Hydrogen production from biomass using a low temperature electrolysis pathway

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INTRODUCTION

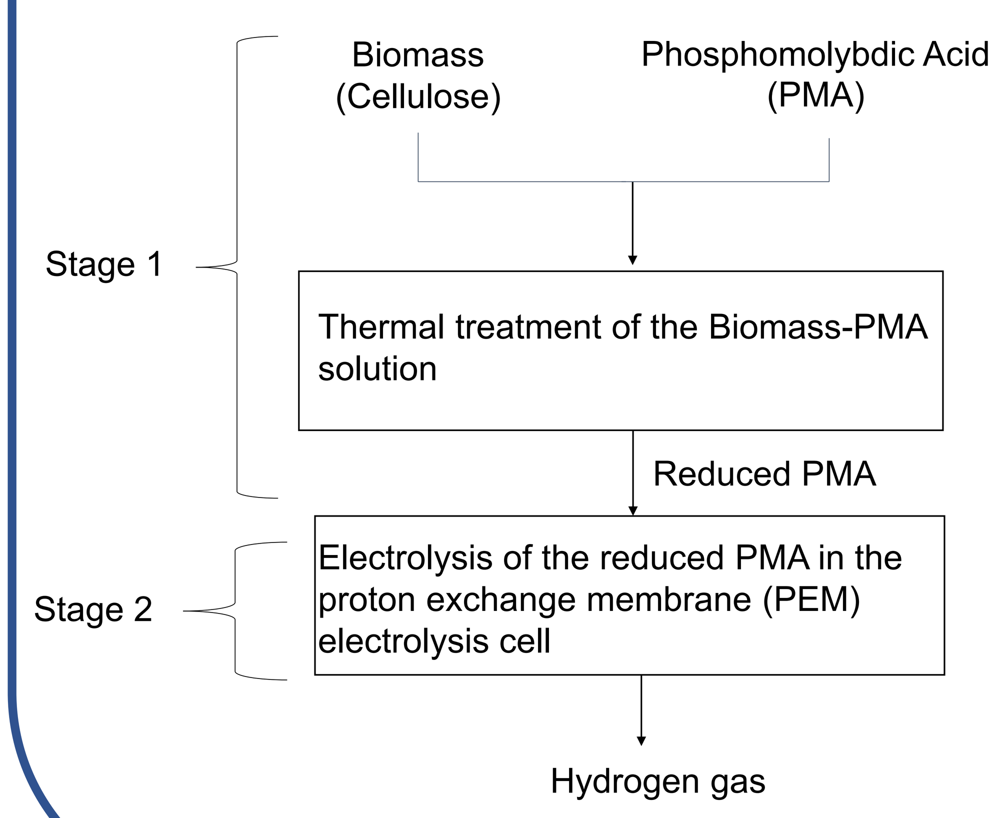
Hydrogen is a clean fuel that has the potential to decarbonise many industrial processes. Currently only about 5% of global hydrogen is produced through zero-carbon routes [1]. Consequently, there is a growing interest in finding effective carbon-neutral alternatives to produce hydrogen sustainably. Biomass from waste streams such as lignocellulose biomass, distillery waste and wood waste are viable feedstocks that could potentially replace crude fossil-carbon based feedstocks. Conventionally, biomass can be converted into synthesis products via gasification or other thermal processes. Biomass gasification route has been extensively explored, albeit highly energy intensive [2-3]. More recently, the electrolysis of biomass is considered a potentially viable option. At present, there is no energy balance and range of optimum operating conditions that would make the biomass electrolysis process favourable and competitive.

OBJECTIVES

- To determine the optimal conditions for the biomass-phosphomolybdic acid (PMA) reaction.
- To determine the current and potential range for the biomass electrolysis reaction using linear sweep voltammetry.

METHODOLOGY

The electrochemical process of producing hydrogen proposed by Liu et al [1]. is divided into two stages; reaction of biomass with PMA catalyst in aqueous solution, followed by electrolysis of the reduced PMA solution.



