The alkalinity dilemma in nitrification

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Agenda

- The need for on-site fertilizer production
- Scarcity of alkalinity for nitrification of human urea
- 3 potential soultions to overcome the issue
- Conclusions

Remark:

WE CANNOT ESCAPE THE FUTURE NEED TO PROVIDE FRESH FOOD FOR THE ASTRONAUTS…

Potential solution

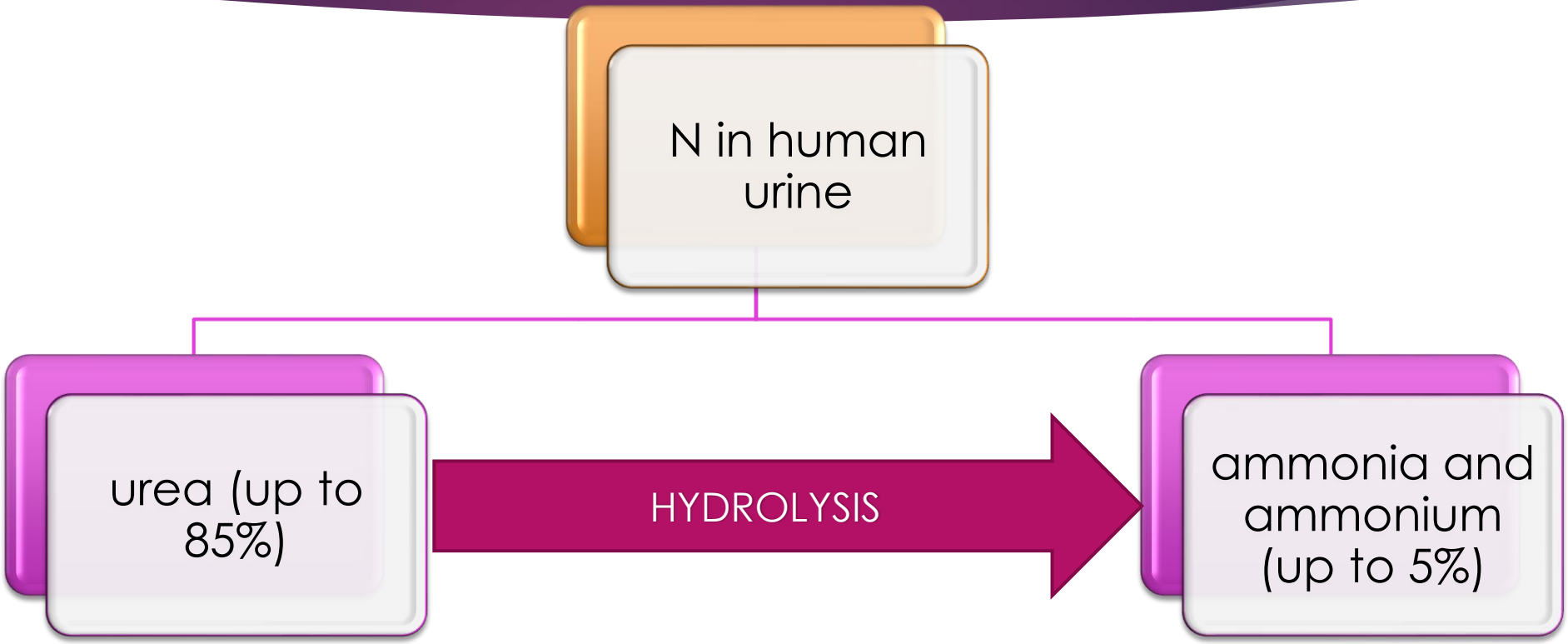
hydroponic plant cultivation?

