Pyroliq 2019: Pyrolysis and Liquefaction of Biomass and Wastes

Proceedings

6-18-2019

# Parametric study of lab-scale and pilot-scale biomass torrefaction for the production of woodstove briquettes

Anna Trubetskaya

J.J. Leahy

Marzena Kwapinska

Robert Johnson

Rory F.D. Monaghan

# PARAMETRIC STUDY OF LAB-SCALE AND PILOT-SCALE BIOMASS TORREFACTION FOR THE PRODUCTION OF WOODSTOVE BRIQUETTES

*Anna Trubetskaya, J.J. Leahy, Marzena Kwapinska, Robert Johnson, Rory F.D. Monaghan*

*June 18th, 2019*

OÉ Gaillimh
NUI Galway

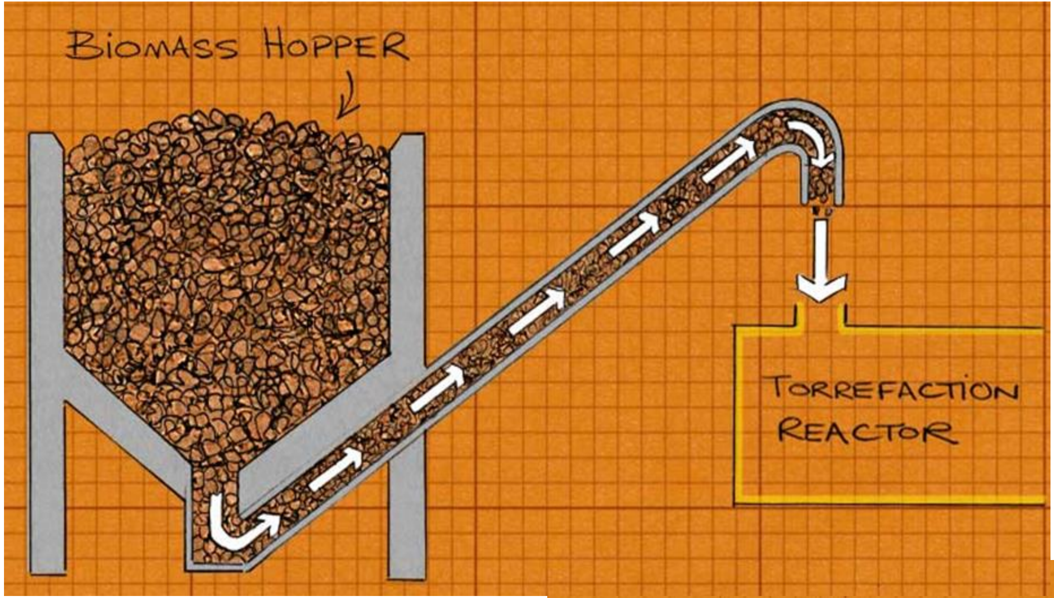
# Introduction

- *Family owned mining business based in Arigna since late 1800's*
- *First briquetting plant was built in 1937 and used a pitch binder*
- *Smokeless briquetting process using starch based binder developed in Arigna and patent granted in 1992*
- *Now Irelands largest manufacturer of coal based smokeless fuel , built up after the closure of the coal mines in 1990*
- *50 employees, €20m turnover, 20% export*
- *The Spion Kop Windfarm was commissioned in 1998 and was supported by the EU Thermie program. This wind farm is located on Corry mountain, on the Leitrim Roscommon border, on a plateau 400 m above sea level.*