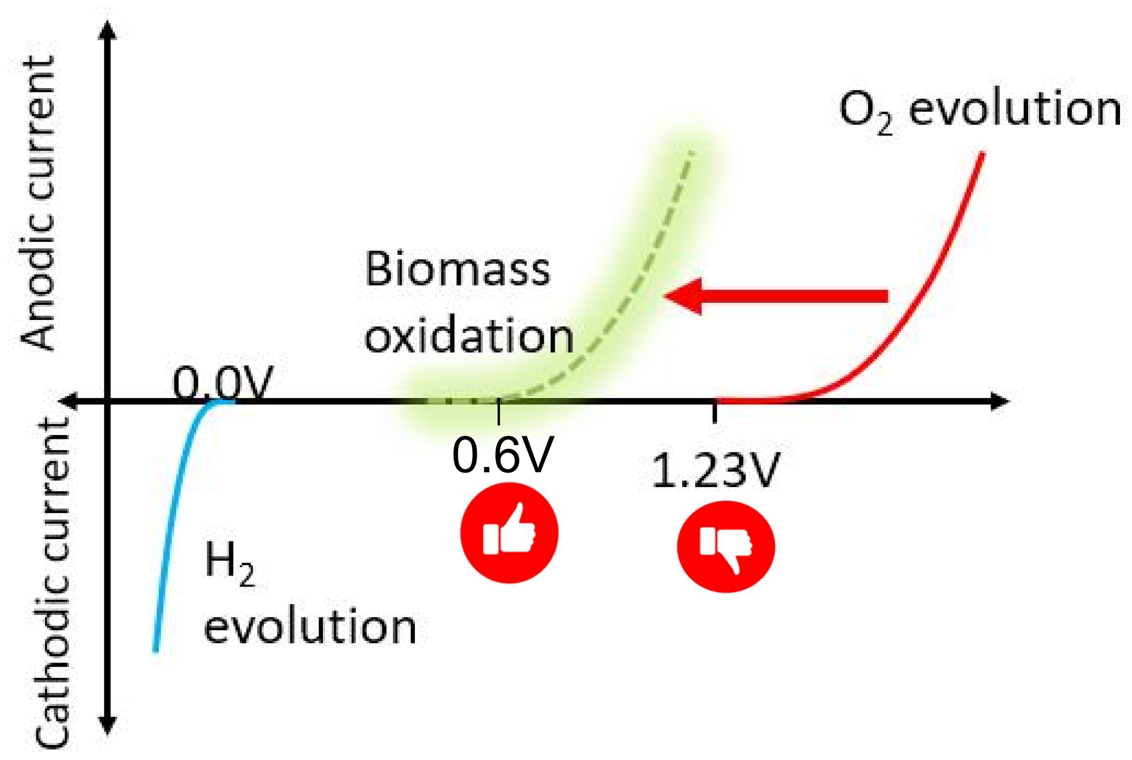


Fig.1 : Cell voltage for biomass electrolysis process compared to water electrolysis.

