Progress Update

Nitrogen Extraction from Water

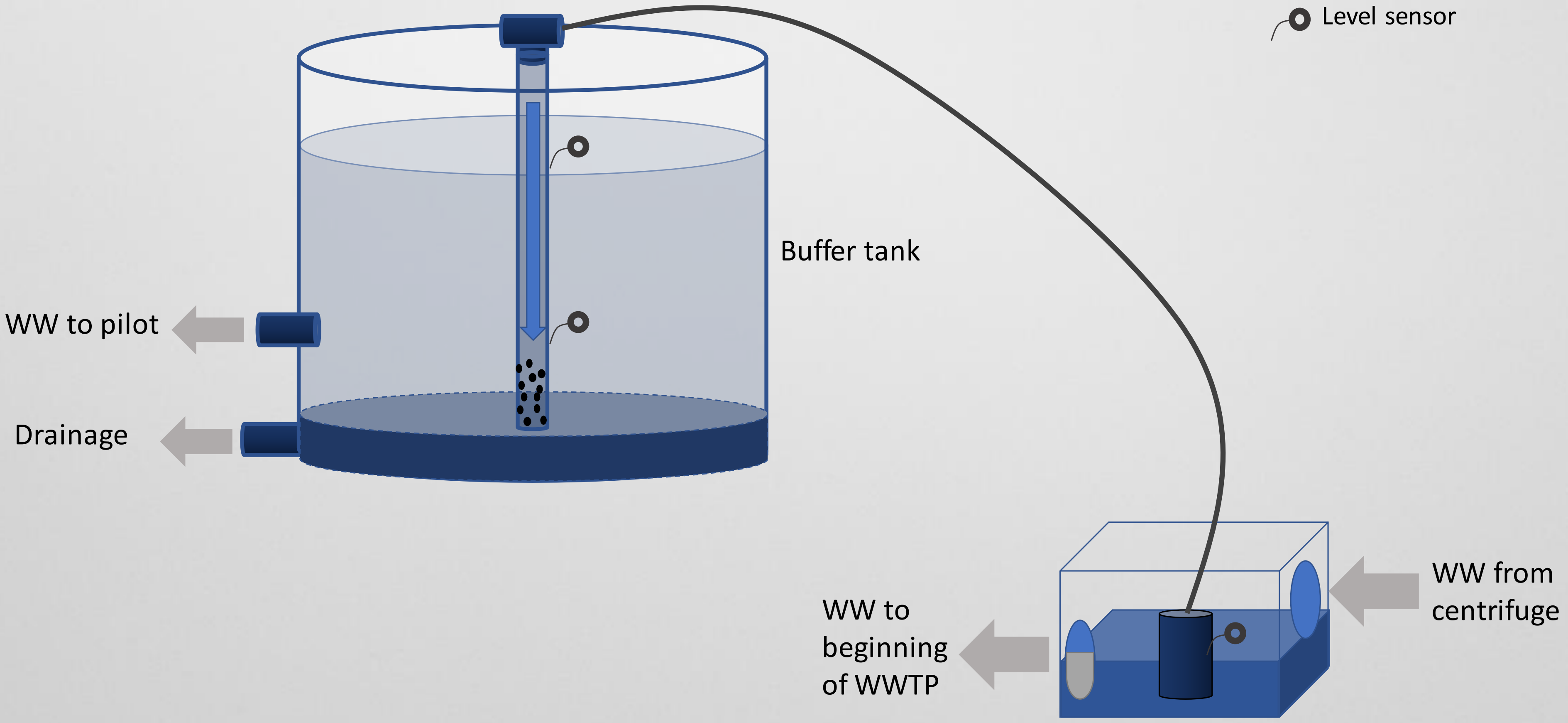
NEWBIES

by an Innovative Electrochemical System

