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Contents

1 Introduction/Motivations/Objectives/Context

- Wastewater in the UK
- How bad is it and evidence
- Establish clear problem
- Bring up MFCs
- Description and discussion of major design parameters
  - A table could be a coherent way show them
- Can use diagram from Zheng and Halme 1995 for visualisation

2 Aims

- Assess currently available literature on MFCs
- Present a clear and logical narrative
- High quality critical analysis
- Set the project within a wider context

3 The Plan

- Literature read in preparation for dissertation
- Covers a range of key topics
  - Background and context:
    - Expand my knowledge
    - Provide information for the reader
      - Strike a balance between this analysis and the critical review
  - Review papers:
    - What is the current situation in the research community
    - Work that has been done
    - Suggested areas of future work
  - Experimental work:
    - Detailed information on current capabilities
    - Results that can be used for comparison to test model viability
    - Helps define what our models should be looking for
  - Modelling Papers
    - Specific work relevant to my project
    - What are the assumptions and why?

        * Parameters that were considered and why?

3.1 Introduction

A broad overview of Microbial Fuel Cells is provided by a textbook on the subject by Logan (2008).

- Power generation
  - Polarisation and power curves are used to characterise MFC power generation
  - Changing the external resistance provides variable voltage
  - *Use a good example to illustrate to the reader*
  - We can use polarisation curve to calculate current and plot current vs voltage or current density
  - Generally split into three sections - middle is the most important as it shows internal resistance of cell
  - Shows how well the MFC maintains a voltage as a function of current production
  - Maximum power can be read off the top of the curve
  - External resistance has to be used as low resistance in the cell is not enough for feasible power generation
  - We don't want to increase internal resistance because the cell will perform significantly worse
- Mixed vs pure culture
  - Jadhav + Ghangrekar 2020
  - Mixed cultures are better for overall functionality
    * Higher specific power
    * Resistance against shock load conditions
    * Reduced substrate specificity
    * Lower Coulombic efficiency
  - Pure have increased power output and Coulombic efficiency
    * Increased cost
    * Risk of contamination
    * Difficult to isolate a single strain
- Air cathode
- Architecture
- Materials
  - Common option is carbon cloth
  - Cheap and porous
  - Good for bacteria to grow on
- Biofilm
  - Layers of bacteria that form on the anode
  - Increasing bacteria increases electron release
  - If biofilm is too thick then there are mass transport issues
  - *How do we control it?*
- Temperature
  - Process is fundamentally biological
  - Therefore bacteria is affected by temperature
  - Higher temperatures generally correlate with larger power output
- Flowrate

3.2 Literature Review

A potential configuration for a domestic Wastewater Treatment Plant (WWTP) was considered by Logan (2008) and is shown below in Figure 1.

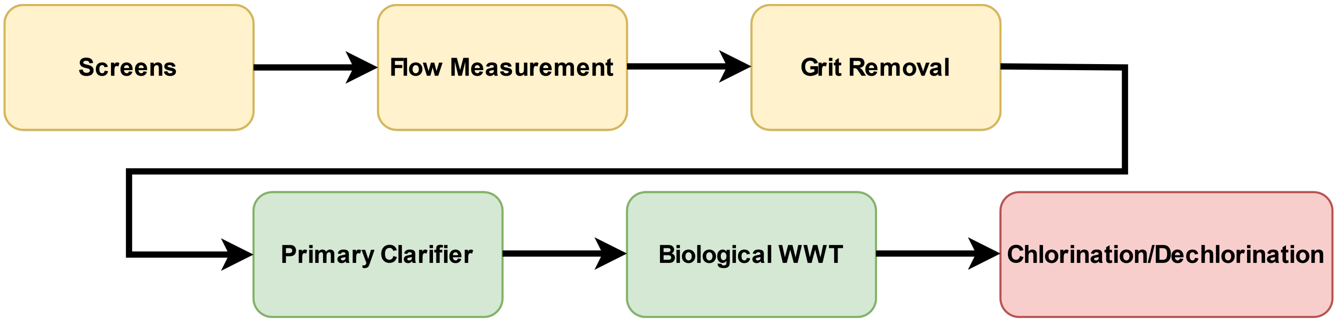

Figure 1: Process flow train for a domestic wastewater treatment plant (Logan,2008)

First the wastewater is screened to remove large pieces of debris that may have entered upstream. The wastewater's flow is then measured and recorded. This allows for comparison with past data to determine any anomalous flow that may enter the system as as result of flooding or similar events. The wastewater then undergoes grit removal to prevent gritty particles such as coffee grinds or bones from damaging pumps. Typically this will involve a hydraulic residence time (HRT) of between 1-20 minutes. Following this, the wastewater will be tested for either its biochemical oxygen demand (BOD) or its chemical oxygen demand (COD). The BOD takes 5 days and shows what material can be biologically removed, whilst the rapid COD test provides an assessment of all organic matter present.