EXPERIMENTAL

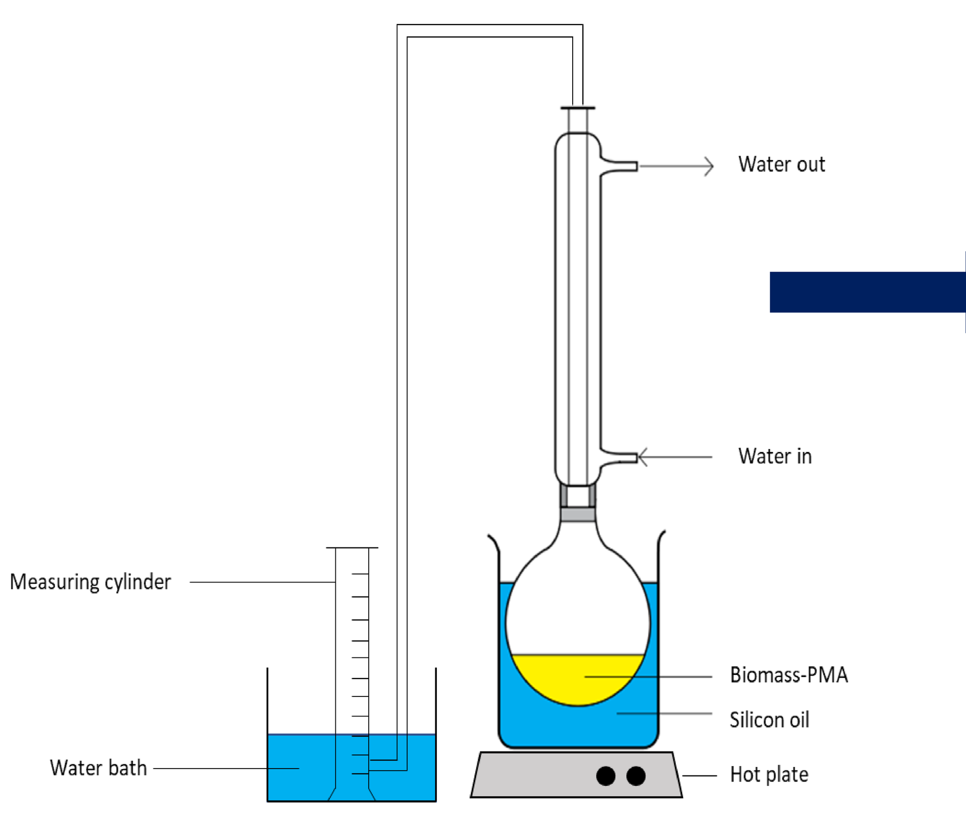


Fig. 2: Schematic illustration of the stage 1 experiment

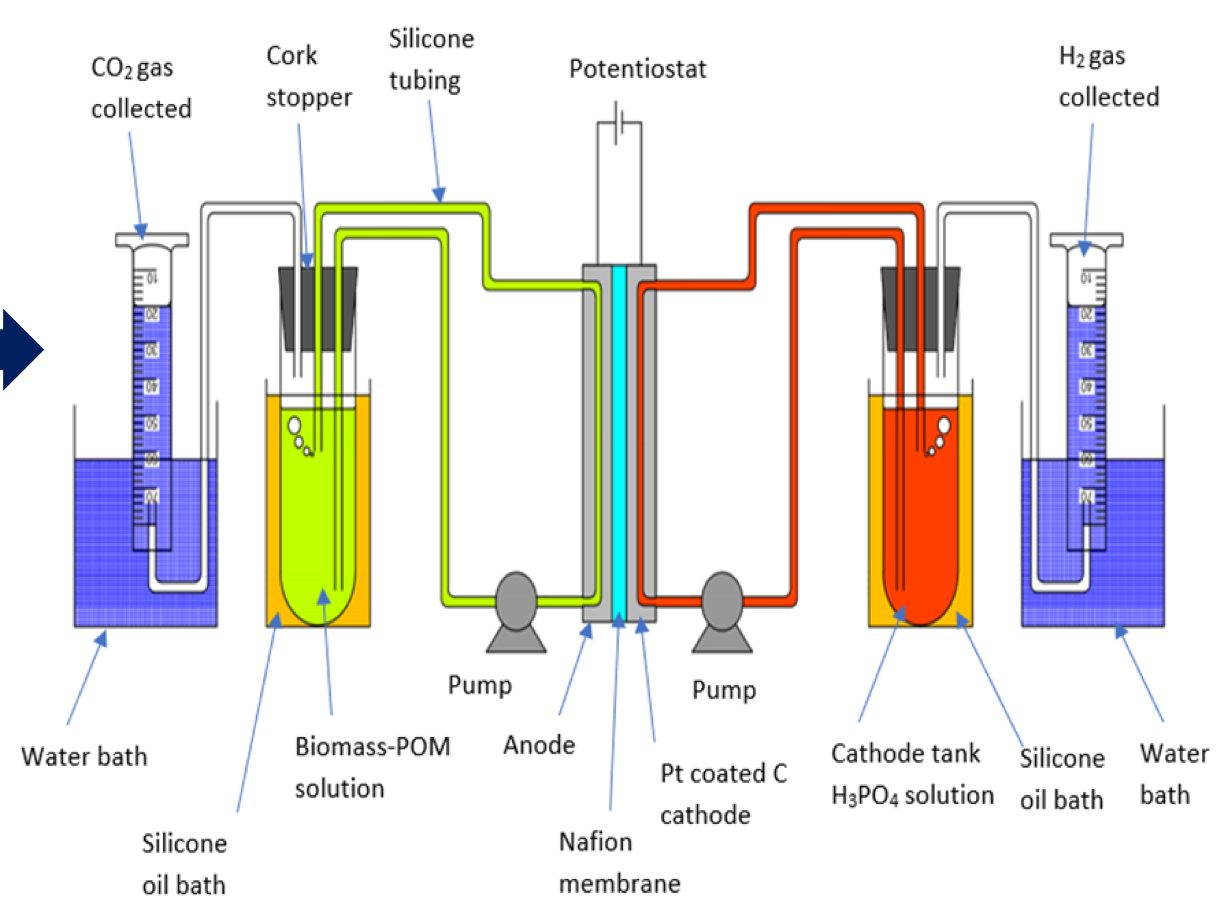


Fig. 3: Schematic illustration of the stage 2 experiment

Stage 1 reaction:
$[C_6H_{10}O_5]_n + xH_2O + yH_3PMo_{12}O_{40\ Ox} \rightarrow$ oxidised products $+ H_5PMo_{12}O_{40\ Red}$