Sam Molenaar / Federico Ferrari

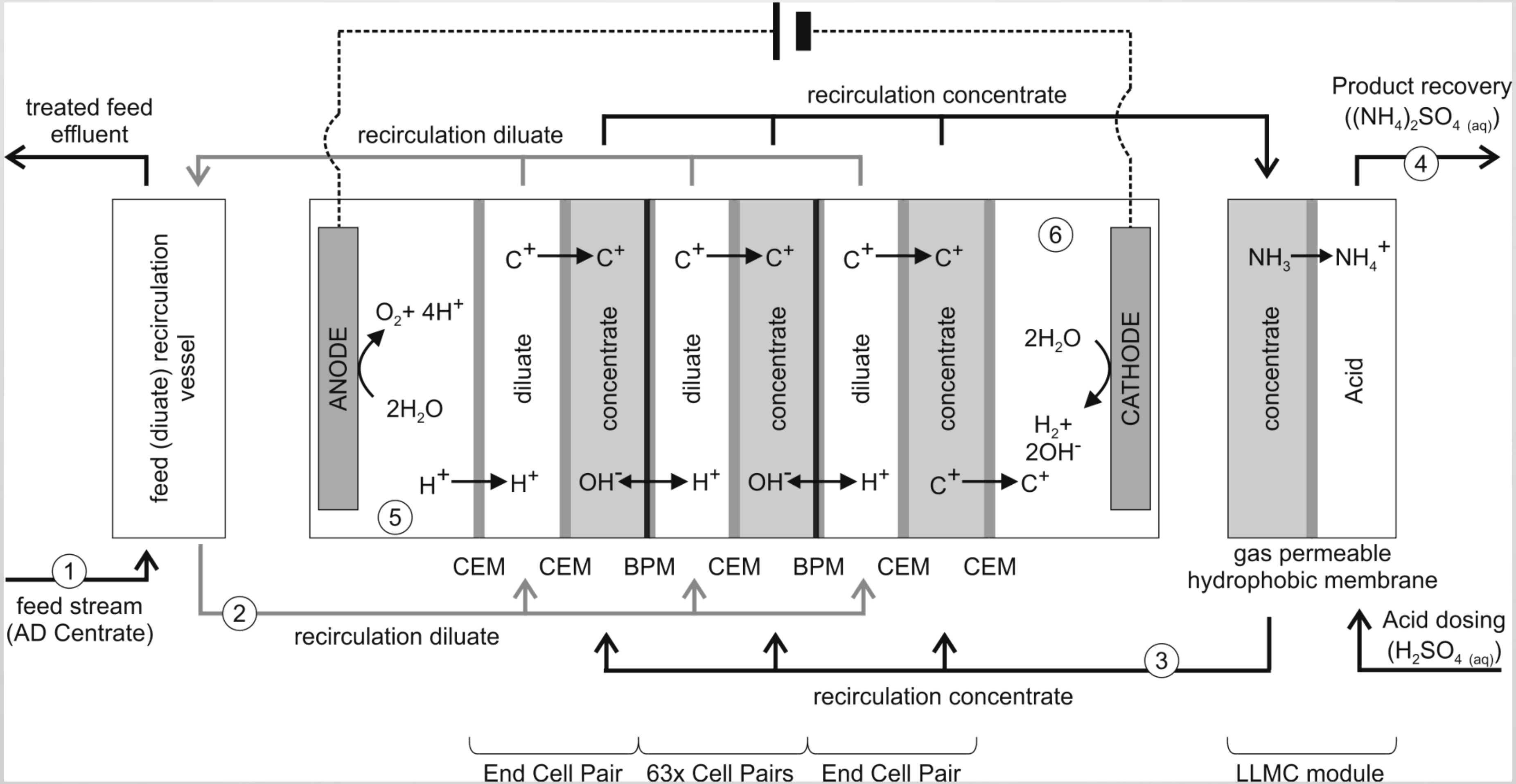
19 November 2019

Pre-treatment: settling tank



LIFE-NEWBIES pilot: Girona (Catalonia, Spain)

