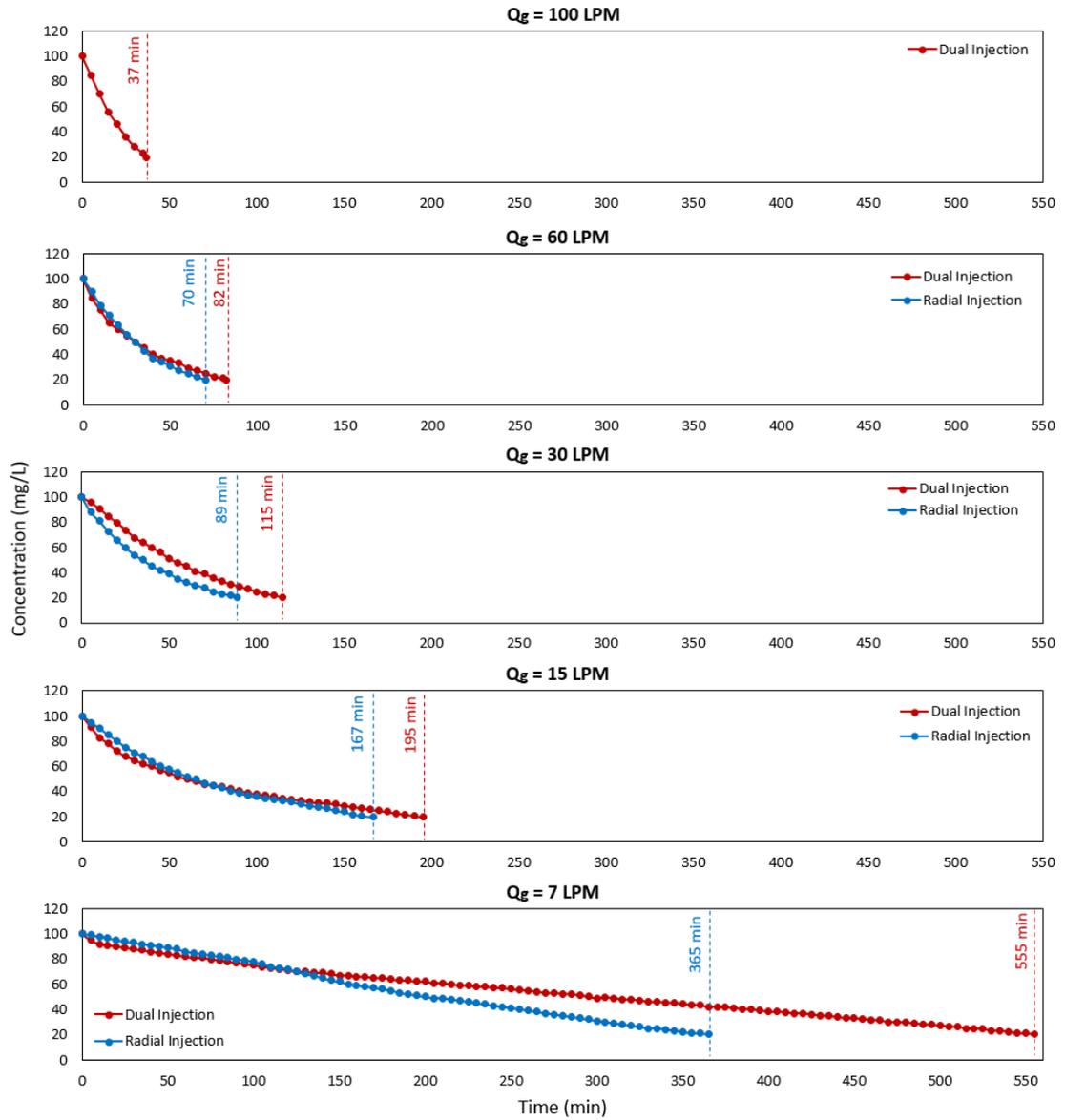


Figure 7: CO₂ degassing curves for 2 -inch FloMov pump

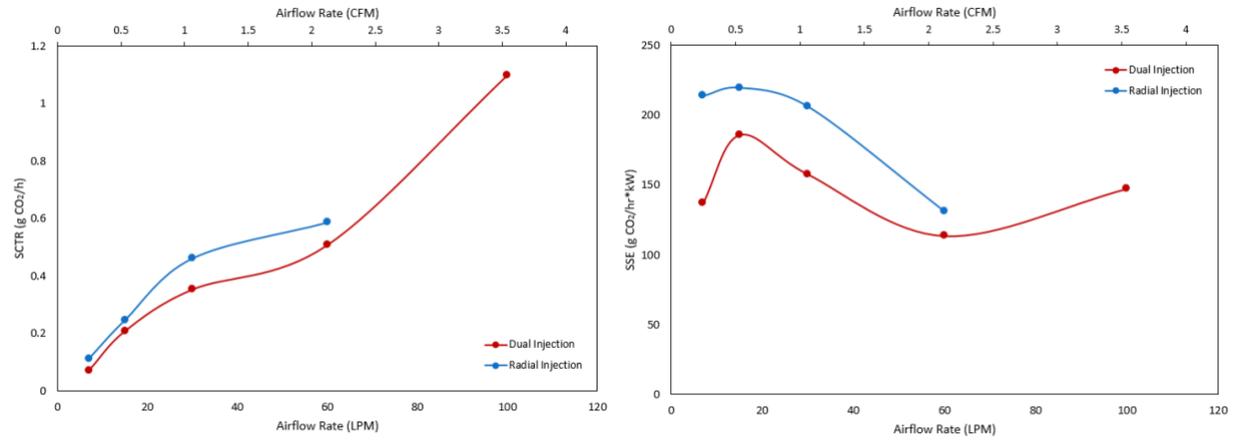
