INTERNATIONAL ENERGY AND ENVIRONMENT CONFERENCE

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HOTEL SEPETNÁ OSTRAVICE

TORREFIED BIOMASS AND ANAEROBIC DIGESTION SYNERGY

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80 YEARS OF LODZ UNIVERSITY OF TECHNOLOGY

NARODOWE CENTRUM NAUKI

Sep 08, 2026

INTRODUCTION

What is Torrefaction?

Mild thermochemical treatment of biomass in a **non-oxidative** environment.

200–320 °C for 10–60 min

Dehydration
Decarboxylation
Devolatilization

It produces a **solid, energy-dense**

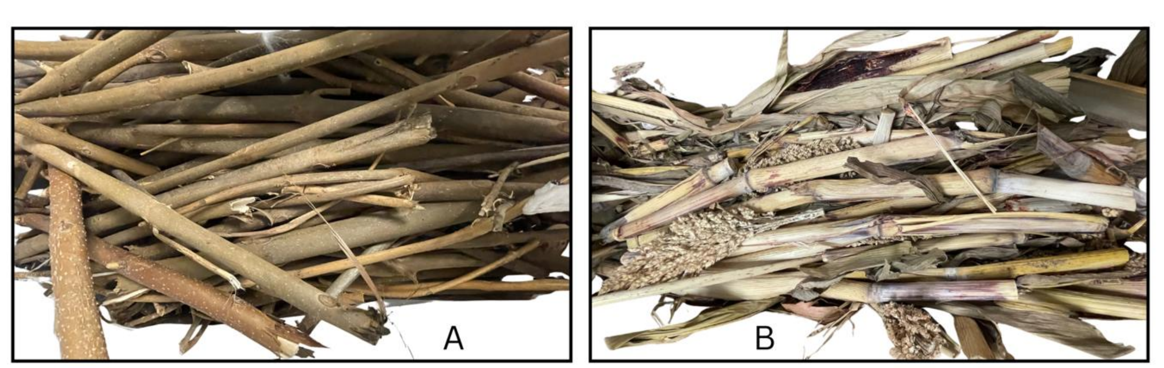
- **Torrefaction**
  - Dry Torrefaction
  - Steam Torrefaction
  - Wet Torrefaction

