Evaluating the Role of Draw Solute Selection in Forward Osmosis Wastewater Processing

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Abstract:

This research is a component in a larger project aimed at developing a more efficient, effective, and lower cost means of concentrating wastewater for use as a chemical feedstock for microbial fuel cells. Human wastewater streams represent a low-cost and under-utilized source of chemical nutrients, with potential for use as a feedstock for microbial fuel cells. One potential roadblock is the dilute nature of those nutrients as typically found in wastewater effluent.
Our project aims to develop a forward osmosis cell and implementation protocol capable of receiving a diffuse stream of chemical nutrients found in typical waste streams and concentrating those nutrients to a level capable of use in a microbial fuel cell. Goals are monetary efficiency, ease of implementation, and efficacy of the derived protocol for operating the cell.

Pursuant to this, a 3D printed forward osmosis cell has been designed utilizing a cellulose triacetate membrane to mediate water exchange between feed and draw water streams, which creates an osmotic pressure necessitating the movement of water from the feed (wastewater) side of the cell to the draw (aqueous solute) side. By optimizing the draw solute choice, our project aims to create ideal water draw from the waste stream, resulting the greatest concentration of solutes in the processed wastewater.

This work presents a narrow focus of this overall project, in which we worked to develop an internal protocol to work with a newly designed, 3D-printable forward osmosis cell. This approach presents a potential greater efficiency in the production and scaling of forward osmosis cells for batch-processing, experimental use, as well as a viable means of concentrating wastewater for further work within the larger project.

Methods:

A series of 1M reference solutions of $MgCl_2$, KH_2PO_4, and NH_4HCO_3 were run as draw solutes through the FO cell opposite distilled water feed solution for 6 hours each, with samples of the draw and feed being pulled at 0,2,4 and 6 hours, respectively. Over the duration of each trial, mass of the feed solution was monitored continuously to plot the movement of water across the membrane. This was done to confirm the most effective solute for use as a batch-process draw solute as mentioned in literature, $MgCl_2$, which our data bears out.

Magnesium Chloride draw solute was then applied on a filtered effluent collected from the Christiansburg municipal wastewater treatment plant to track the movement of water and ions in the cell's intended real-world application.

Results:

A 3D-printed forward osmosis cell has been designed utilizing a cellulose triacetate membrane to mediate water exchange between the feed (deionized water) and draw (1 M magnesium chloride, monobasic potassium phosphate, and ammonium bicarbonate) solutions. For 6-hour operation times, the average water flux for $MgCl_2$, KH_2PO_4 and NH_4HCO_3 draw solutions were 12.52, 8.03, and 10.66 LMH, respectively. In regard to water recovery, this indicates that $MgCl_2$ is the optimal choice for operating the cell in a batch process configuration.

Conclusions:

From the testing conducted in these trials, magnesium chloride is the most efficient solute choice for batch FO processing, showing the highest average solvent flux potential. In one proof of concept test, our derived protocol has show promise in its intended roll of enriching wastewater for use in microbial fuel cells, demonstrating strong gains in electroconductivity, and ion concentration in the processed solution.