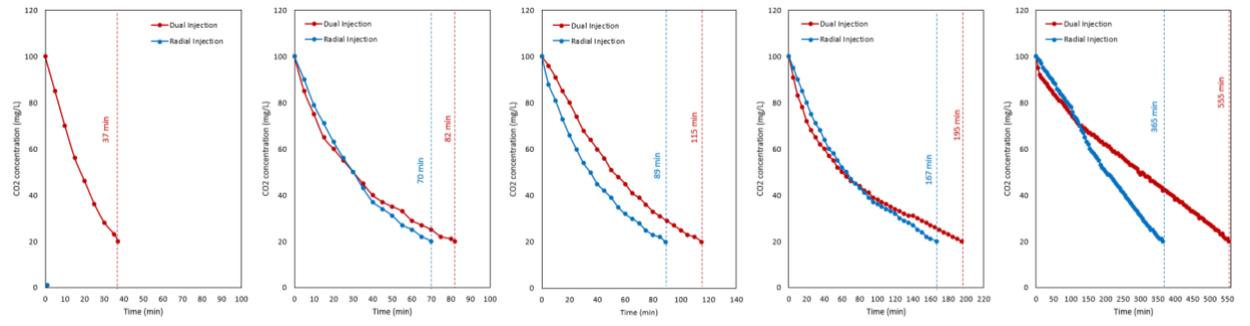


Figure 8: SCTR and SSE graphs (The values are per 1 liter of water)

Results (4-inch FloMov)