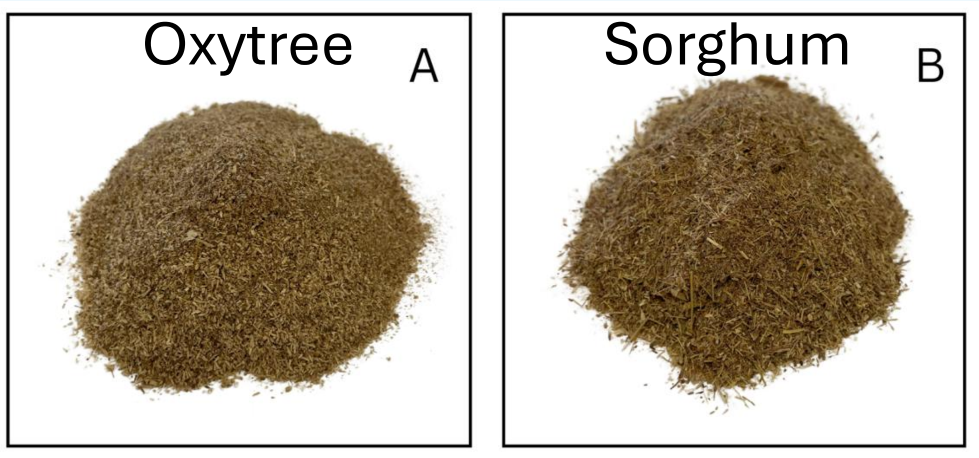

OXYTREE


SORGHUM

MATERIALS and METHODS

Oxytree Sorghum





Characteristic Analyses

Proximate Analysis

Total solid (TS g/kg) at 105 ℃ for 24 h

Volatile solid (VS g/kg) at 550 ℃ for 2 h

Ash (g/kg) at 800 ℃ for 4 h

Ultimate Analyses

CHNO elemental analyzer

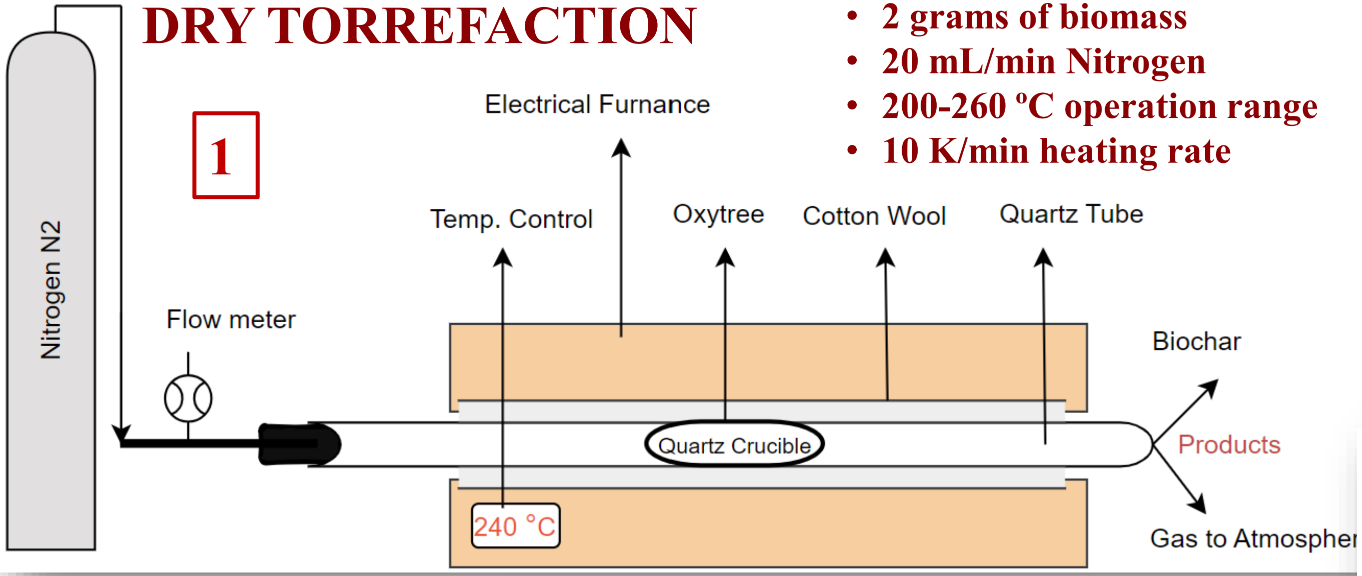
GC-MS Analysis

SEM-EDX analysis

3 TYPES OF TORREFACTION PROCESSES

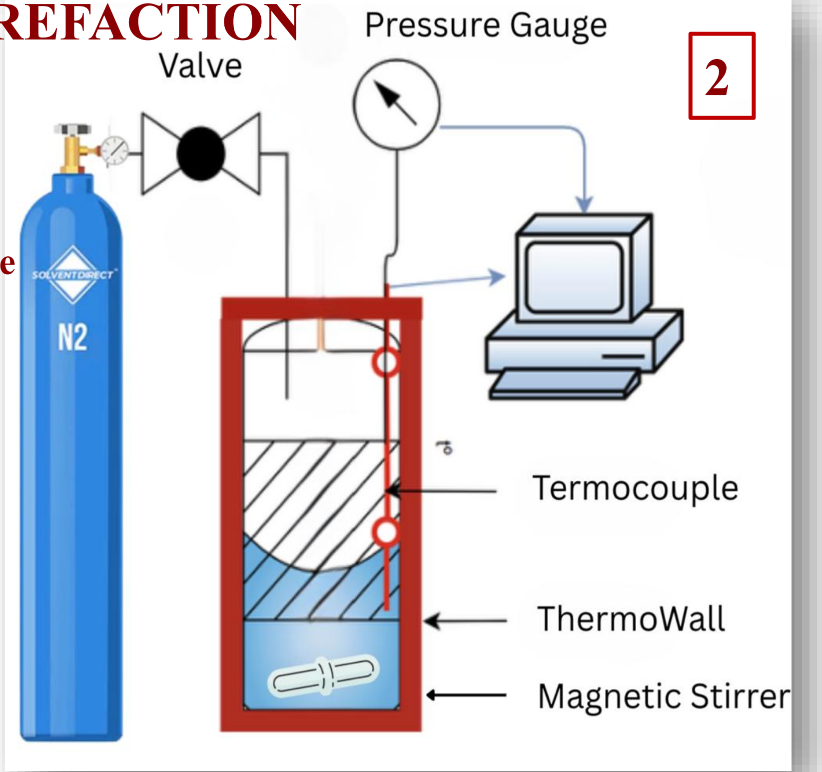
DRY TORREFACTION

- 2 grams of biomass
- 20 mL/min Nitrogen
- 200-260 °C operation range
- 10 K/min heating rate



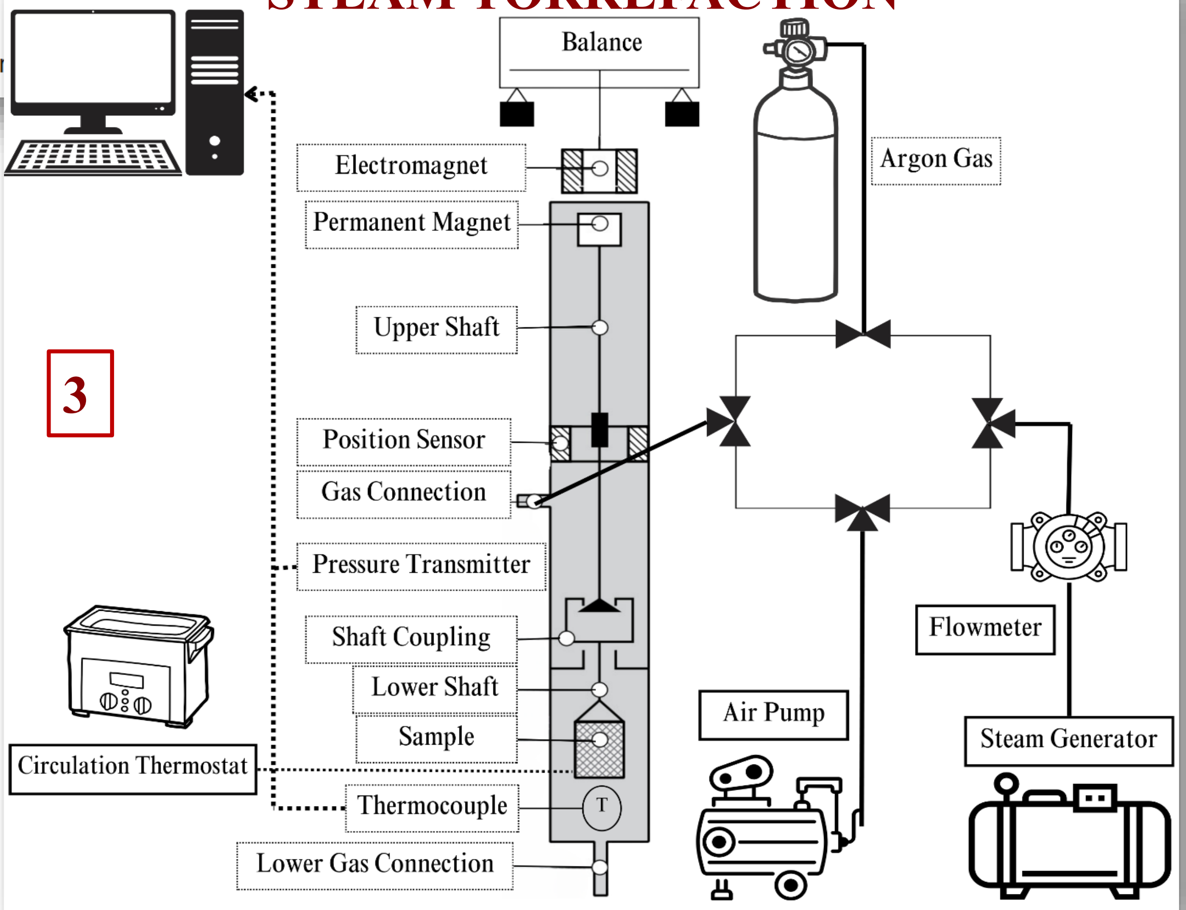
WET TORREFACTION

- 3 grams of biomass
- 1/10 liquid ratio
- 30 mL ionized water
- Autogenic pressure
- 200-260 °C operation range
- 10 K/min heating rate
- 400 rpm mixing
- 3 bars start