# Arigna torrefaction pilot plant

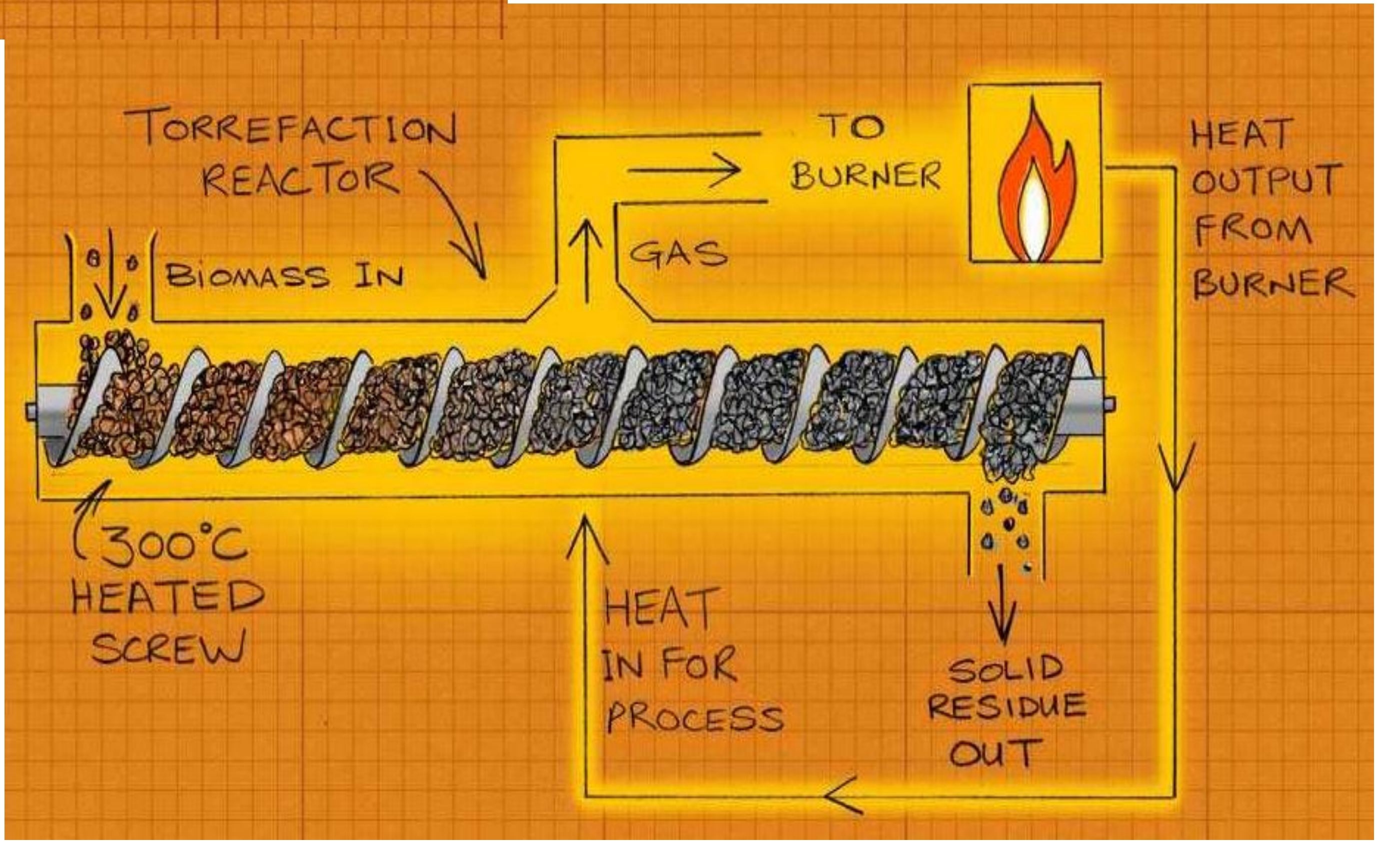
1. Capable of producing 35 - 40% of existing plant feedstock
2. Throughput 1.1 $m^3$ $h^{-1}$ (biomass input - 0.7 tph; density - 0.47 kg $L^{-1}$)
3. Carbon retention stands at 73.9%
4. Screw reactor heated by thermal oil