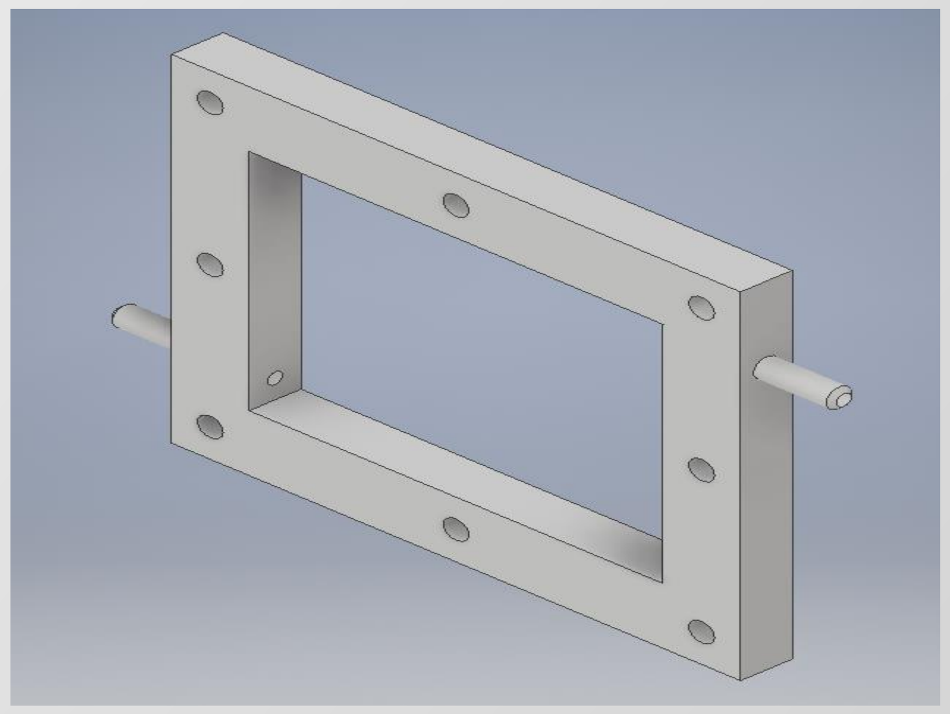

Figure 1: Design for 3d printed forward osmosis cell chamber

Figure 2: Assembled FO cell composed of two chambers separated by CTA membrane