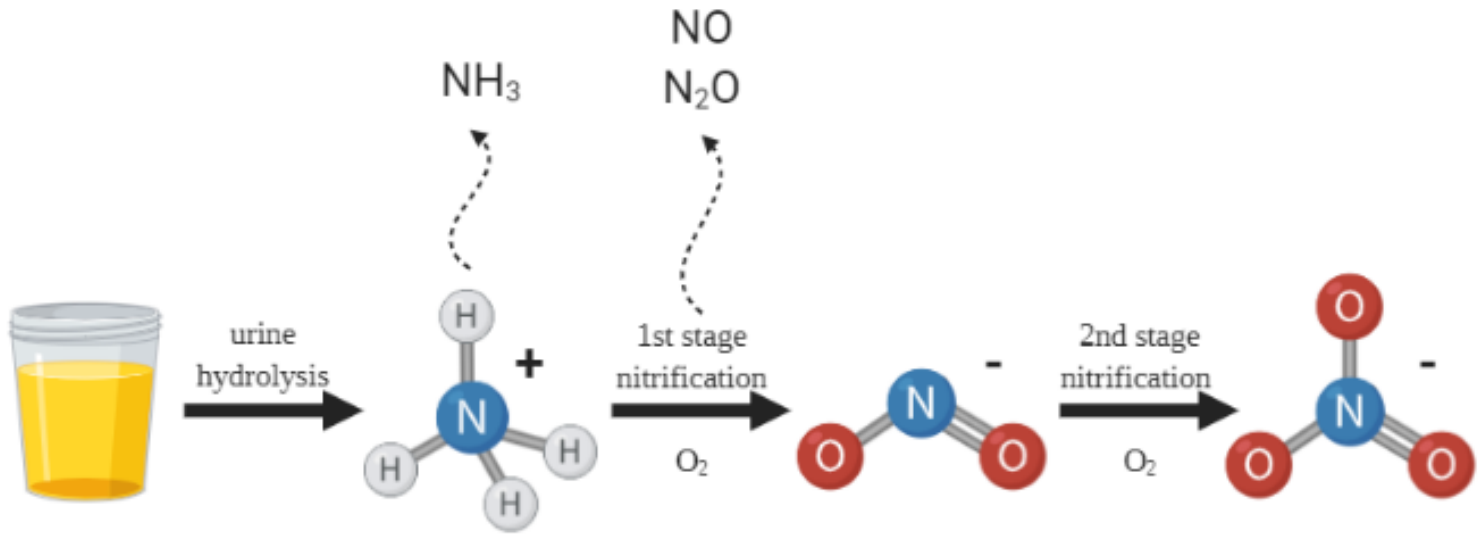
emerging problem: fertilization

Where to find a fertilizer in space?...

IN HUMAN URINE, OF COURSE!

Nitrogen in human urine





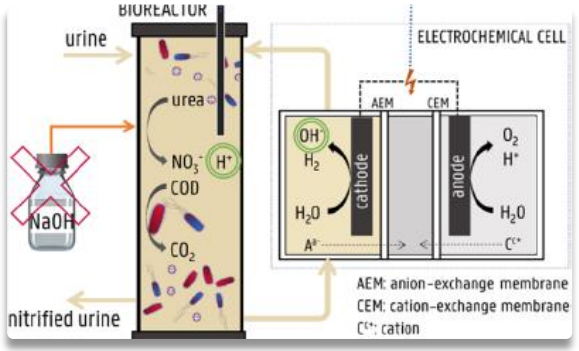
Alkalinity correction is demanded!

The process requires alkalinity to balance pH and being source of inorganic carbon for nitrifiers growth. The stoichiometric requirement is **2 mol OH^- per mol NH_4^+.** Fresh (not hydrolysed) urine is deprived of alkalinity. As a result of hydrolysis only **one mol OH^-** is generated for **each mol** of created **NH_4^+**, so hydrolysis enables conversion of **half of the ammonium ions** to ammonia.

3 potential solutions:

Conventional

Alkalnity addition by means of NaOH, KOH, $Ca(OH)_2$



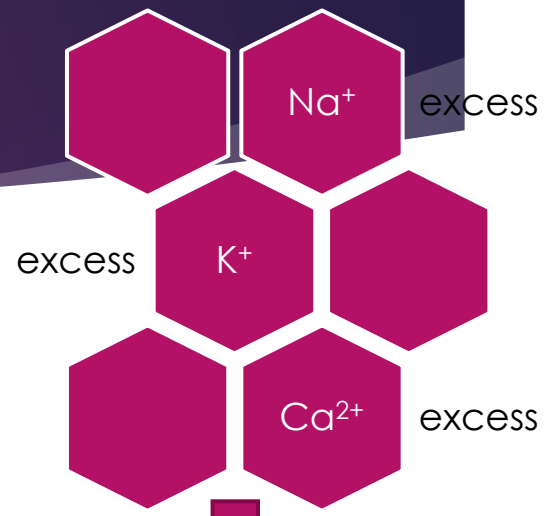
Clever

Electrochemical cell

Simple and alternative

Nitrification of mixed streams

A conventional way



- **alkalinity correction** by the addition of sodium hydroxide or sodium bicarbonate, less frequently calcium hydroxide
- it disturbs the mass balance and causes that the system accumulates excess ions in large amounts
- for example: the added amount of sodium cations will be more than 7 times higher than its natural content
- clearly: alkalinity correction is constantly required and therefore Na^+ will continue to accumulate in system and in short period of time, **Na^+ content will exceed plants tolerance**

How to deal with the excess cations in space?

