Salinity Reduction

Executive Summary Report

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CHANGE RECORD

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Text amendments with respect to the previous issue are identified by a vertical bar in the outer margin. Minor text amendments like underlining, punctuation, spelling, page numbers and deletions are not necessarily marked.

Future long-term deep-space exploration missions require the implementation of regenerative Life Support Systems (RLSS) based on the concept of closing loops between the resources and wastes available onboard such as urine. The latter is of particular interest since it is rich in nitrogen, phosphate and potassium; valuable elements for food production. Yet, the valorisation of urine as NPK source remains difficult due to its high sodium chloride content, which can be toxic and limits bio-utilization. The aim of the Salinity Reduction of Yellow Waters (SaRY) project is to study technologies able to reduce urine salinity (focusing on sodium), to select relevant technologies compatible with space via a trade-off assessment, and to demonstrate their adequacy through testing.

After elaborating the SRU requirements, a literature review was performed to identify relevant technologies to achieve the objective. It was essential to first select a treatment to stabilise urine prior to salt removal to inhibit enzymatic urea hydrolysis and avoid uncontrolled precipitation and ammonia volatilization. To select the most promising technologies, an analysis with ALiSSE (Advanced Life Support System Evaluator) criteria was performed supported by trade-off tests. From these activities, a preliminary concept of a salinity reduction unit (SRU) was proposed. In this concept, urine is first stabilized by electrochemical alkalinisation requiring no chemical input and leading to the precipitation of divalent cations (i.e., calcium, magnesium) and phosphate. Stabilised urine is then treated by electrodialysis (ED), able to separate total nitrogen and organic compounds, which remain in the diluate, from the salts, which collect in the concentrate. ED concentrate is directed towards ion exchange (IX) resins which selectively remove sodium by replacing it by potassium. The ED diluate is then subjected to an oxidation and nitrification step (combined within a nitrifying sludge) to convert nitrogen into an assimilable form (i.e., nitrate) for higher plants and to consume organic compounds, which can be toxic to higher plants and microalgae, such as *Limnospira indica*, the selected microalgae in MELiSSA.

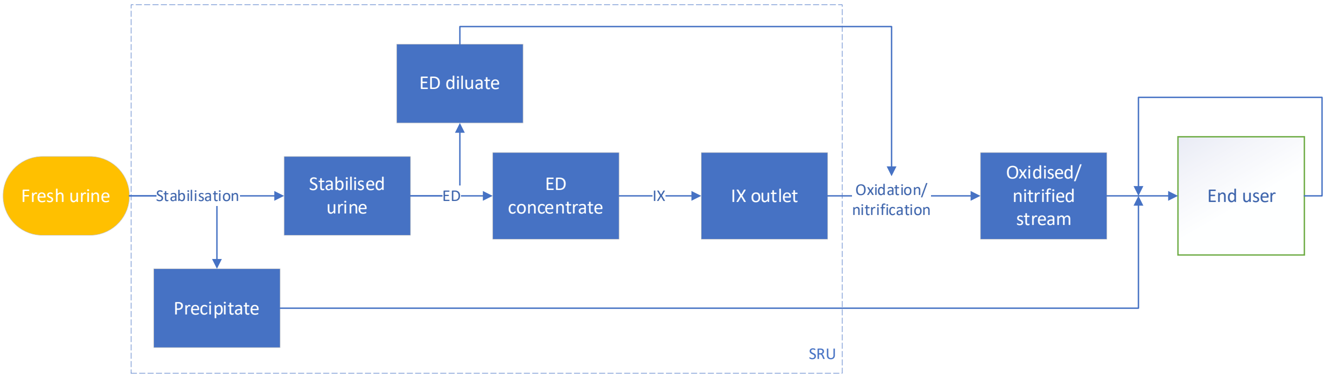

Figure 1: SRU block flow diagram. Based on the results from the feasibility tests, IX outlet is also included in the oxidation/nitrification step along with ED diluate.

The feasibility tests showed that urine alkalinisation effectively prevented urea hydrolysis, induced precipitation of divalent cations (~ 85% of Ca^{2+} and Mg^{2+} removed) and phosphate (43%), and also allowed to get rid of 53% of chloride by migration to the anode compartment. Electrodialysis also showed good performances with ~72% of the sodium present in stabilised urine being concentrated in the final ED concentrate, ~94% of total nitrogen and ~86% COD (chemical oxygen demand, a proxy for organic compounds) remaining in ED diluate. With ~14% COD being transferred to the concentrate compartment, we suggest to include the IX outlet in the oxidation/nitrification step along with the ED diluate. In addition, the selective removal of sodium by ion exchange was demonstrated with ~98% sodium removed from ED concentrate. However, COD behaviour on the resins is inconsistent, with COD being released for half of the batches (up to 20 % of total COD) and adsorbed for the other half (up to 38 % of total COD). As far, no unambiguous explanation can be given for the release and adsorption of COD. Considering the whole process, ~ 72% of initial sodium content in fresh urine can be removed, taking ED diluate and IX outlet as the final products. The final products consist in the precipitate rich in divalent cations (Ca^{2+} and Mg^{2+}) and phosphate, ED diluate rich in nitrate, and IX outlet rich in potassium. Toxicity tests highlighted the potential of these products as growth medium for *L. indica* and higher plants after dilution and nitrification although the toxicity tests on higher plants gave mixed results and suggest that more research is needed.

From the data gathered during the feasibility tests, a preliminary design of an integrated SRU running continuously and in an automated way was proposed. To operate in microgravity conditions, a few adjustments are needed to separate the precipitate (e.g., use of membranes), to handle the gas produced during alkalinisation and ED, and to move urine along IX (e.g., pump instead of gravity). With the alkalinization and ED module running continuously, no cleaning nor rinsing is foreseen in nominal mode but a cleaning-in-place (CIP) can be considered at low frequency if needed. The consumables include water which can be recovered from another LSS component (e.g., hydroponic system) and potassium to regenerate the resins. Potassium could be recovered from in-situ resources (ISRU) for example but this requires more investigation. Also, the membranes of both ED and alkalinisation need to be replaced after several months, as well as the electrodes after several years. The by products include the anolyte from stabilisation, which can be reused as an acid source (e.g., cleaning of ED module), the sodium-rich solution from resin regeneration, and water (reusable) from resins rinsing. While not in the scope of the proposed SRU, further treatment of the final products include nitrification where COD contained in ED diluate and IX outlet are consumed, and urea from ED diluate converted to nitrate to be assimilable by higher plants. The final products can be diluted and combined in different proportions to better fit end users requirements. After its passage by the end user compartment, the nutrient depleted urine can be recycled and reinjected in the SRU to be replenished with nutrients from fresh urine.

To conclude, the activities performed in the frame of the SaRY project demonstrated the relevance of the proposed technologies composing the SRU to desalinate fresh urine. It also highlighted the potential of using the outlet stream as growth medium for *L. indica* and higher plants after dilution and nitrification, although the toxicity tests on higher plants gave mixed results and suggest that more research is needed. The upcoming main activities encompass the design of a breadboard with a focus on microgravity constraints and automation to collect additional data to go for a flight demonstration. In addition, a deeper investigation is needed to better understand COD behavior on the resins, to find an alternative source of potassium and to optimise the valorisation of the SRU outputs.