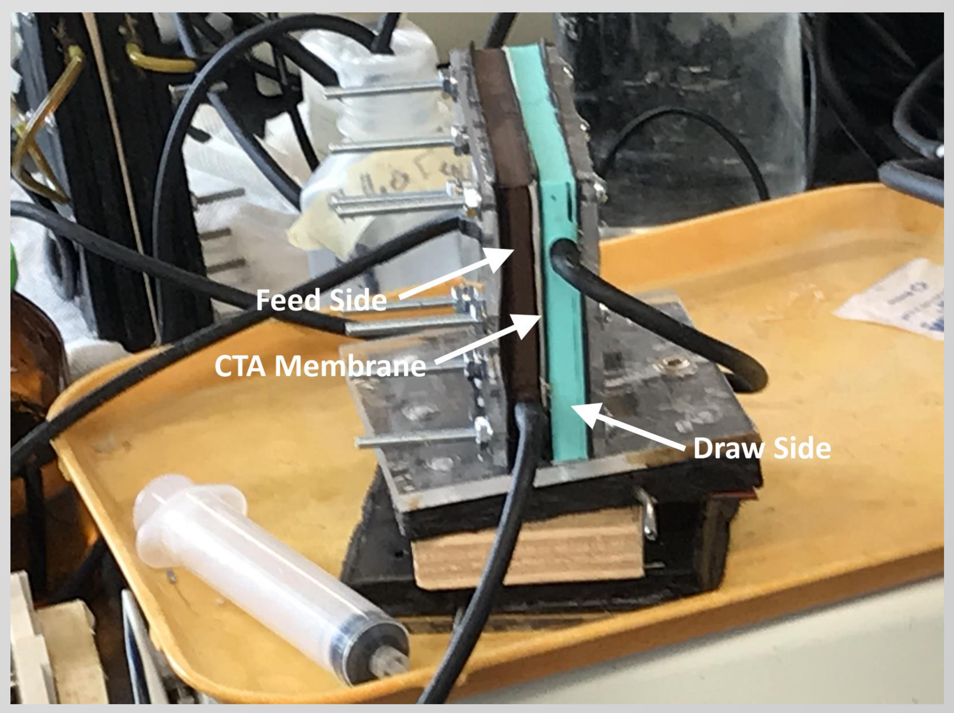

Figure 3: Functional layers of the FO cell

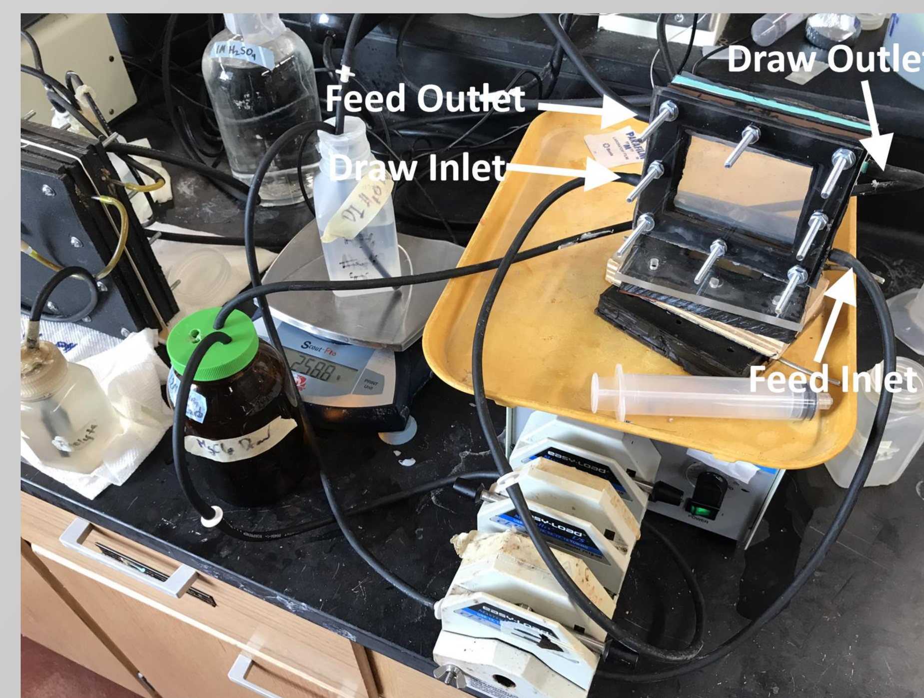

Figure 4: Layout of cell used for all experimental trials