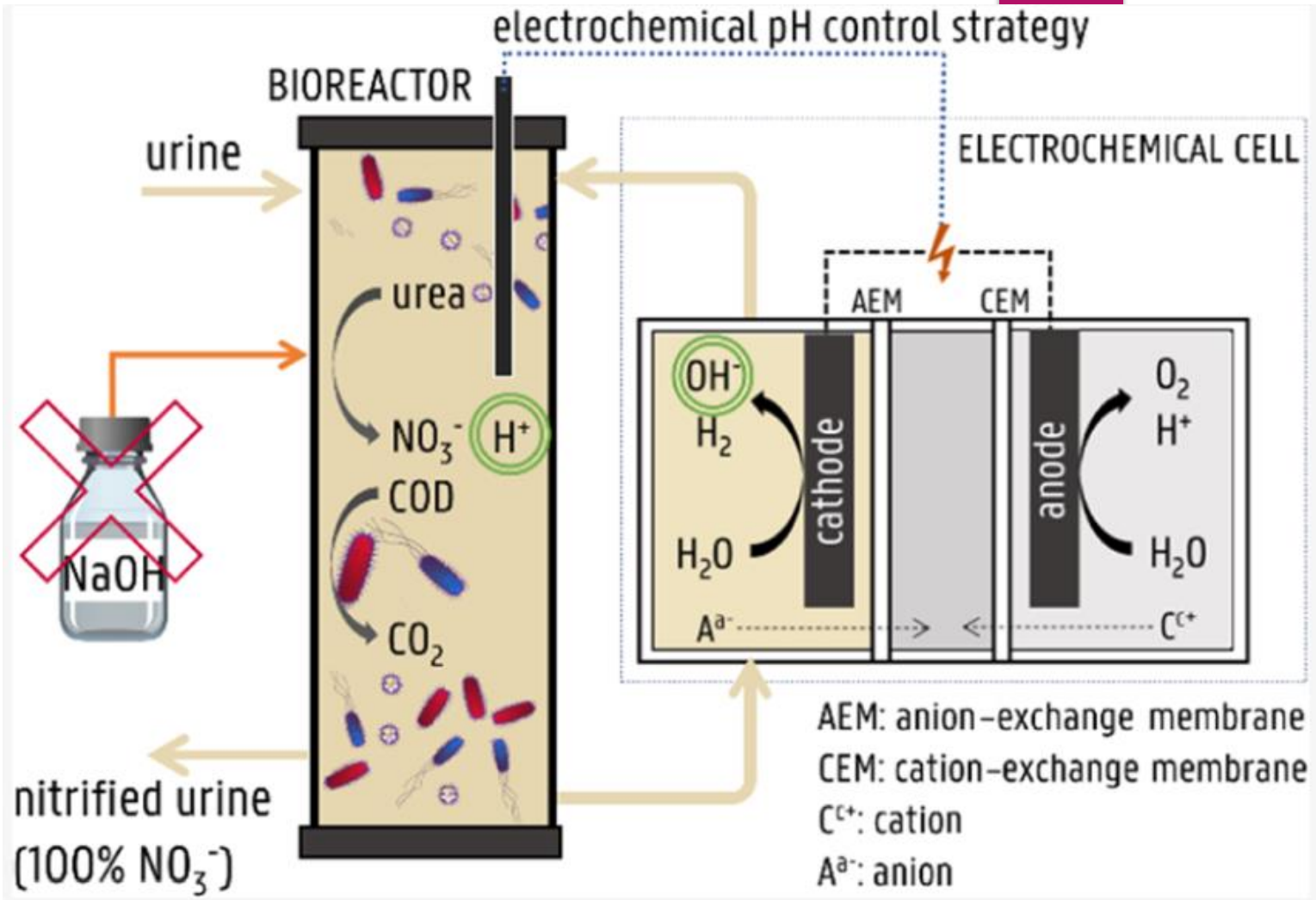
- In terrestrial conditions: membrane processes, sorption…

high cations removal rate

- not selective
- require energy
- prone to scaling and biofouling
- require dealing with sorbents

Clever solution

De Paepe et al. **Electrochemical In Situ pH Control Enables Chemical-Free Full Urine Nitrification with Concomitant Nitrate Extraction**, Environ. Sci. Technol. 2021, 55, 8287−8298



Clever solution

no need to chemical supplementation with bases (no excess cations accumulation)

its evaluated costs are in the same range as the cost of NaOH addition

- requires energy consumption

- requires constant electrochemical monitoring of pH

- requires stable influent composition (*a priori* alkalization of the collected urine to a pH of up to 12)

- needs to be tested for larger scales

Can we use urine directly?