Some of the biological material present as particulates is then removed in the primary clarifier, usually by collecting solids that accumulate at the bottom of the tank in a process with a HRT between 1-3 hours. Once this has been done the biological material will have been reduced to around 200 mg L^{-1} and the water will be ready for the wastewater treatment. It is proposed that this step will be done by a system based on MFCs to take advantage of the electricity generation and other related benefits over current systems. Finally the wastewater goes a chlorination stage to kill of any remaining bacteria and then a dechlorination stage to prevent harm coming to aquatic life located where the water is released.

Within recent years interest in MFCs has increased. This is made clear by review papers considering the current state of modelling work such as those by Ortiz-Martínez et al. (2015) and Xia et al. (2018). These papers are very useful as they provide a broad overview into the technical work in key areas such as potential cell architecture, key parameters to consider and common model assumptions.

For instance, comprehensive models that seek to model all major processes such as the mass diffusion and substrate consumption can be either half cell models that consider the activity around the anode or full cell models that consider both the anode and cathode. Whilst the reaction around the anode is generally considered the limiting stage within the cell, the model for this proposed project will be a full model to provide as much insight into the internal processes of the cell when supplied with a low temperature feed. As a result, the model will be able to produce outputs relating to the biofilm thickness, fuel flow rate and concentration in addition to the electricity generation for comparison to experimental data.

The experimental work around MFCs has been studied for longer than the modelling aspect and as a result there are plenty of papers available that provide experimental data for comparison with the results from a model. For this project, the main papers considered for this proposal focused on long term operation of MFCs. Santoro et al. (2012) operated a cell for 26 weeks, operated at 30°C whilst Moon, Chang, and Kim (2006) were able to operate multiple cells for 2 years over a range of temperatures. These results illustrate the

operational viability of MFCs as successful long term operation reduces the need for maintenance or replacement of cells. This in turn allows MFC systems to be operated for longer resulting in reliable wastewater treatment.

However, the temperatures considered by both of these papers are not reflective of typical temperatures of UK wastewater *Access Database evidence*. Therefore, the is scope for research into the performance of MFCs at lower temperatures to determine potential power outputs and thus potential feasibility.

To provide experimental data for direct comparison with the proposed model the work done by Cheng, Xing, and

Logan (2011) has been considered. This research involved testing the power output of MFCs between 4-30°C having initialised them at 15°C or 30°C prior. This research suggests that cells initialised at higher temperatures produce reasonable quantities of power and could be used within a WWTP in the UK. This is an important fact to establish prior to any modelling work as it demonstrates that operation of these cells at lower temperatures is possible and therefore time spent modelling them is not being wasted.

The large amount of experimental work provides plenty of data to validate new and existing MFC models. One such example is a model developed by Oliveira et al. (2013) that could correctly predict how the substrate concentration and temperature affected the cells biofilm thickness and performance. As part of this the temperature considered by model was adjusted between the values of 20°C, 30°C and 40°C. The key takeaway from this is that there are models accurate and reliable models available that allow for adjustment of the temperature. Therefore, this model could potentially be adapted to investigate MFC performance at lower temperatures as part of the proposed project

Other potential models that could be used as the basis for the project include those considered by Pinto et al. (2010) and Zeng et al. (2010). Both of these were able to successfully predict MFC behaviour and performance when compared to experimental data despite being based on different principles. Pinto et al. (2010) developed a half-cell model based on the anode whilst Zeng et al. (2010) developed a model based on the cathode. This was unusual as the anodic step is generally considered to be reaction limiting. The existence and accuracy of these models demonstrates that there is good degree of flexibility available when initially building and then refining a model. As a result, the final model considered by the project may differ significantly from the one considered initially.

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