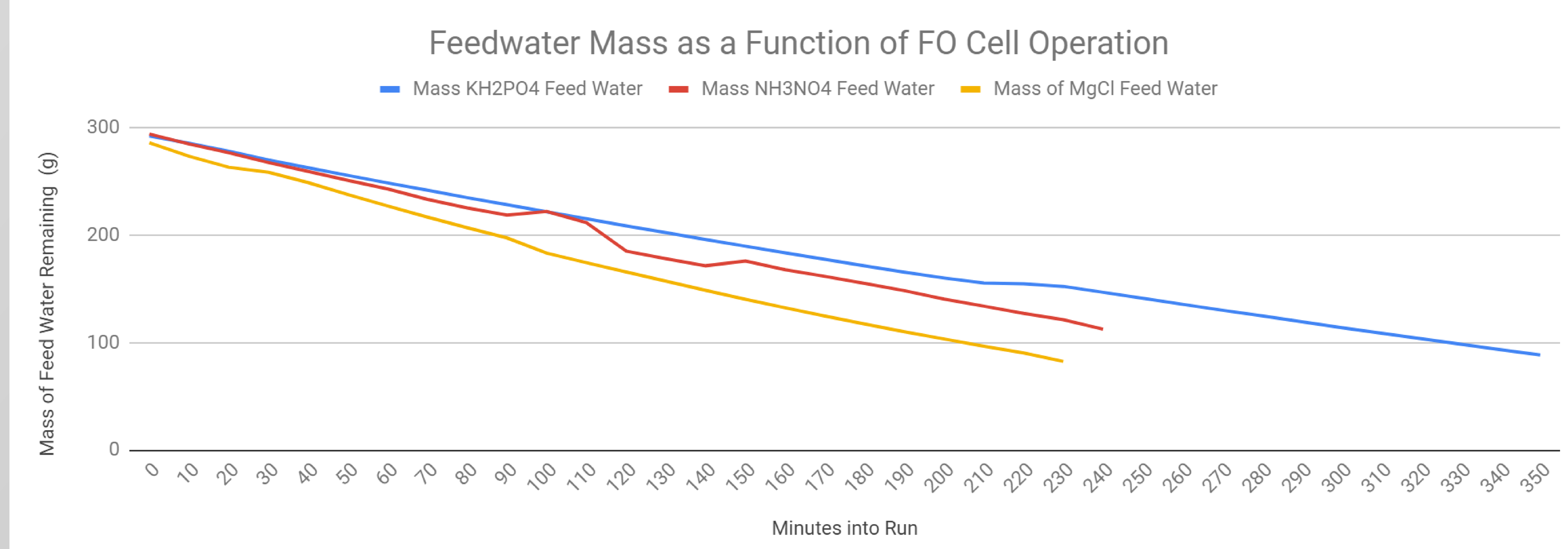

Figure 5: Mass of feed water remaining in reservoir when FO cell was operated with different draw solutes