Pilot installation: BP-ED configuration

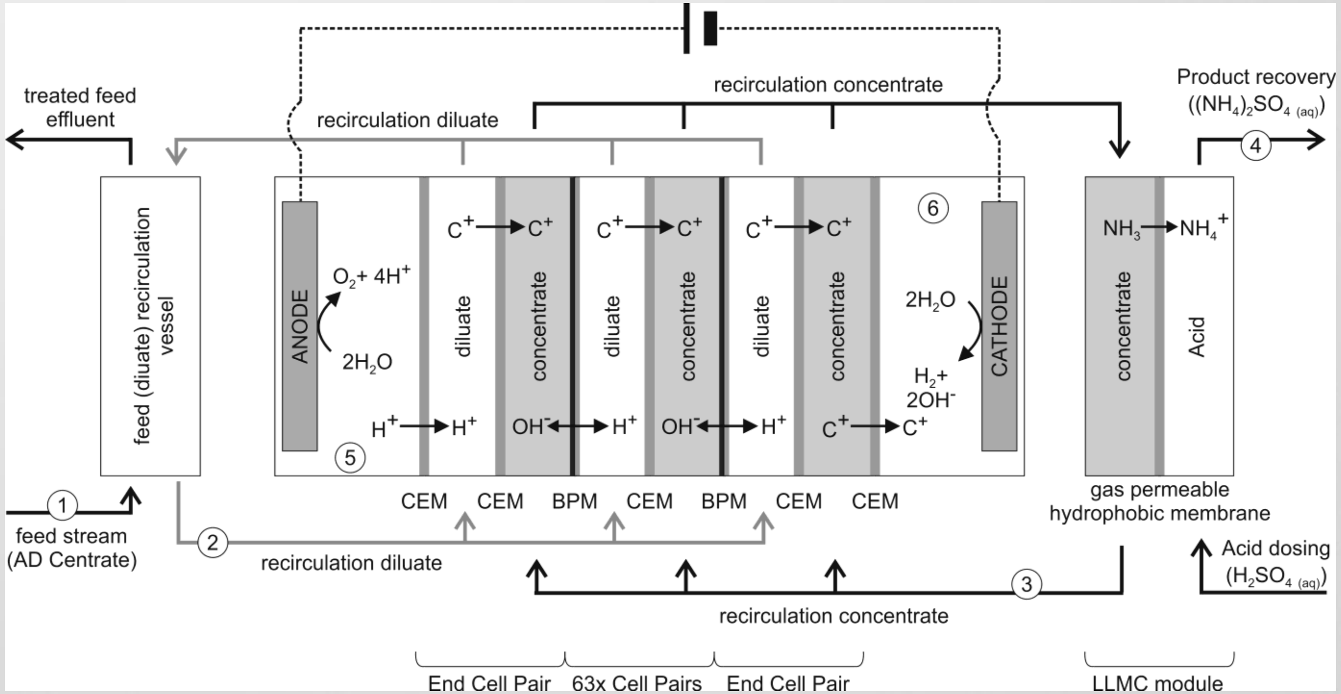


Pilot installation: BP-ED configuration

- Bipolar membrane Electro Dialysis (BP-ED) using cation exchange membrane (CEM) and bipolar membrane (BPM)

- Ammonia recovery by liquid/liquid membrane contactors (LLMC) from the concentrate

- 3.15 m^2 CEM and 3.15 m^2 BPM membrane surface area



Initial operational strategy

Pilot designed to control process with:

(1) Conservation of cation concentrate throughout cleaning cycles

(2) Cleaning of stack/TMCS triggered by:

high voltage on stack

Time interval on TMCS

pressure drop of recirculate pumps

(3) Only TMCS and Stack compartments included in cleaning

Nitrogen Extraction from Water NEWBIES by an Innovative Electrochemical System

Practical issues encountered

1. Small voltage window at required current density led to very frequent cleaning of stack
2. Fast onset and rate of flow reduction led to frequent cleaning or required substantially decreased flow rates
3. Slow resumption and (progressively) decreased rate of stripping after cleaning cycles
4. Progressive shortening of runs throughout cleaning cycles
5. Pump and flow sensor failures
6. Doubts about LLMC performance

Nitrogen Extraction from Water
NEWBIES
by an Innovative Electrochemical System

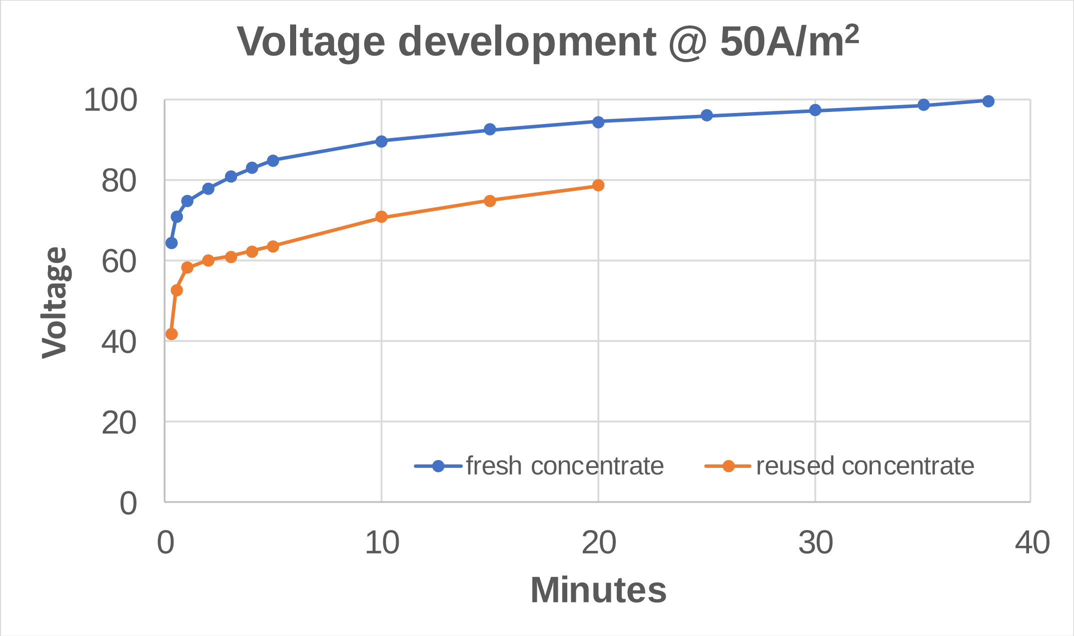
Operational Voltage Window

Conductivity lower than anticipated

- Requires higher voltage to drive current through stack
- Larger transport number w.r.t. calcium