- the production of fertilizer from urine is gaining more and more attention in the **terrestrial environment**
- urine can replace commercial fertilizers when there is too much phosphorus and potassium in the soil
- otherwise, urine fertilization needs to be **supplemented with ash** to increase potassium and phosphorus content…
- …however, human faeces have high contents of these elements in ionic form…

How to find the best solution?

nitrification of urine solely

- impossible due to the lack of alkalinity (**only half** of nitrogen is going to be nitrified)
- pre-treatment of urine is crucial in terms of providing nitrogen forms absorbable by plants (i.e. **nitrates**)

fertilization with fresh urine directly

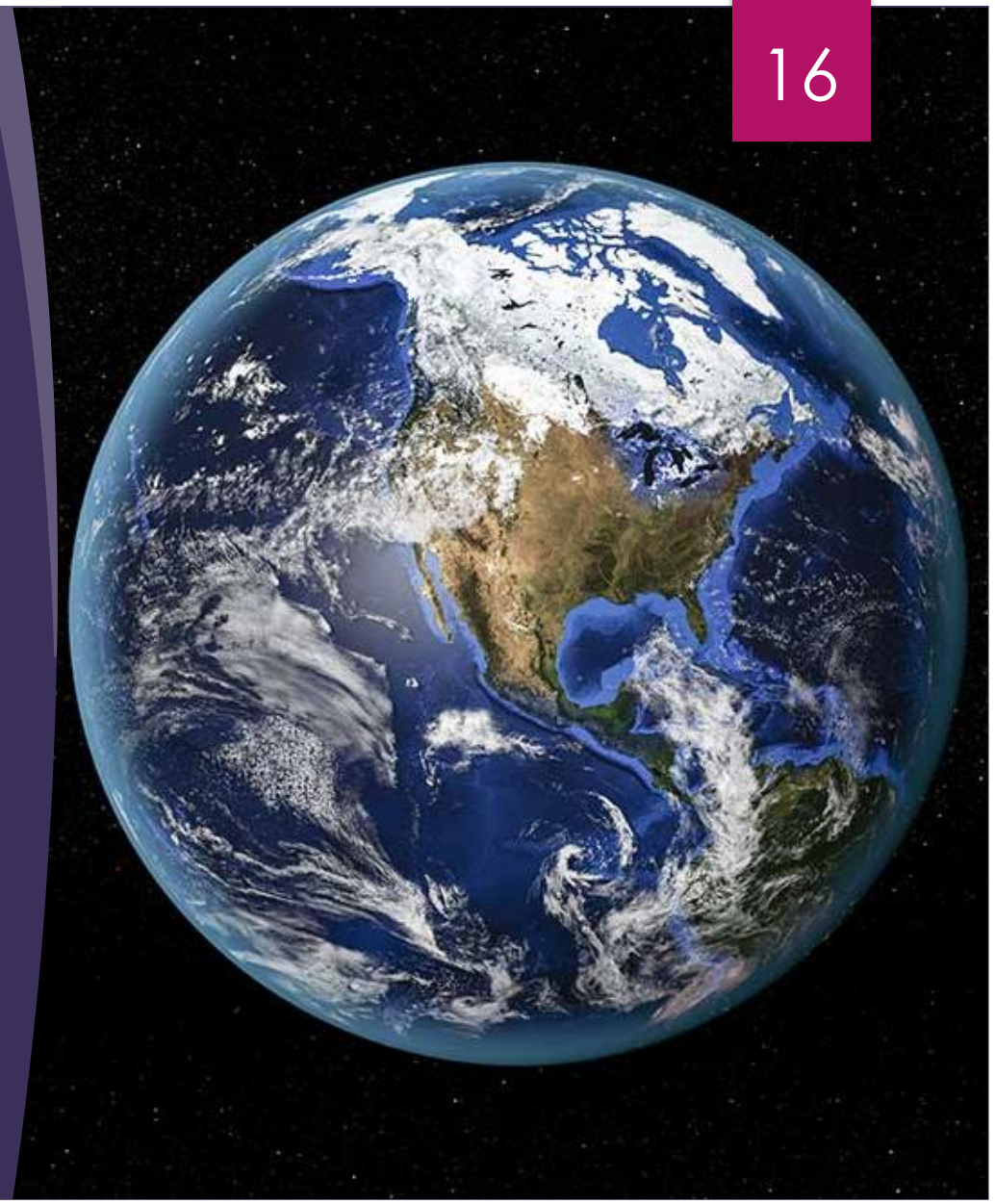
- impractical in extraterrestial applications (supplementation with ash demanded)
- insufficient nitrate concentration
- other problems: distinct odour, high pH ranges and the presence of high concentrations of pharmaceuticals

fertilization with fresh human excreta directly

- difficult to obtain and manage in a hygienic way
- insufficient nitrate concentration

Why this is merely extra-terrestrial problem?