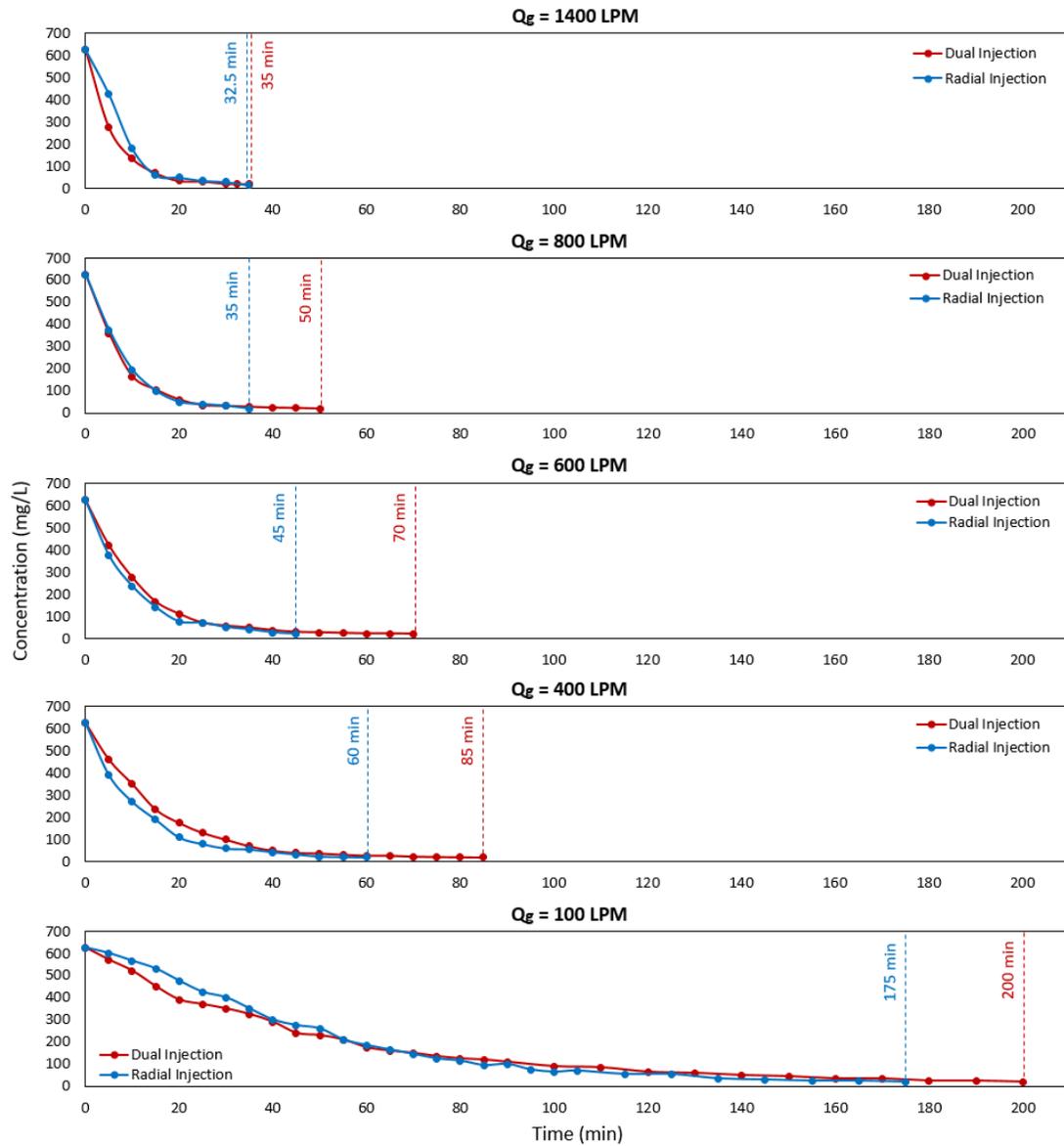


Figure 9: CO₂ degassing curves for 4 -inch FloMov pump

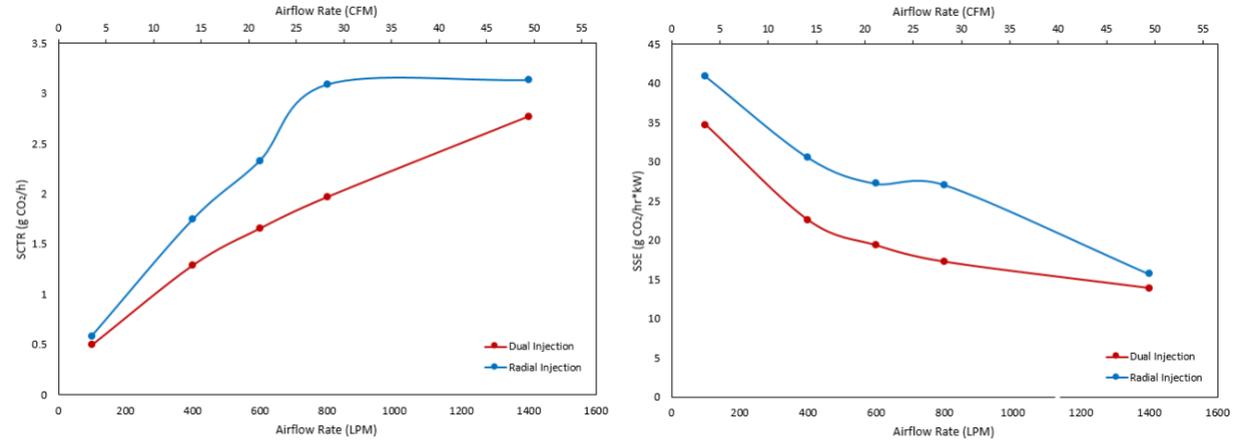
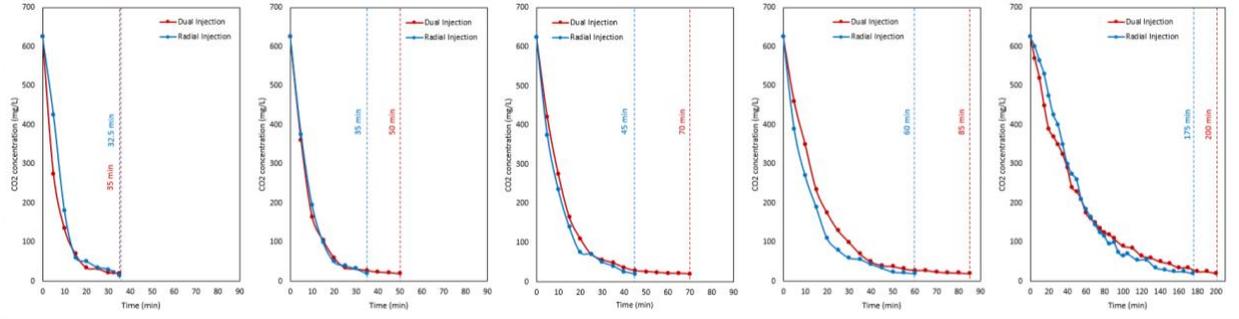