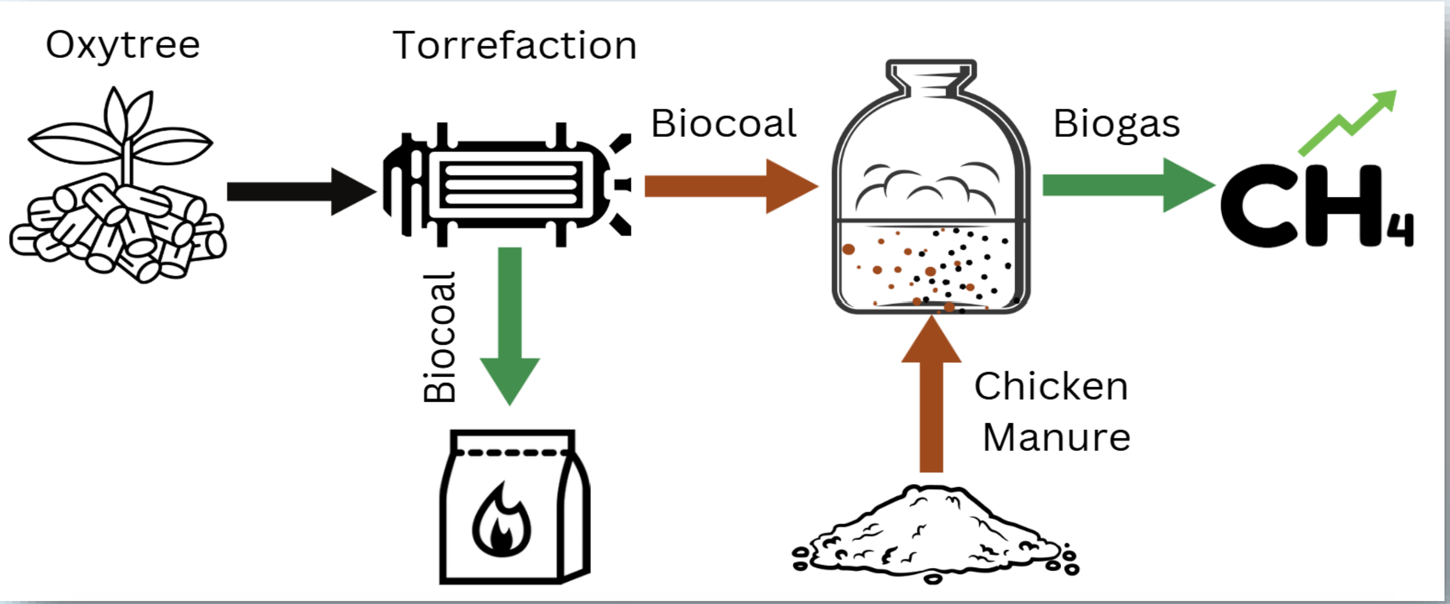


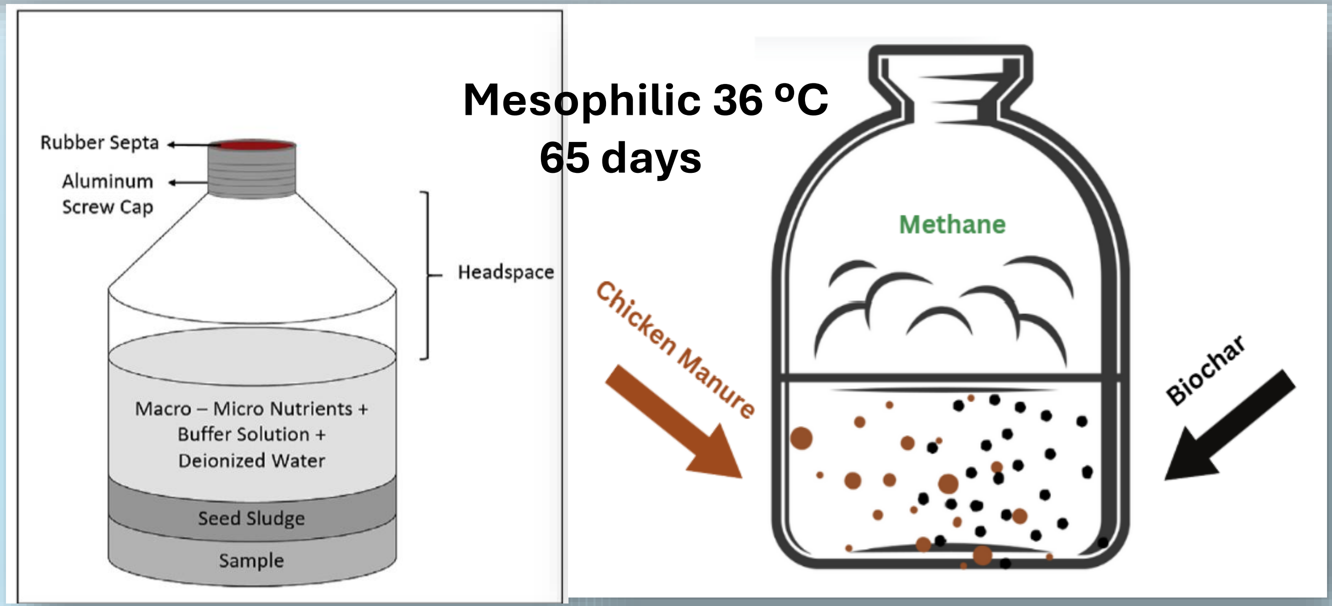
STEAM TORREFACTION

- 150 mg of biomass
- 80 μL/min water feed
- 100 mL/min Argon
- 200-260 °C operation range
- 10 K/min heating rate
- 2.5 bars constant