Stage 2 Cell reactions:
$H_5PMo_{12}O_{40\ Red} \rightarrow H_3PMo_{12}O_{40} + 2H^+ + 2e^-$ (Anode)

$2H^+ + 2e^- \rightarrow H_{2\ (g)}$ (Cathode)

Stage 1: Experimental conditions

Potentiostatic mode

- Concentration of cellulose: 0.3 mol/L
- Concentration of PMA: 0.1 - 0.3 mol/L
- Reaction Volume: 20 ml
- Stirring speed set at 3
- Temperature: 90, 95, and 100 °C
- Reaction duration: 1, 2.5 and 4 hours

Stage 2: Experimental conditions

- Temperature: 80 °C
- Scan rate: 5 mV/s
- Scan range: 0 – 1.2 V

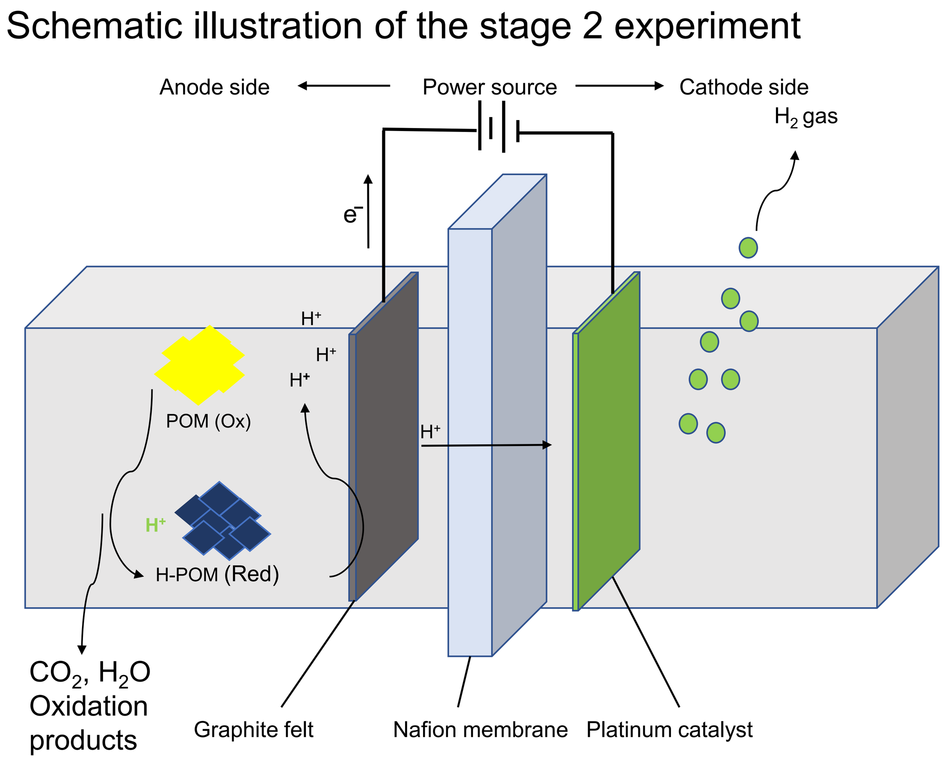


Fig. 4: Schematic illustration of the proton exchange membrane (PEM) electrolysis cell for stage 2 experiment