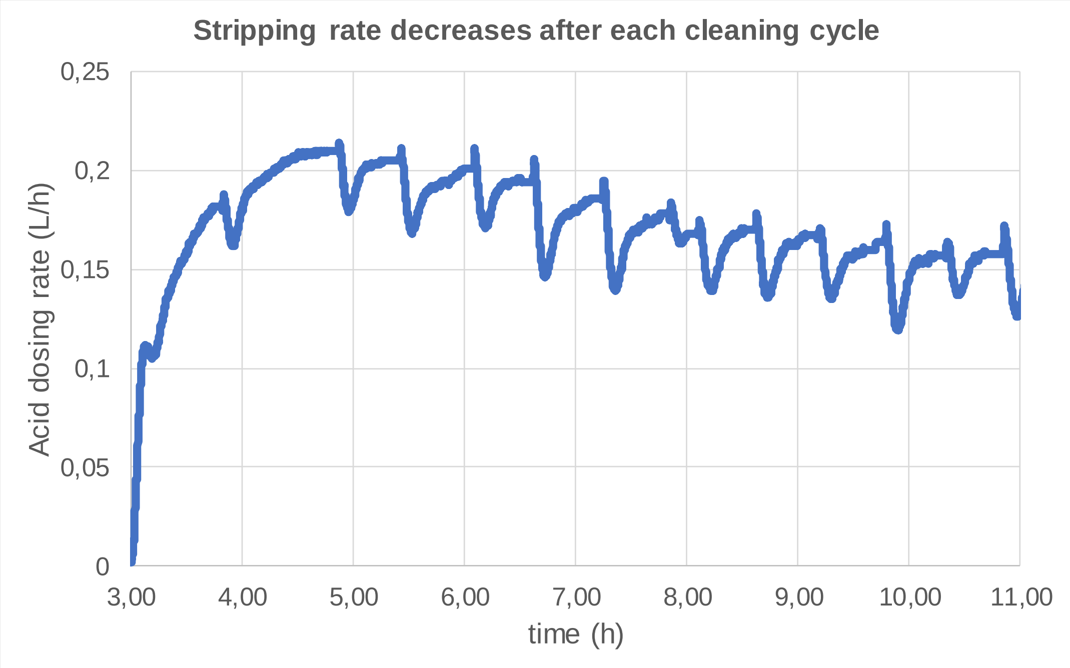
Power supply limited to 100V

- Won't allow testing over relevant time intervals beyond 50A/m^2
- May increase relative share of ionic shortcut through concentrate



Slow resumption/decreased rate of stripping after cleaning

- Increase in conductivity cation concentrate after cleaning due to carry-over
- Resumption of stripping became progressively worse:
    - Carry-over of rinsing acid leads to lower pH of cation concentrate: needs to be neutralized
    - Higher osmotic pressure difference between feed en concentrate causes increased water transport, diluting concentrate over next run
    - Co-ion transport of chloride over CEM may decrease ED selectivity
    - Greater difference in conductivity between feed and concentrate enlarges ionic shortcut issue



Pump and flow sensor failure

- Precipitation of calcium carbonate caused issues with moving parts in cation concentrate flow:
- Gradual decrease of recirculated flow rate, independent of cleaning
- Complete blocking of pumps. Recovered by cleaning with acid
- If only pumps are cleaned, eventually also flow meters get stuck
- Rate of precipitation within pumps strongly dependent on amount of cleaning cycles and operation of stack:
    - ✓Keep current going
    - ✓Don’t backwash concentrate through pumps
    - ✓Prevent carry-over of rinsing acid

Effectiveness of currently used TMCS

When NH3 not sufficiently stripped, higher concentrations accumulate in concentrate, leading to:

- higher concentrations of co-ions:
  - Larger water transport
  - Higher pH
  - Larger absolute transport number of co-ions (lower CE)
  - Larger calcium deposits (scaling issues)
- (Back)diffusion of NH_3 from (cation) concentrate to diluate (Feed ED)