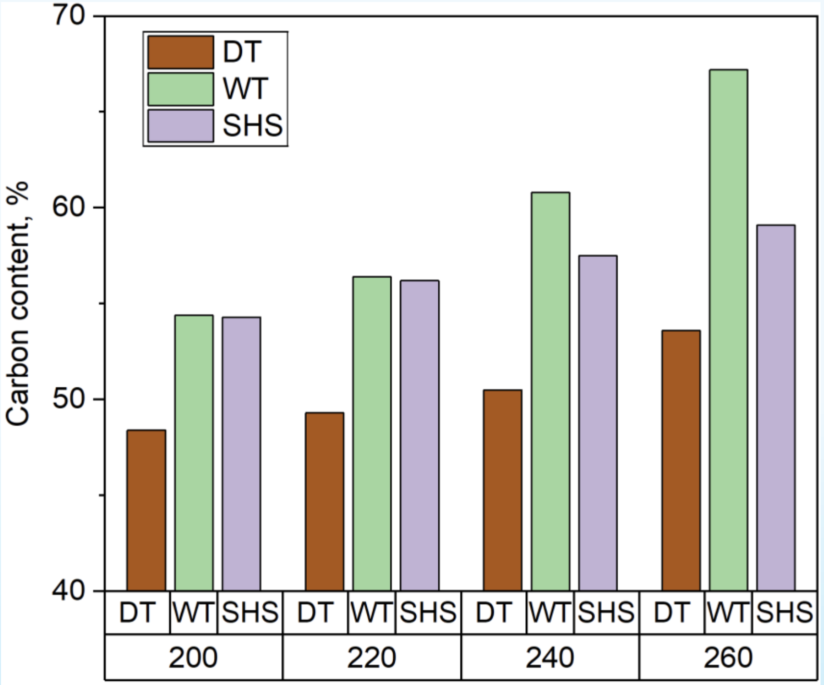
ANAEROBIC DIGESTION – Biochar Additive

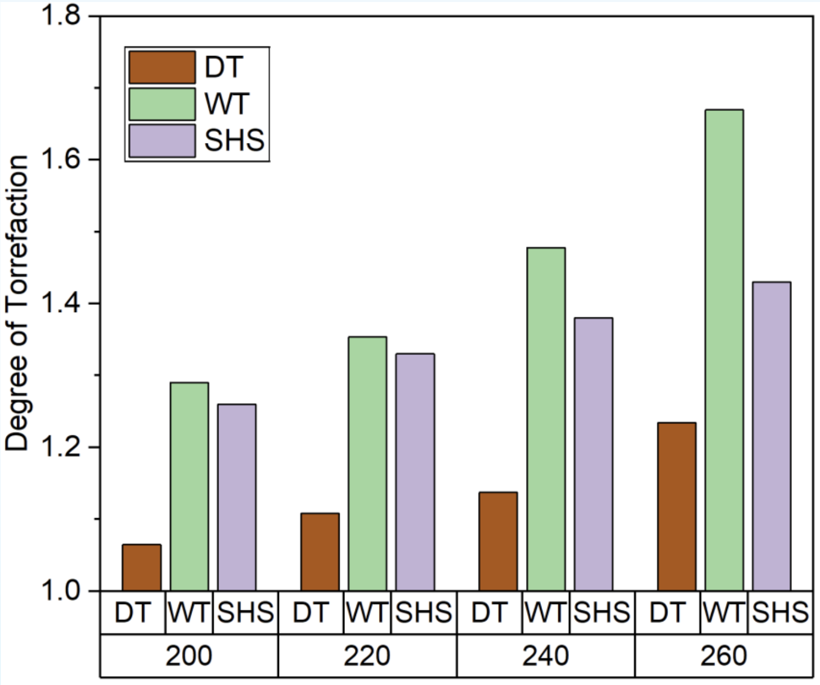


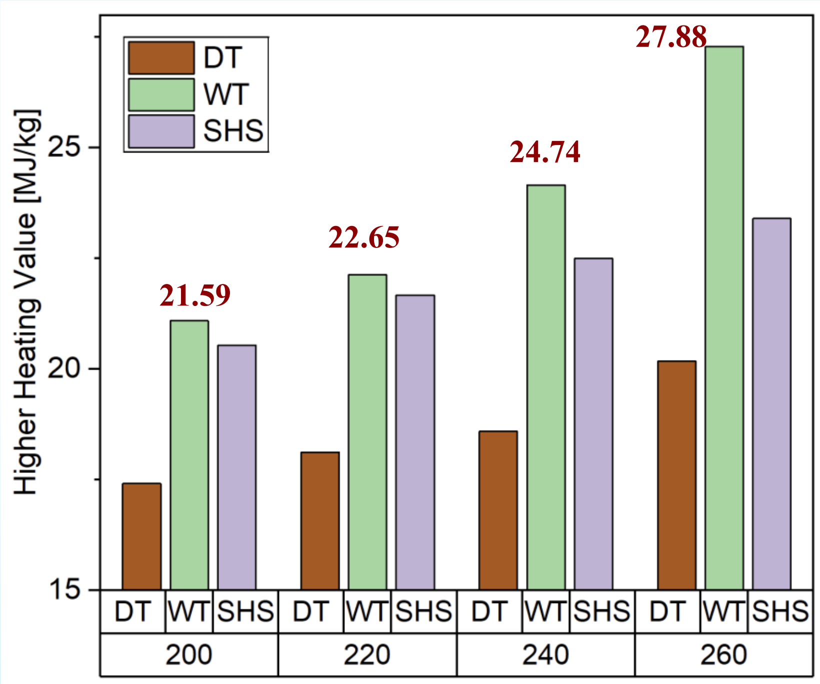


RESULTS

Energy Densification OXYTREE

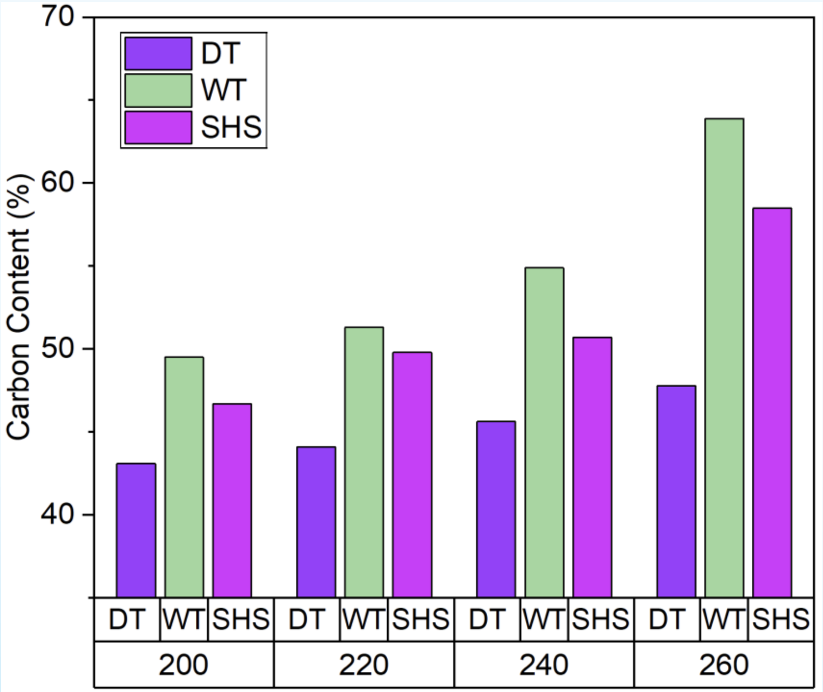


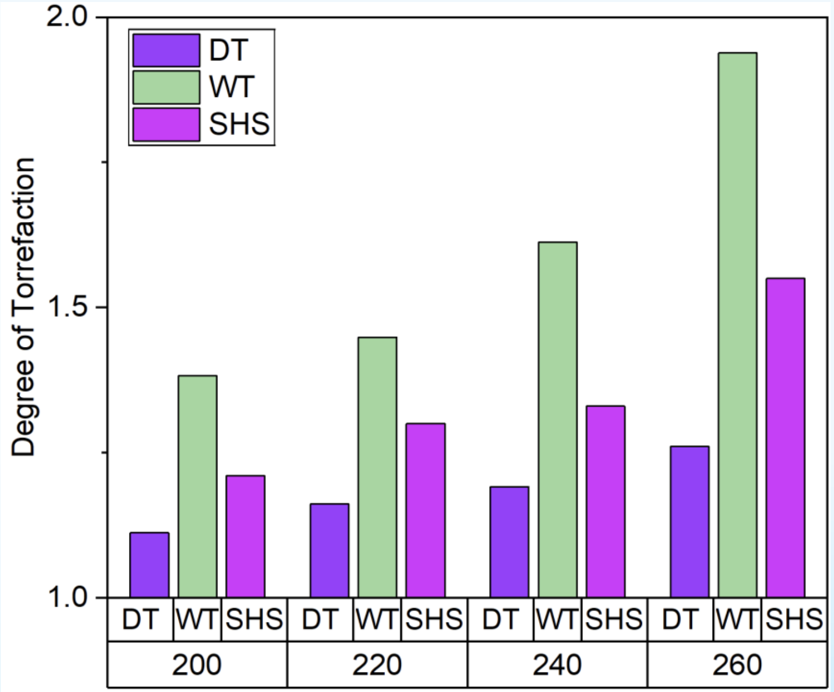