Figure 10: SCTR and SSE graphs (The values are per 1 liter of water)

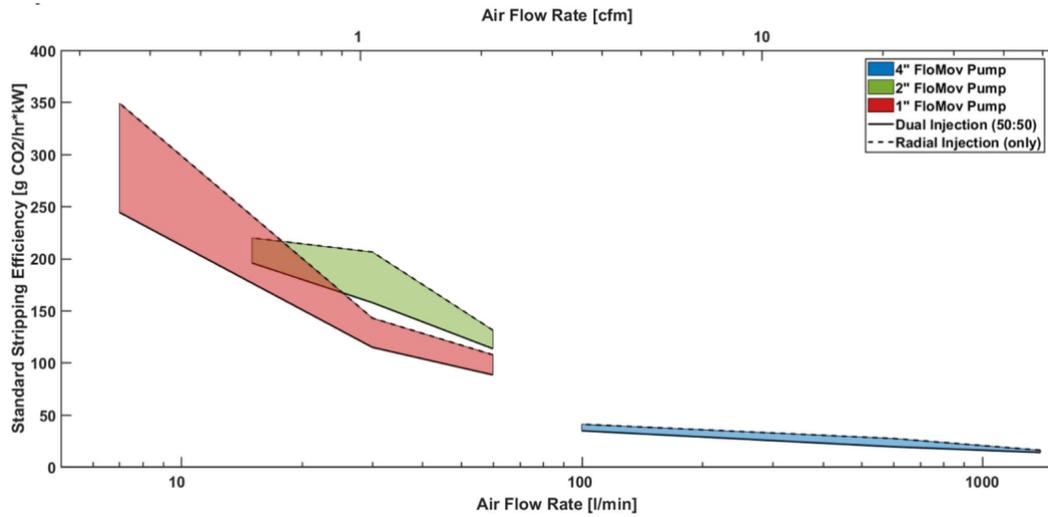


Figure 11: The combined SSE graphs

References

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