RESULTS

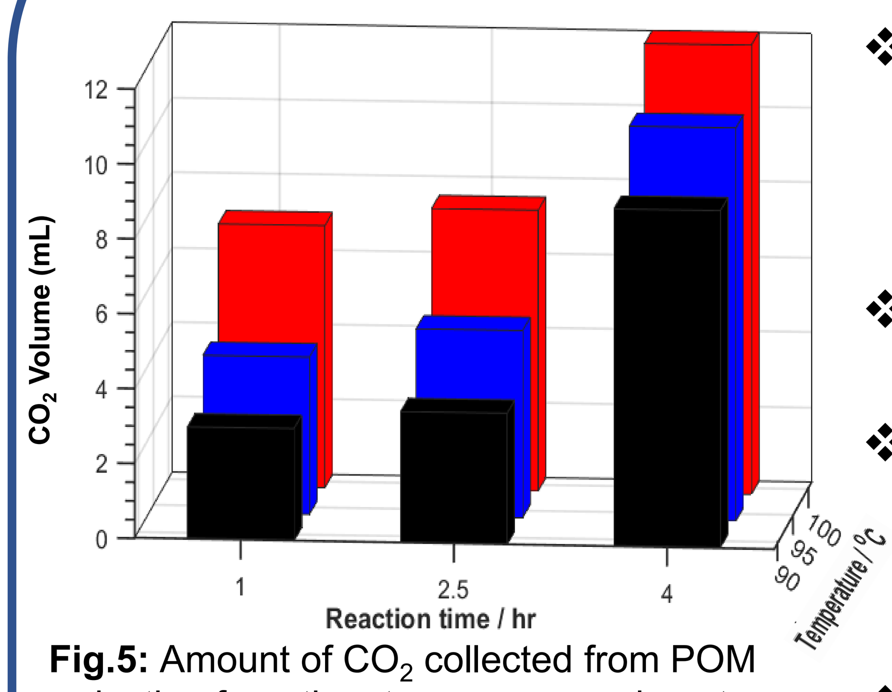


Fig.5: Amount of CO_2 collected from POM reduction from the stage one experiment

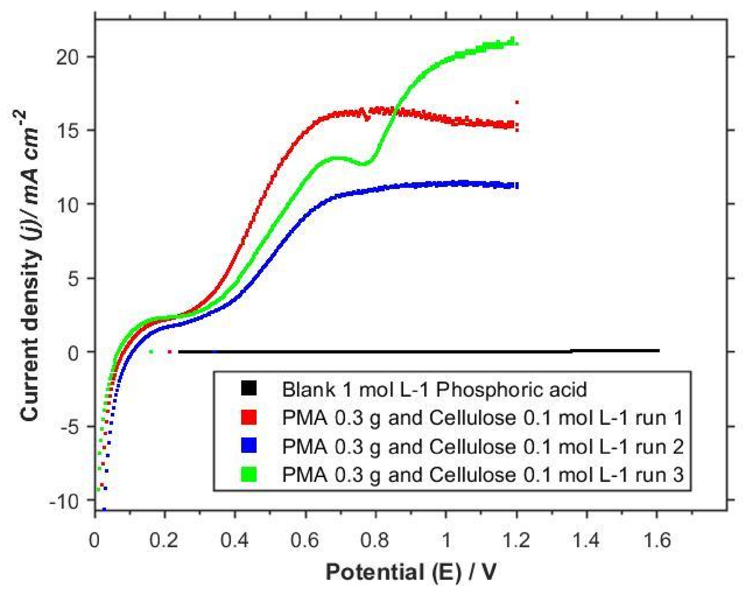


Fig. 6: LSV plot showing an experiment without biomass and with biomass in a PEM cell

- CO_2 released in stage 1 increased with increase in temperature, reaction time, and PMA concentration which indicated higher rates of PMA reduction.
- The optimal conditions were found to be 100 °C, 4 hours, and 0.3 mol/L.
- To begin the stage 2 experiment, a control test was carried out with only phosphoric acid (1 mol L^{-1}) pumped into the anode and the cathode side of the PEM cell.
- As expected, there was very minimal current was observed even when the potential was increased to 1.2 V as the applied potential is lower than 1.23 V which is the standard potential of water electrolysis. The linear sweep voltammetry (LSV) plot for the process without PMA and with PMA as shown in figure 6.
- The onset of electrolysis was observed at 0.3 V in the presence of H-PMA.

CONCLUSIONS

- The effectiveness of the thermal process improves with increase in temperature, reaction time, and concentration of the PMA.
- Optimal conditions for stage one experiments were observed to be 100 °C, reaction time of 4 hours, and PMA concentration of 0.3 mol/L.
- Linear sweep voltammograms indicated that electrolysis could be achieved at potentials as low as 0.3 V using H-PMA, which is much lower than the onset potential for water electrolysis (1.23 V).
- However, no measurable level of hydrogen gas was produced during the LSV experiments due to their short time intervals.

FUTURE WORK

- To perform further experiments with the PEM cell to establish the amount of hydrogen produced and the energy efficiency of the process.
- To investigate the use of different biomass types and catalyst in the PEM cell.
- To model the electrochemical process and comparison will be made with biomass gasification process.
- To investigate the use of alkaline membrane compared to proton exchange membrane.

REFERENCES

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[2] The Future of Hydrogen, IEA, 2019 Paris https://www.iea.org/reports/the-future-0f-hydrogen IEA.17.
[3] F. Dawood, M. Anda, and G. M. Shafiullah, "ScienceDirect Hydrogen production for energy : An overview," Int. J. Hydrogen Energy, no. 7, pp. 3847–3869, 2019, doi: 10.1016/j.ijhydene.2019.12.059.

ACKNOWLEDGEMENTS

The author Pamela Iwube is financially supported by the Niger Delta Development Commission.