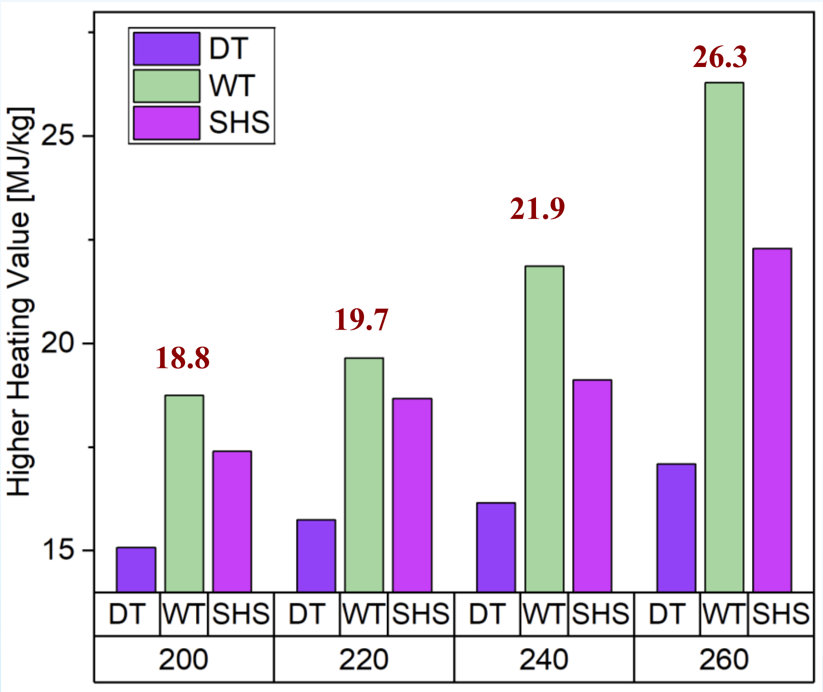


WT > ST > DT

Results: Energy Densification SORGHUM

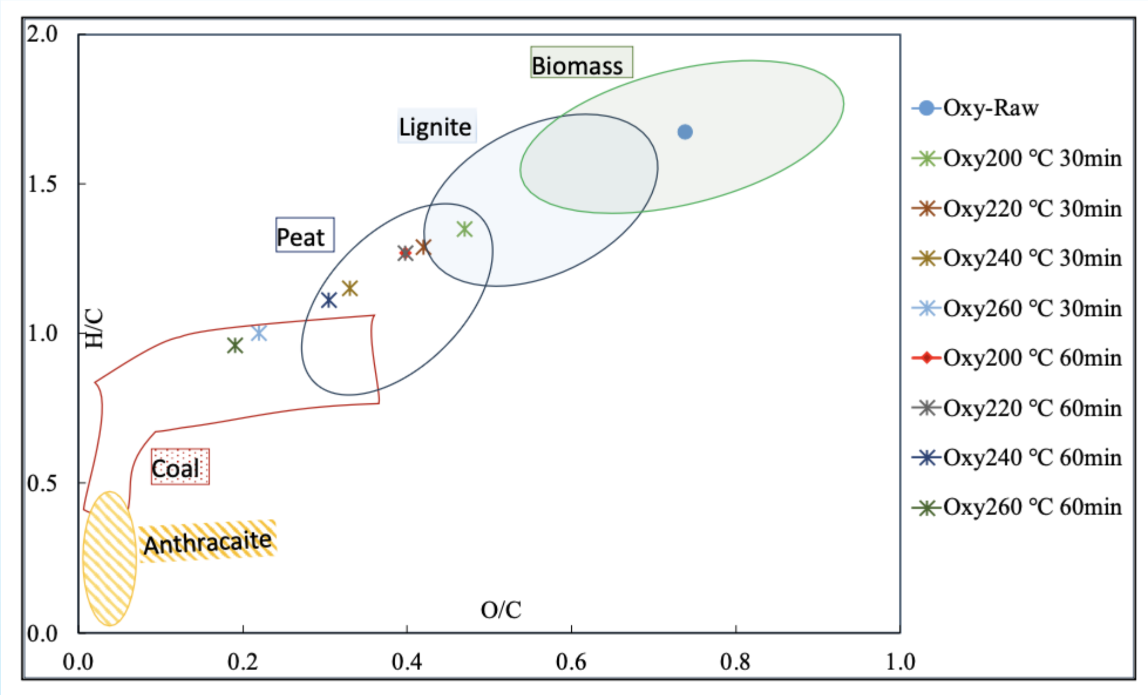


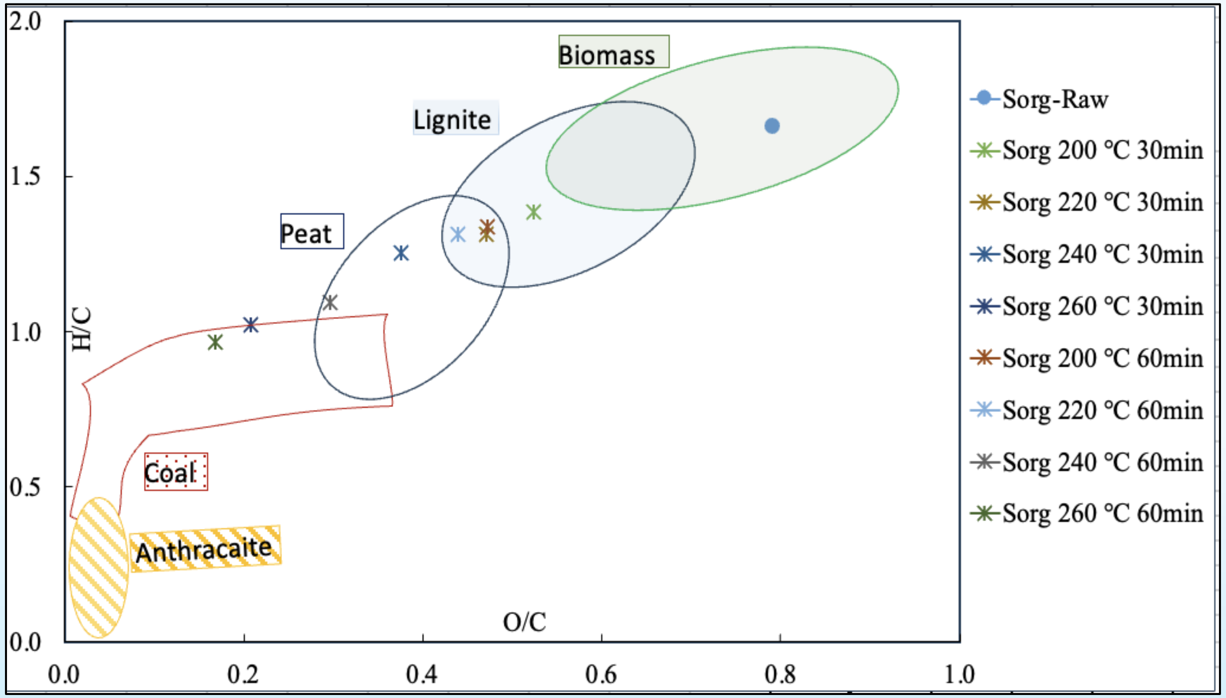




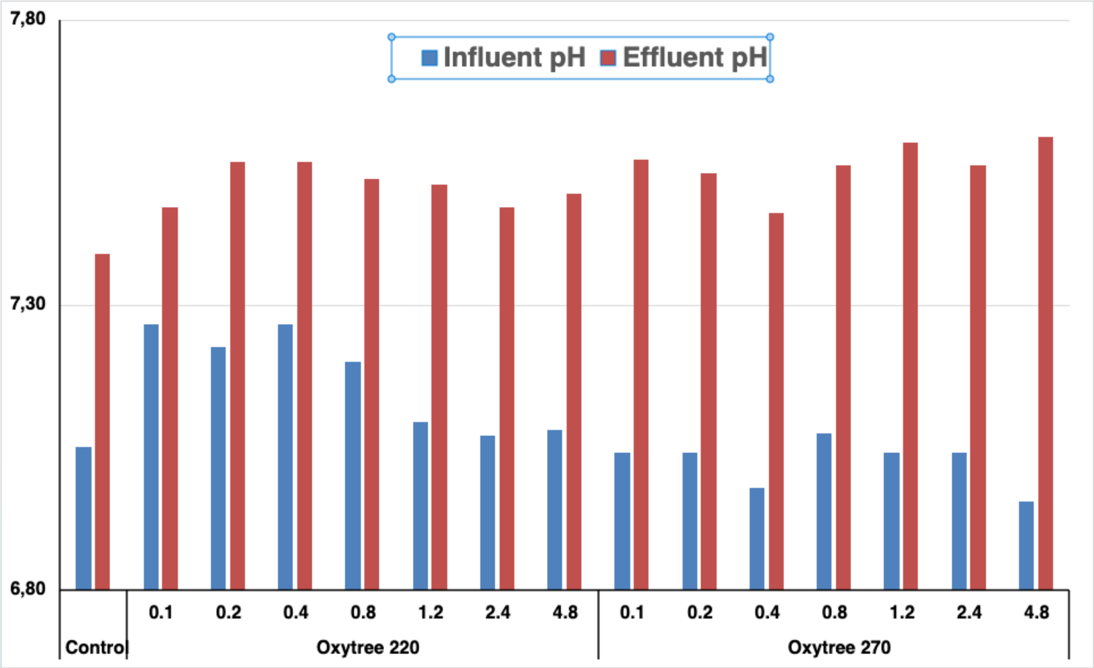
WT > ST > DT

Energy Densification Van Krevelen



