JC² October, 6-8 October, 2021

Supercritical water oxidation (SCWO) using hydrothermal flames in microreactor for micro-gravity environment with DECLIC

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MOTIVATION

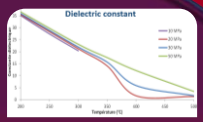
Develop safe technologies for sustaining life on board long duration space exploration and interplanetary missions

➔ *Conversion of human biological wastes to reusable chemicals (water, CO_2 , etc.).*

➔ *Understanding coupled thermo-chemical-hydro phenomenon at high pressure & temperature*

SCWO

Water is polar at ambient conditions → becomes non-polar at supercritical conditions (T > 374°C and P > 221 bar).



✓ Dissolves organic chemicals and gases → medium for oxidation of organic matter.

Merits

* No pre-requisite to dry the wet waste streams.
* Absence of inter-phase reactant transport → low reaction time scales.

X **Limitation:** Precipitation of inorganic salts

- Impaired heat transfer
- Clogging of the reactor
- Loss in process efficiency

HYDROTHERMAL FLAMES

Cold combustion (400 < T(°C) < 600, P > 23 MPa)) :

Water + oxidant (O_2, H_2O_2, air, …) + Organic matter + (Organic fuel) ➔ CO_2 + H_2O + solids

* Due to auto-ignition of organic fuel (methanol , ethanol etc.)

✓ **Further Merits**

* Facilitates injection of waste at lower temperature & attain supercritical conditions inside the reactor → prevents precipitation of salts
* Possible to have smaller reactor designs.
* lower reaction times ~10ms -100ms.
* High conversion efficiency.

MOVING TOWARDS MICROSCALE

Why?

* Small size aptly suited for space applications (safety).
* More uniformity in reactions.

Challenges

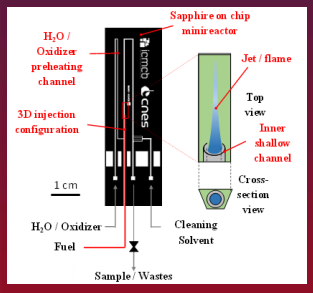
* Realization of microfluidic reactor.
Appropriate material having thermal and mechanical strength
* High surface-area to volume ratio → heat losses more predominant → flame stability
* Identifying ignition/extinction characteristics

METHODOLOGY/DISCUSSIONS

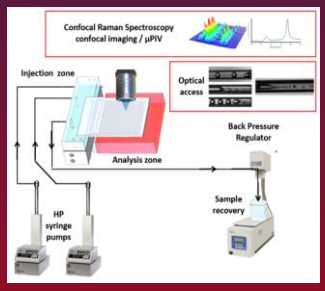
Combined experimental & numerical approach.

EXPERIMENTAL

* Use sapphire micro-chip , withstand higher P, T up to 600°C and 40 MPa , chemically compatible with SCW.



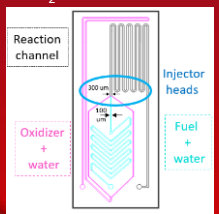
Micro-reactor setup



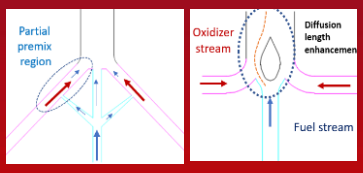
Experimental setup

Micro-reactor design criteria

Sufficient length to achieve decomposition of H_2O_2 into water & O_2.



Injector head to facilitate premixing.



Premixing of fuel and oxidizer

↓

Reduce auto-ignition time & Anchored flame

NUMERICAL

* Solve governing equations of mass, momentum, energy and species.
* DNS of hydrothermal flames using single step reaction kinetics.

Parameters of interest :

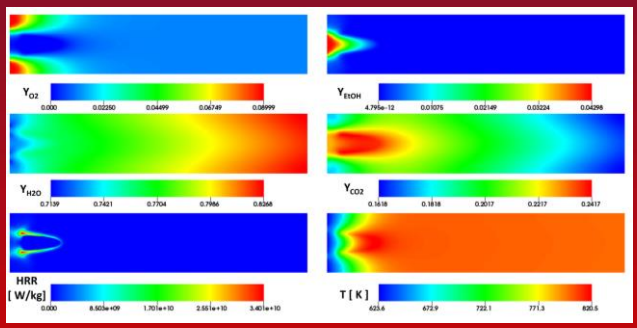
* Inlet temperature.
* Flow rate.
* Concentration of fuel & oxidizer.
* Ignition & extinction temperature
* Flame stability

Computational domain

Single step irreversible reaction

C_2H_5OH + $3O_2$ → $3H_2O$ + $2CO_2$

(Fuel) (Oxidizer)



Contour plots for $T_{injection}$ = 350 C , U = 10 mm/s (both fuel and oxidizer)

(Simulation done using NOTUS on supercomputer of CNES)

CONCLUSION & PERSPECTIVES

* Treatment of organic waste using SCWO in the presence of hydrothermal flames is proposed.
* Advantages of microscale reactor are sought for space application.
* Micro-reactors are designed to have premixing to reduce ignition delay & anchored flame
* Numerical simulations capture the formation of flames. Parametric study to be undertaken to understand flame dynamics at micro-scale.