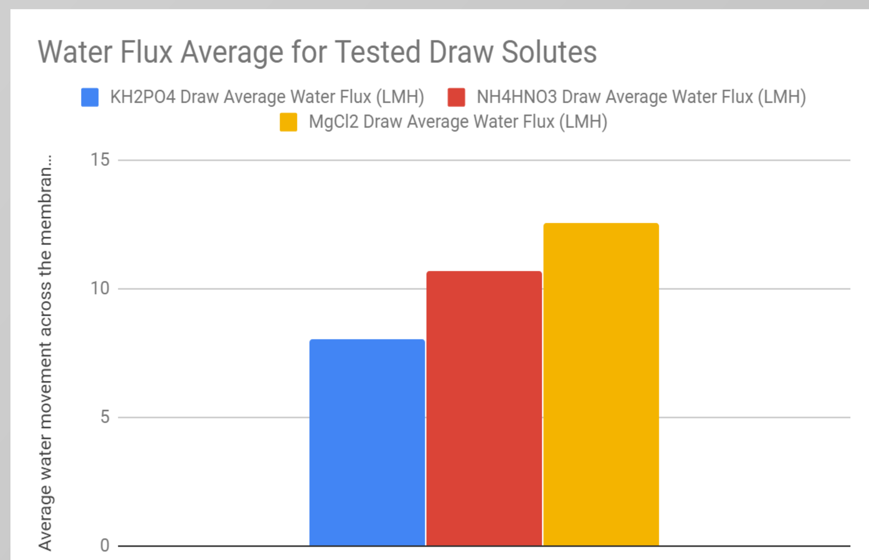

Figure 6: Average water flux for the tested draw solutes

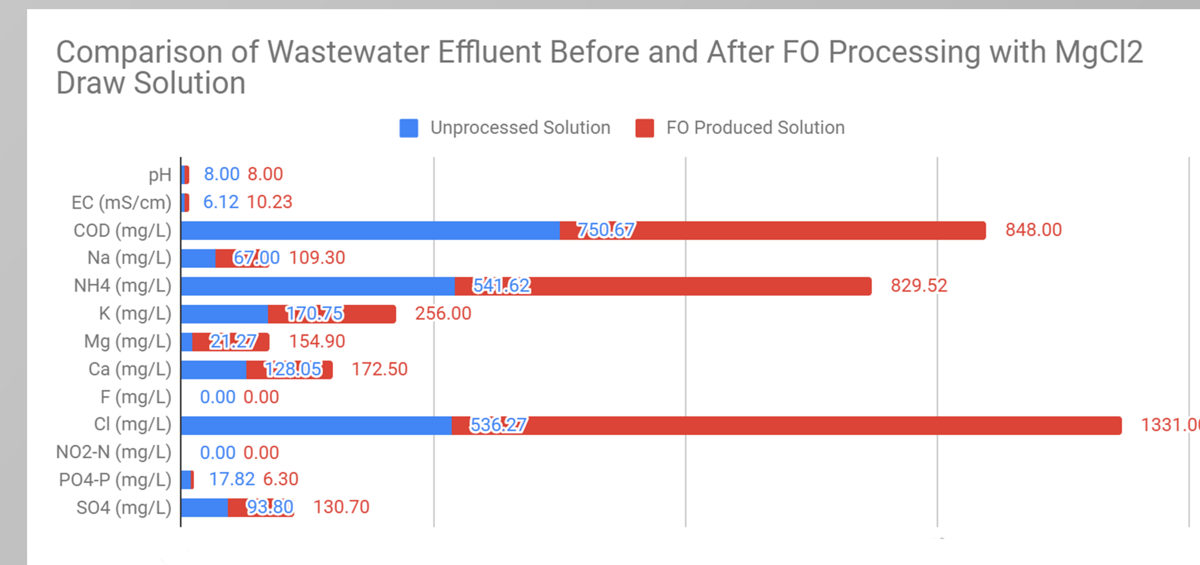

Figure 7: Comparing unprocessed and FO processed wastewater the developed FO protocol

Linking Research to Education Module

Typically, chemists use spectroscopy and specialized chromatography to establish chemical content and purity. Measuring electrical conductivity of an aqueous solution presents a more generalized approach to generating similar data in terms of solute purity. It also directly addresses the effect of chemical solutes on water's physical properties.

Throughout our research into the FO cell, electrical conductivity of baseline and treated solutions was used as a general means of establishing cell effectiveness daily in the lab while waiting on samples to be processed at night via ion chromatography. Taking this approach back to my teaching, we will be using EC to establish solution concentrations, and more indirectly, relative purity.

The module outlines lesson that was created using this research experience introduces the concept of aqueous conductivity as a means of verifying solution concentration and purity. Students will synthesize magnesium chloride using a given quantity of magnesium metal precursor, wash and dry the product, and determine experimental yield given the stoichiometry of the base reaction. Students will then prepare a 1 molar solution with their experimentally derived product and compare its electrical conductivity to a lab standard to assess the purity of their product. Students will then calculate percent error comparing their own solutions EC to that of the standard.