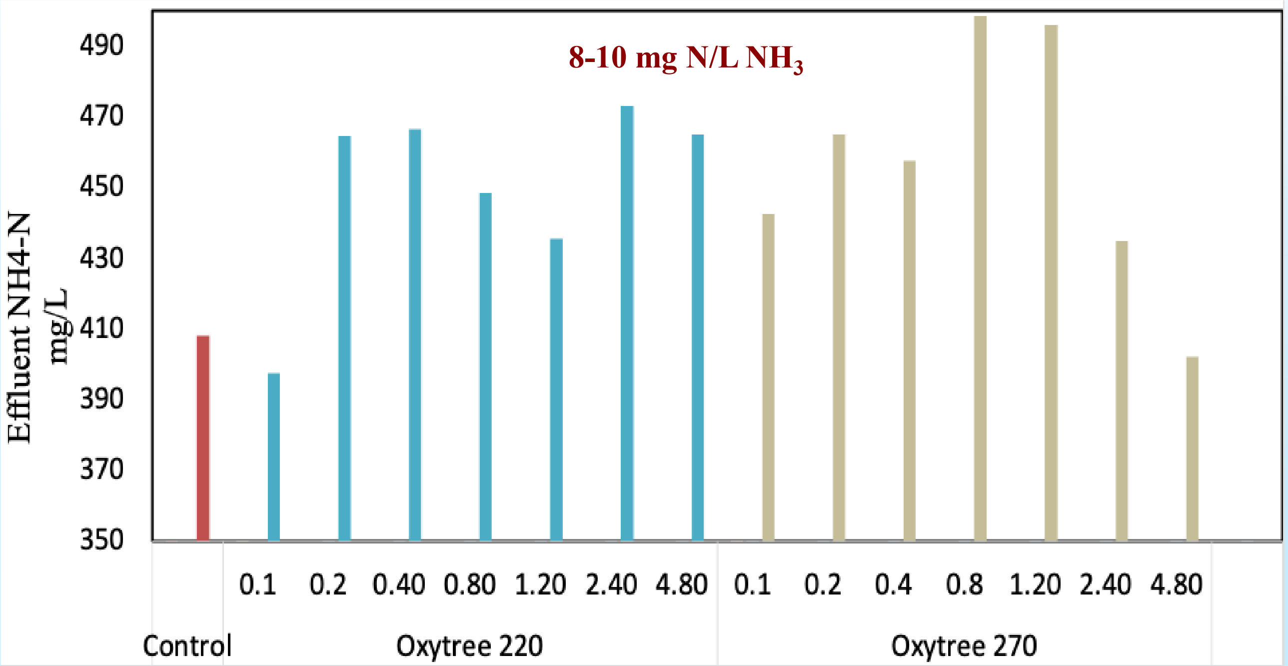


Biochar as Additive - Anaerobic Digestion



220 ºC = NH_4-N **10% higher**, effluent pH **7.5**

270 ºC = NH_4-N 12% higher, effluent pH **7.55**



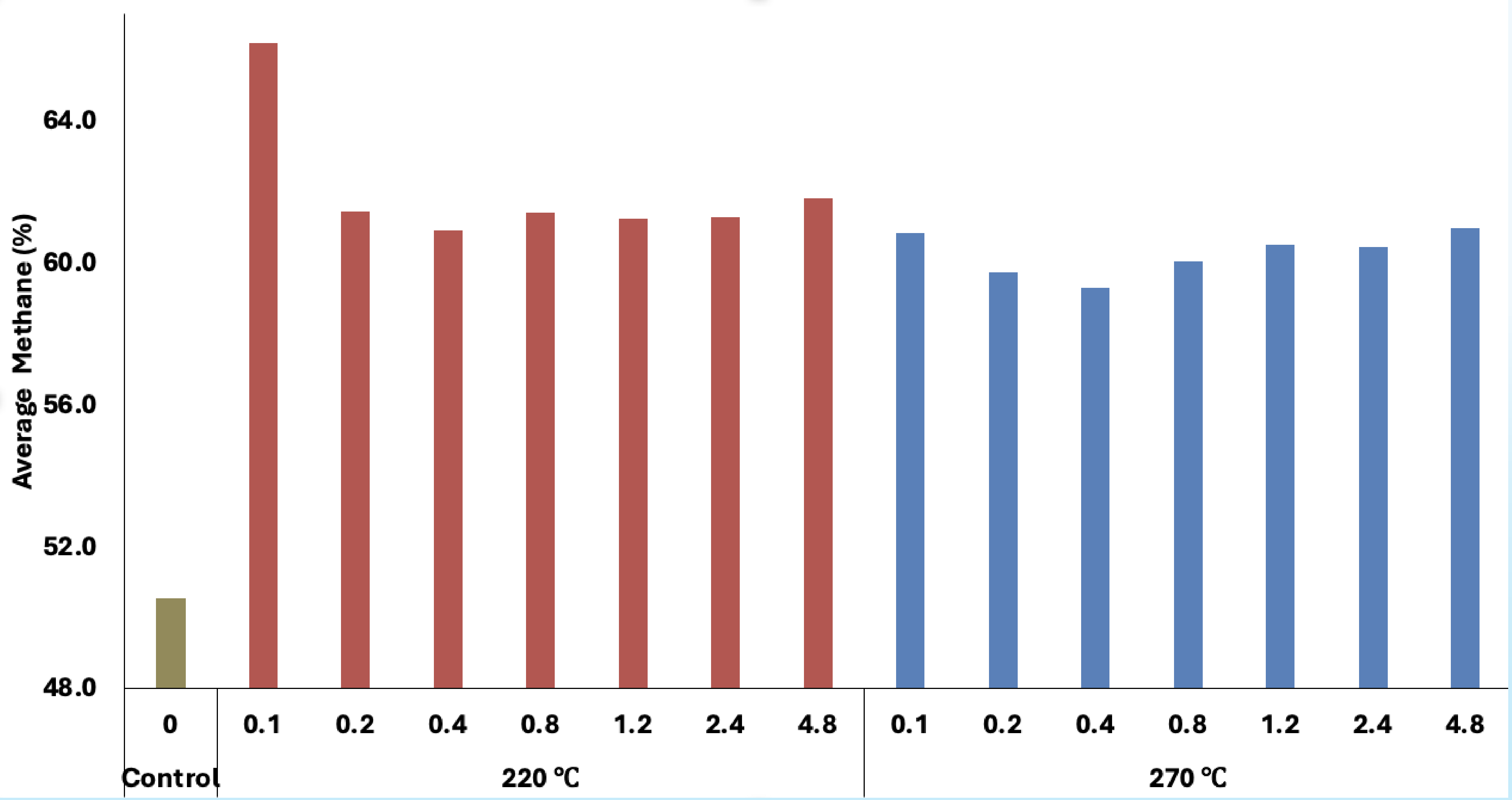
The NH_4-N rise mainly signals **faster conversion**, not toxicity.