# Torrefaction process

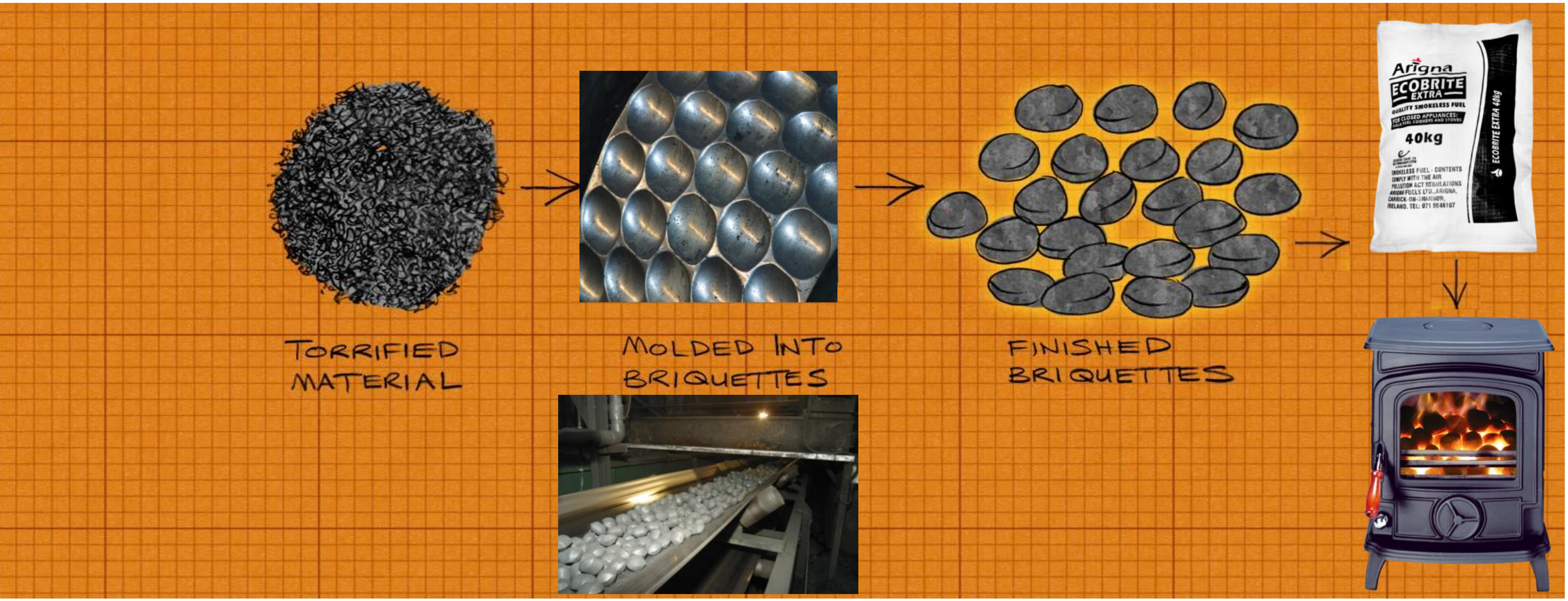



2. This in turn produces an energy rich gas which is burned to sustain the reaction with no additional heat input, known as an autothermal reaction.

1. We take raw biomass and heat it to in excess of 300 °C to dry the material, kick-starting a thermal reaction to break down the biomass structure.



# Briquetting process



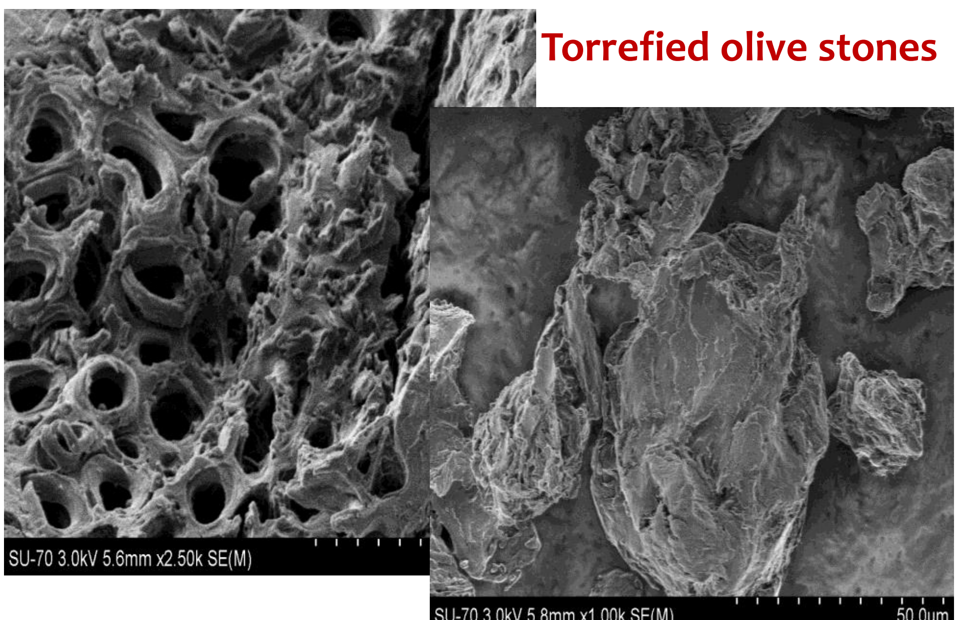

After this the torrefied product is cooled, blended with our existing products and briquetted.