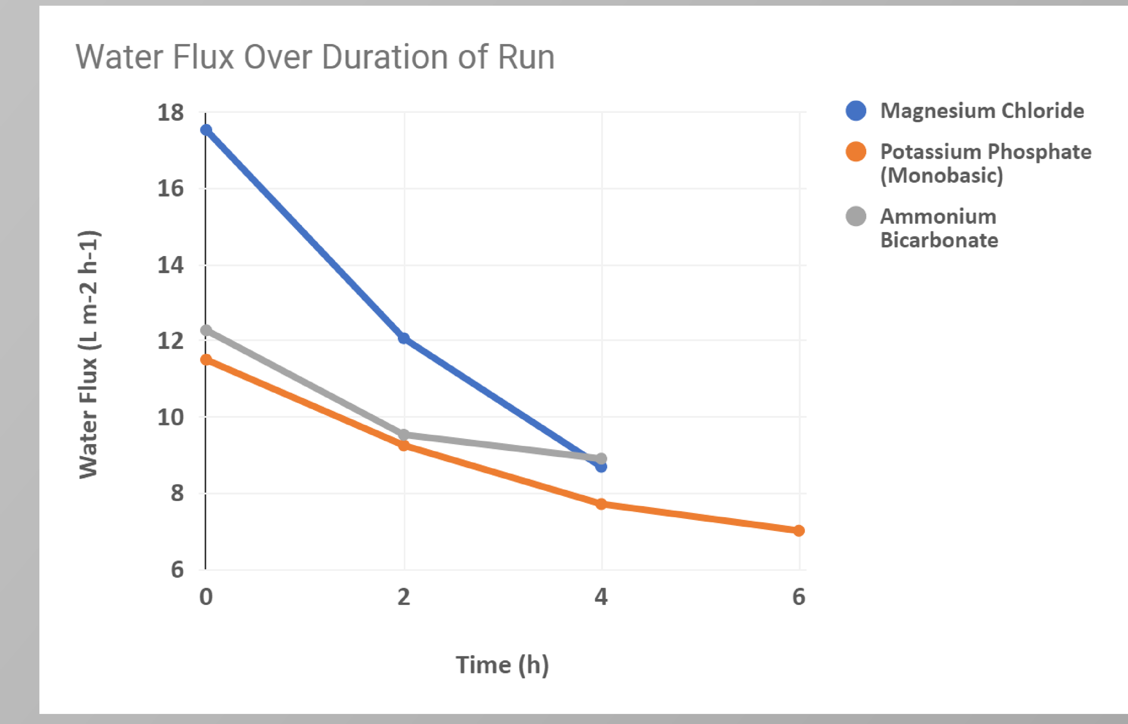

Figure 8: Decrease in water flux over time due to dilution of draw solution

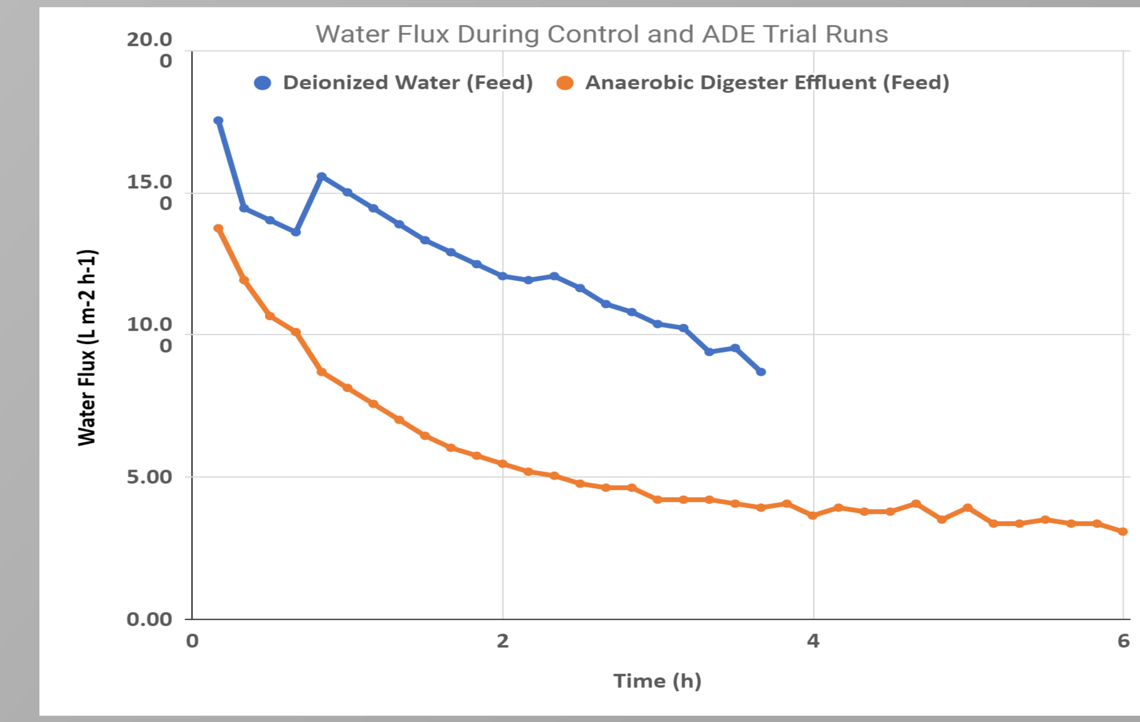

Figure 9: A combination of membrane fouling and a reduction is osmotic pressure slowed water flux during trials using wastewater

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