The system **runs faster (decreases lag time), CH_4 increases.**

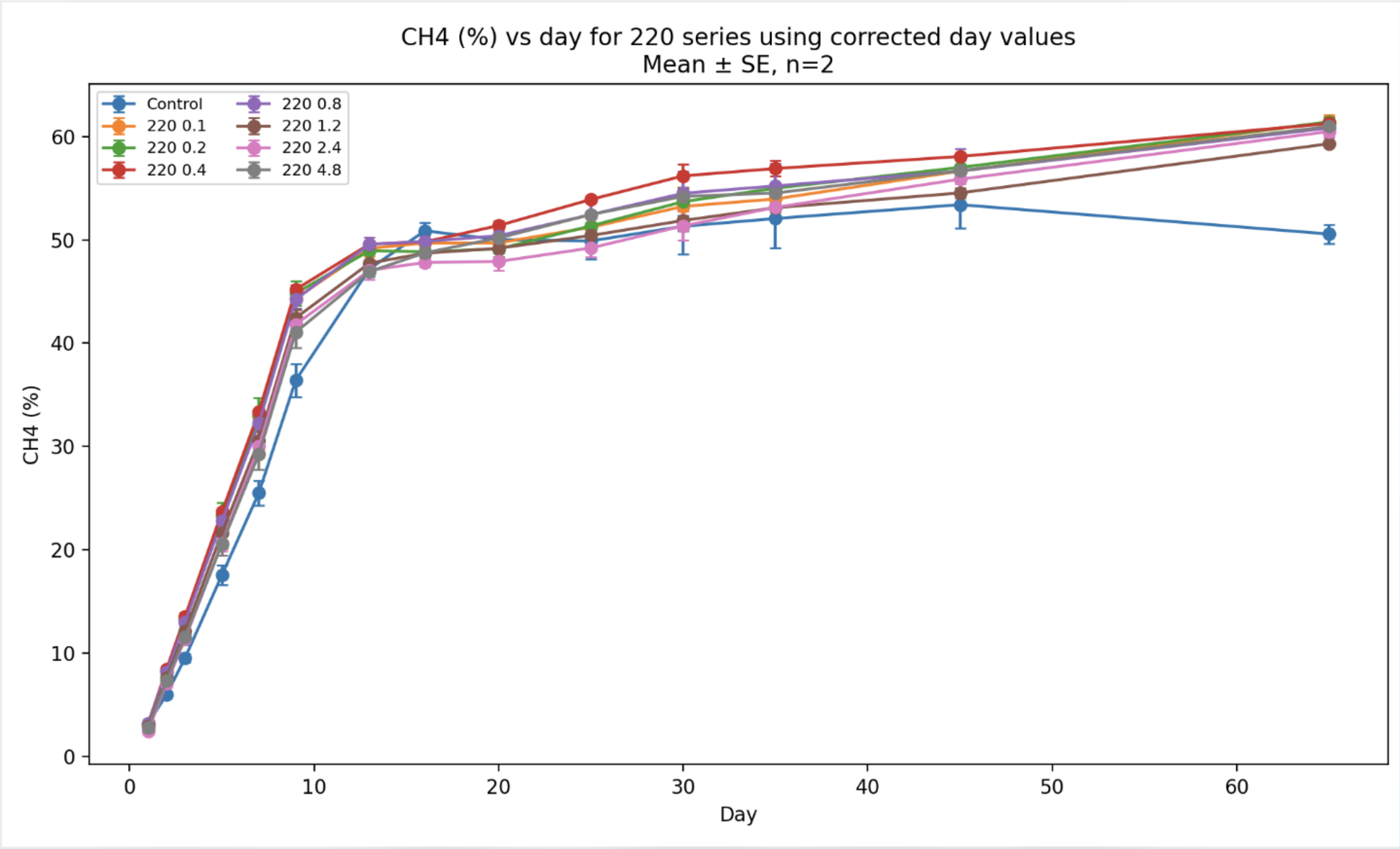
At pH 7.5, only 2% of TAN is free ammonia NH_3 → **8–10 mg N/L NH_3**

Inhibition for methanogens usually **starts at 80–150 mg N/L**

Methane composition (%) on day 60



Methane composition daily (%)



- chicken manure added = **2.29 g**
- chicken manure VS = **262.31 g/kg** = **0.26231 g VS/g manure**

$$2.29 \times 0.26231 \approx 0.6007\ g\ VS$$

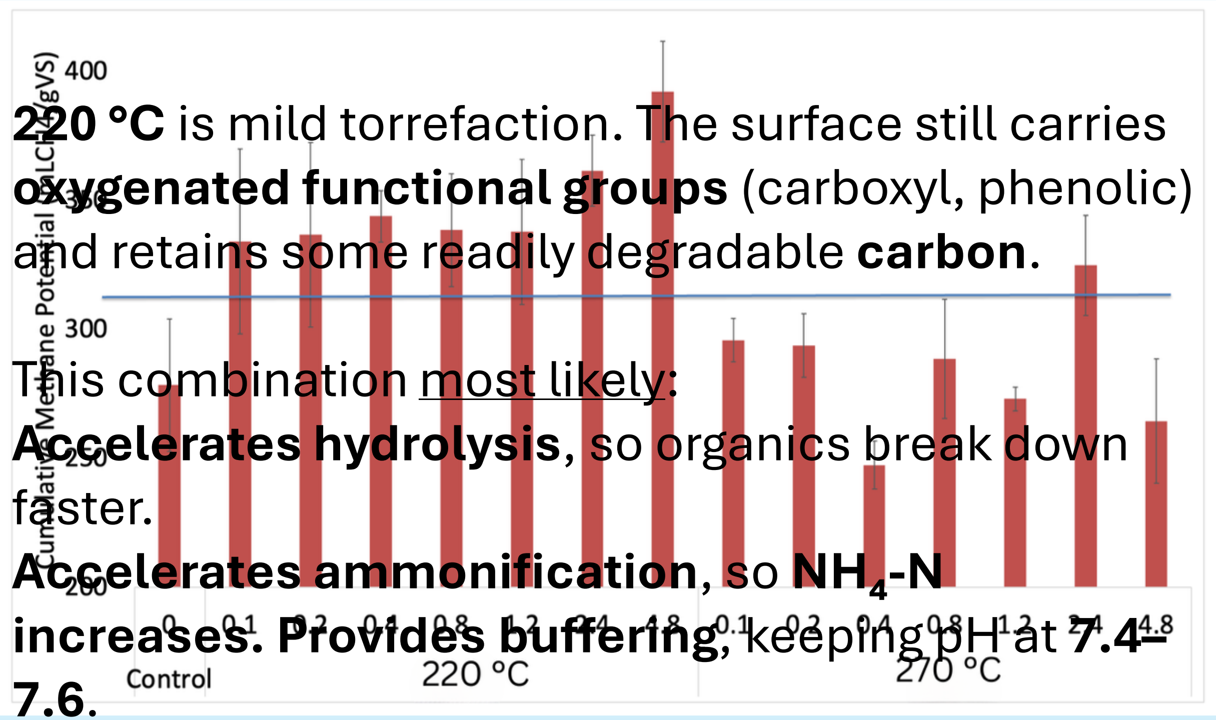
$$\text{Biochar } mass\ (g) = \frac{0.6 \times target\ ratio \times 1000}{biochar\ VS\ (g/kg)}$$

Dose 0.4 should be:

- target ratio = **0.4**
- substrate VS = **0.6 g**
- raw oxytree VS = **928.55 g/kg**

$$0.6 \times 0.4 \times 1000/928.55 = 0.258\ g$$

Biochar as Additive - Anaerobic Digestion

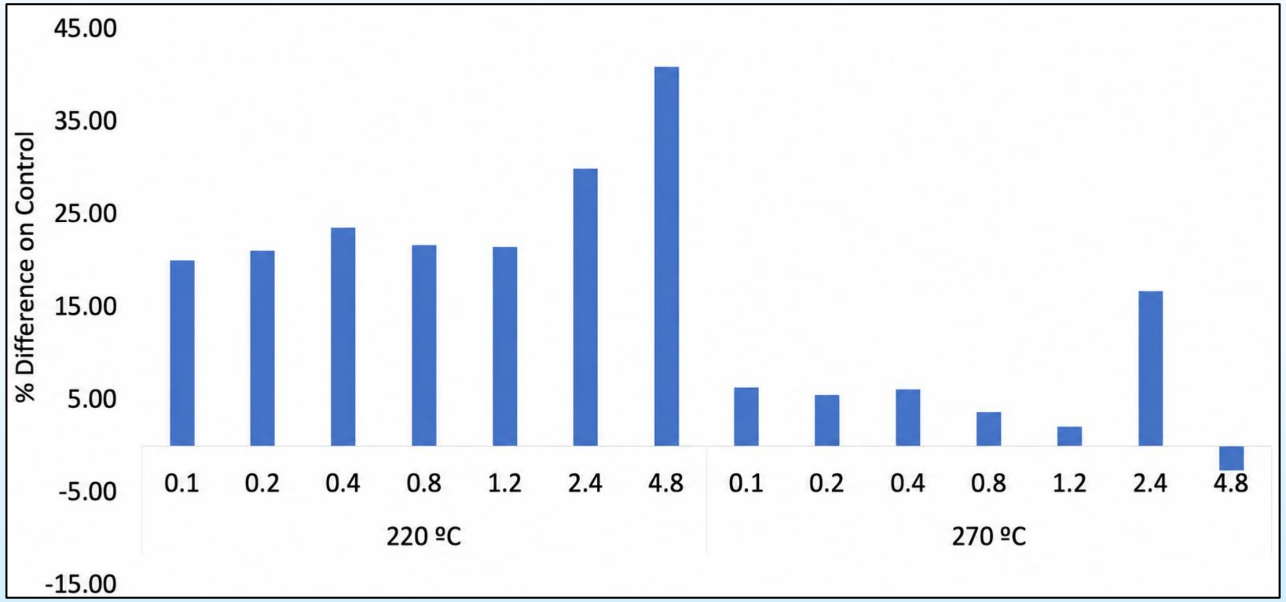


220 °C is mild torrefaction. The surface still carries **oxygenated functional groups** (carboxyl, phenolic) and retains some readily degradable **carbon**.