- on Earth, full nitrification of wastewater is conduced, however no alkalinity addition is required in most cases
- it is possible because municipal watewaters are indeed the mixture of tap water, grey water, yellow water and black water
- the important source of alkalinity on Earth are **cleansing agents** – this source is going to be missing in space

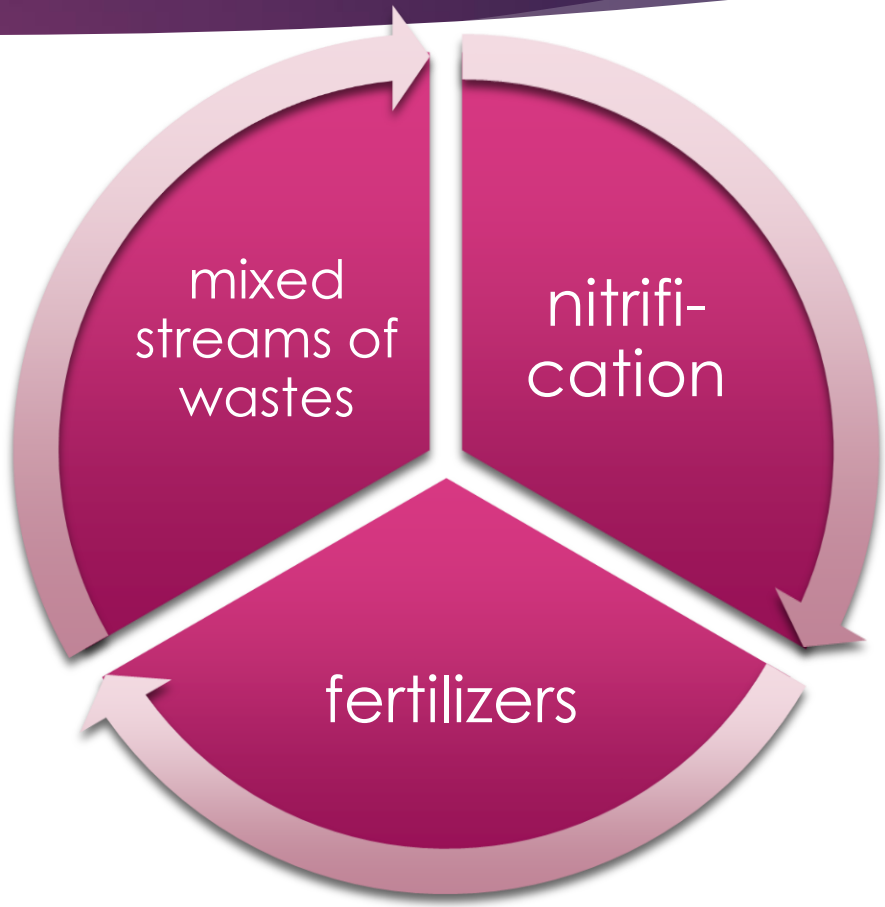


Simple and alternative solution:

Why not to use as a substrate for nitrification mixed streams of all possible wastes produced during space missions?

Closed loop system

- the nitrification will provide a sufficient nitrates concentration in the final product
- the alkalinity requirement for nitrification will be met by definition
- the fertilizer will have much more **balanced composition** which will meet plants requirements
- problem of wastes will be partially solved in the same time
- **the simples solutions are the best solutions ☺**



To sum up, urine solely cannot be taken into consideration regarding soilless crop cultivation due to the scarcity of phosphorus and potassium in this stream. However, this problem could be solved by the application of **a mixed stream of different wastes**, including human faeces. Moreover, **nitrification** in a bioreactor seems to be a **necessary pre-treatment** of urine (or a stream of mixed wastes) for fertilizer production in space mission conditions, where no autochthonous soil bacteria exist.

Conclusion

It seems that a reasonable solution for the alkalinity demand regarding full urine nitrification during space missions may be a simultaneous treatment of all waste streams in a nitrification bioreactor. In this way, both the dilemma of alkalinity and elemental composition mass balance in a closed loop would be met by definition.

Take-home message

The alkalinity dilemma could be easily solved by the treatment of a mixed wastes stream instead of overcoming the lack of alkalinity in urine by chemical, physical or electrochemical methods.

Thank you for the attention!

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