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Biological Treatment of Produced Water

Introduction:

Produced water (PW) is a byproduct that comes out of the ground with oil and gas during oil and gas exploration and production. PW's chemical and physical characteristics vary based on the reservoir characteristics and on the extraction process. PW is one of the largest waste streams generated in the Oil and Gas industry and is estimated to be around more than 110 billion barrels per annum in the world in 2019, out of which, 21 billion barrels is produced by North America alone [1]. PW contains various aromatic and aliphatic hydrocarbons, phenols, polycyclic aromatic hydrocarbons, heavy metals (e.g., Cu, Pb, Zn, Ni, Cd, Cr), and additives (e.g., antifoam, biocides, scale, and corrosion inhibitors) which are added to the extraction process to increase efficiency and prevent operational issues [2]. Given the complex chemical and physical nature of the PW, it is paramount to treat and dispose of the PW safely, otherwise, the PW contaminants can severely impact the receiving water bodies, soils and air [3].

Over the years, multiple chemical and biological treatment techniques have been developed for PW treatment, including coagulation-flocculation, electrocoagulation, hydrocyclone, membrane filtration, gas flotation, etc [4]. However, reinjection to the disposal wells been the mostly preferred method for PW treatment in the oil and gas industry. The cost of treating one barrel of PW is $0.775, whereas the reinjection cost is 0.75-8 $/barrel [5]. Currently, most of the generated PW is reinjected into the disposal wells, and it is more expensive to reinject than to treat the PW. The cost of treating one barrel of PW is $0.775, whereas the reinjection cost is 0.75-8 $/barrel [5]. In addition to the high cost of these treatment techniques, significant input of chemicals and incomplete removal of metals are

still the main limiting factors with the existing treatment processes [6]. This leads to the need for a more sustainable pathway to treat the PW.

The traditional removal of containments happens to be costly, labor intensive and environmentally unsustainable. In contrast, algal bioremediation of produced water has benefits of being environmentally cautious and reliable to treat produced water. Thus, the pollutants in PW serve as nutrients for the algae and other microorganisms inhabiting the produced water. However, significant dilution of produced water is often required in algal-based systems due to complex chemical contaminants present in PW.

Materials and Methods:

As a product of my previous research, *Galdieria sulphuraria* showed the best performance. Additionally, this algal strain can sustain high temperatures. It has a low pH, tolerates high salt and metal concentrations. *Galdieria sulphuraria* can outcompete wastewater pathogens and can handle a variety of chemicals. Therefore, in the current research it was used to treat the produced water as such. The strain of algae grown on-site and was grown under 24 hrs of continuous illumination inside the incubator at 42°C. A 16/8 hour- light and dark cycle with a temperature of 28°C. The carbon dioxide levels inside the incubator were kept around 3% and were measured every morning. Hence, giving the microorganisms an environment to increase in biomass for experimentation.

Cyanidium media (CM) was used as the standard growth media for *Galdieria sulphuraria*. In the early stages of the research, the development of large-scale culture was needed. The incubator's CO_2 levels were kept at a constant rate between 2-3% (vol/vol). All flaks used were autoclave prior to usage. To start the small-scale reactors to grow the bulk number of algae needed, CM was added to the bottom of the flasks. The algae was then added, and the flasks was placed into the incubator. Thus, the algae being in the incubator optimal density (OD) of the algal growth was then measured every morning with the spectrophotometer. The biomass density was analyzed within the confides of 'ash dry weight'. All OD value of *G. sulphuraria* were taken from 750 nm. As a result of the algae was tested for ammonia nitrogen and phosphate-phosphorus The HACH DR 3900 (HACH, Colorado, USA) with the HACH vials and powders gave different measurement ranges for each sample. The tasks of ammonia and phosphate measurement was preformed every

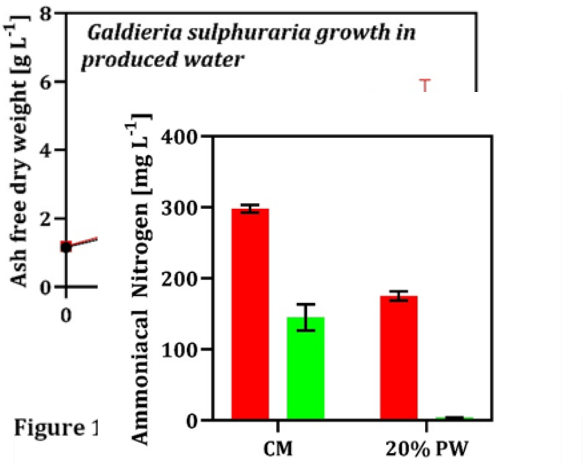

Figure 1

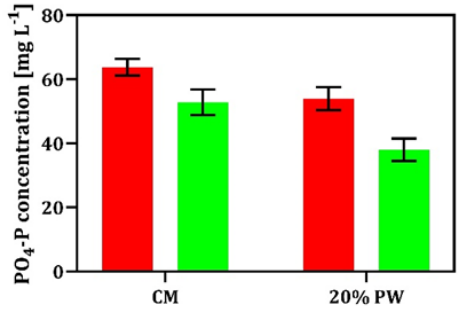

Figure 2: Ammoniacal and Phosphate Removal

other week. Once the algae needed a larger space to grow, they were transferred to larger Erlenmeyer flasks. Once a bulk amount of media was created the algae was then transferred into 10 mL reactors inside the incubator. Therefore, the continuation of the growth would create enough culture to be moved to 10 L large scale reactors. The 10 L large scale reactors were kept in lab temperature control room at 40°C. The OD of these 10 L reactors were taken every day to ensure the biomass growth.

Discussion:

The 1 L reactors were tubular bubbling bioreactors in an in-lab temperature control room at 40°C. The light cycle conditions were 12/12 while the CO_2 levels were kept at 2-3% (vol/vol). The two conditions in the 1 L reactors consisted of 5 tubes with control media and 5 tubes containing 20% PW. This experimental setup lasted for 7 days in the 1 L reactors. As a result, the reactors containing 20% PW showed the best results. The final biomass with the control media was 5.38 ± 0.680 g L^{-1} while the 20% PW had a biomass of 3.20 ± 0.396 g L^{-1} (Figure 1). The nutrient removal in the 1 L reactor showed significant results (Figure 2). The ammoniacal removal was greater in the 20% PW with a 97% outcome. In contrast to the control media only removing 41% of all ammoniacal nitrogen removal. The 20% PW in the case of ammoniacal nitrogen removed almost all the chemical completely. The phosphate removal of with 20% PW removed 33%.

Conclusion:

G. Sulphuraria for bioremediation is sufficient for removing Ammoniacal nitrogen and PO_4-P in PW. Additionally, the collective biomass and substantial nutrient removal indicates the benefits of agal based systems. Therefore, further experiments in 10 L reactors are needed to evaluate the nutrient removal and biomass growth in pilot-scale reactors. Thus, leveraging the data obtained from these pilot scale reactors to optimize the systems' performance in real life applications.

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