This combination <u>most likely</u>:

Accelerates hydrolysis, so organics break down faster.

Accelerates ammonification, so **NH_4-N increases. Provides buffering**, keeping pH at **7.4–7.6**.



270 °C means more carbonization: **Less degradable carbon** → weaker "kick" to hydrolysis.

Results: Function 2 Biochar as Additive - Anaerobic Digestion

Hydrolysis rate k (Day^{-1})

Lag Phase λ (Day)

First order model

$$M = P.\left[1 - e^{(-kt)}\right]$$

M. Gompertz model

$$M = P.\exp\left\{-\exp\left[\frac{R_m.e}{P}(\lambda - t) + 1\right]\right\}$$

220 °C biochar: faster hydrolysis (**k↑ 31% vs control**), shorter lag (**λ↓ 49%**), and higher ultimate methane (**P↑**) with excellent fits.

270 °C biochar: hydrolysis rate **k↑ 60%** , but **lag longer** and **ultimate P lower** than 220 °C

	Metric	**Unit**	**Control**	**220 °C — mean (range)**	**270 °C — mean (range)**
Modified Gompertz	R_m	mL $CH_4 \cdot g^{-1}$ $VS \cdot d^{-1}$	16.6	17.41 (15.6–18.2)	18.80 (16.9–21.0)
	λ	**d**	**1.98**	**1.01 (0.85–1.26)**	**1.57 (1.03–1.84)**
	P	mL $CH_4 \cdot g^{-1}$ VS	250.2	284.76 (267.1–295.3)	237.31 (202.1–276.3)
	R^2	–	0.98	0.988 (0.984–0.992)	0.995 (0.988–0.998)
1st order	Metric	Unit	Control	220 °C — mean (range)	270 °C — mean (range)
	k	**d^{-1}**	**0.05**	**0.0657 (0.060–0.070)**	**0.0800 (0.070–0.090)**
	P	mL $CH_4 \cdot g^{-1}$ VS	307.8	318.9 (295.0–329.8)	264.7 (223.4–308.7)
	R^2	–	0.981	0.986 (0.984–0.990)	0.977 (0.971–0.986)

Results- Overall

Anaerobic Digestion Additive:

Area / Metric	220 °C	270 °C
AD - hydrolysis rate	High	High
AD - lag phase	Low	Higher
AD - methane potential	High	Low

Target conversion	Control k=0.05	220 °C k=0.0657	Days saved	270 °C k=0.0800	Days saved
95%	60 days	45.6 days	14.32 days	37.5 days	22.5 days

Thank you for attention!

Lodz University of Technology

Results- Overall

Energy densification:

Dry Torrefaction | **Wet Torrefaction** | Steam Torrefaction

Oxytree proved its potential with Sorghum

- **28 MJ/kg**
- **75 % E. Yield**
- **Suitable for WT and DT**

- **27.7 MJ/kg**
- **74 % E. Yield**
- **Better results on WT**

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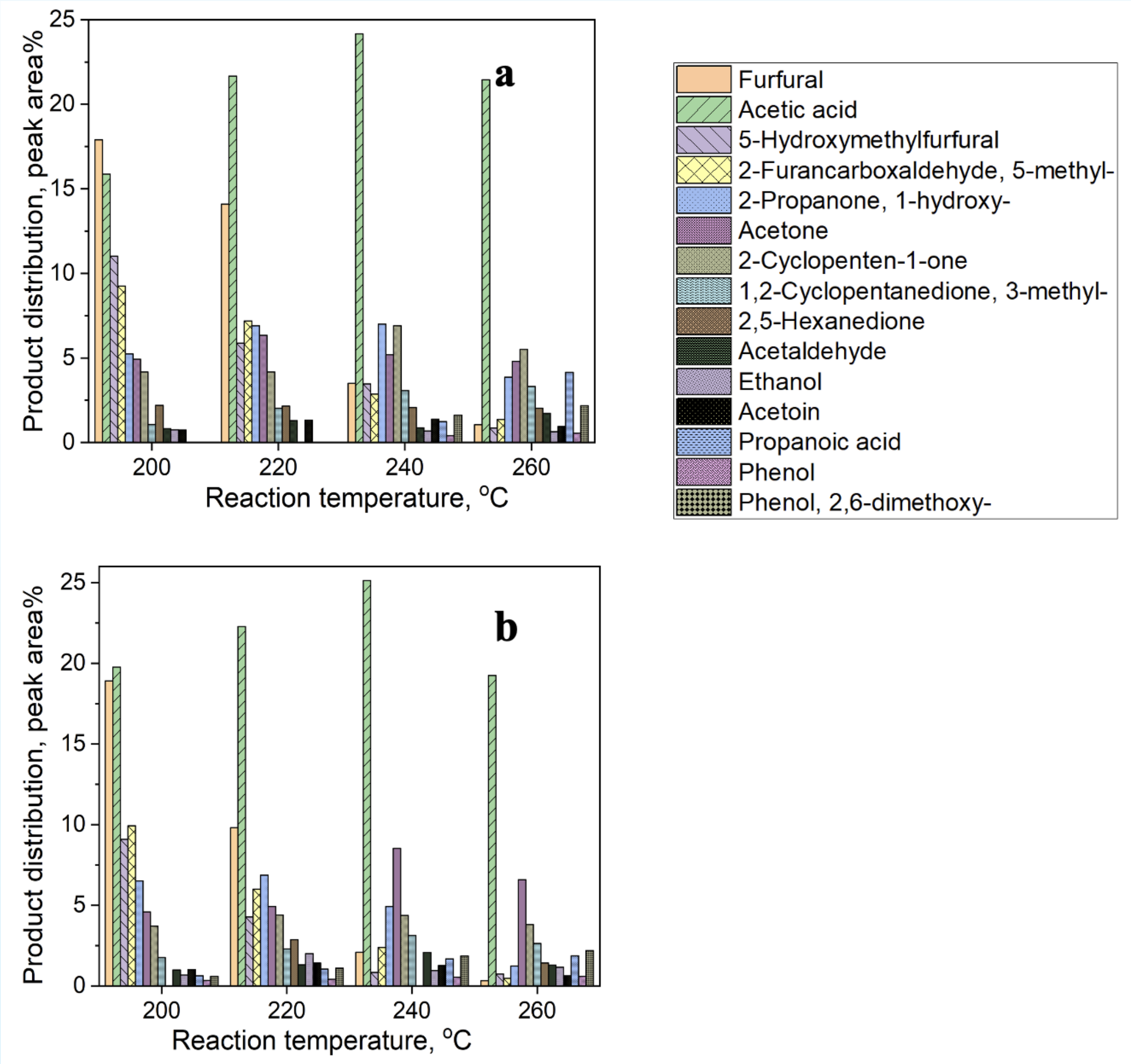
INTERDISCIPLINARY DOCTORAL SCHOOL

Results: WT Beyond the Solid Phase



Liquid phase composition of Oxytree WT A)30 min, B) 60 min

- Acetic acid was the dominant product
- Shorter residence time preserved more furfural and 5-HMF
- Longer residence time shifted the liquid phase towards acetic acids and ketones