# Challenges

- Formation of tar and innovative ways to use the collected tar
- Condensation of tar and formation of solid tar
- Use of local feedstocks i.e. wood, especially in a briquetting process
- Mold on the briquette surface
- Design of torrefied briquettes
- Absence of the predictive tool to show the composition and yields of torrefaction products

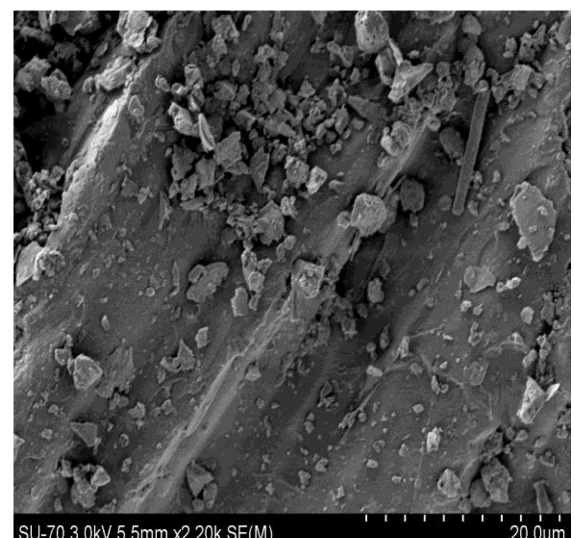
# Objectives

- Develop an innovative method for the quantitative and qualitative analysis of briquette structure
- Evaluate the value of tar by-product on the torrefaction pilot plant performance
- Establish the mass balances of torrefied biomass and establish a model
- Compare the emission factors of fossil fuels, wood, and torrefied biomass briquettes




**Torrefied olive stones**

**Anthracite coal**



# Feedstocks

Olive stones (Tunesia)

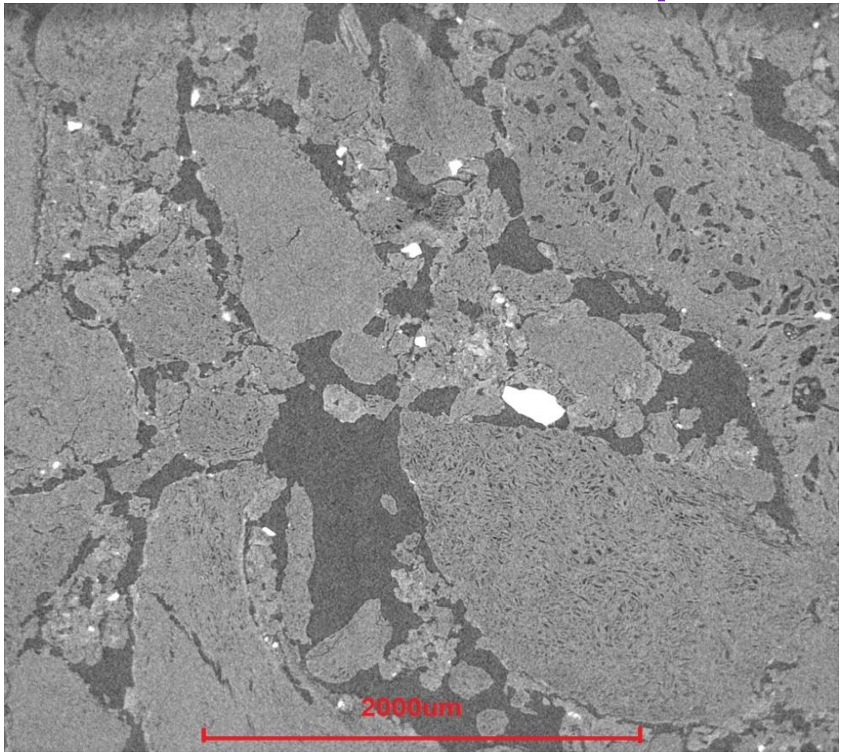


## Lignocellulosic and ash composition

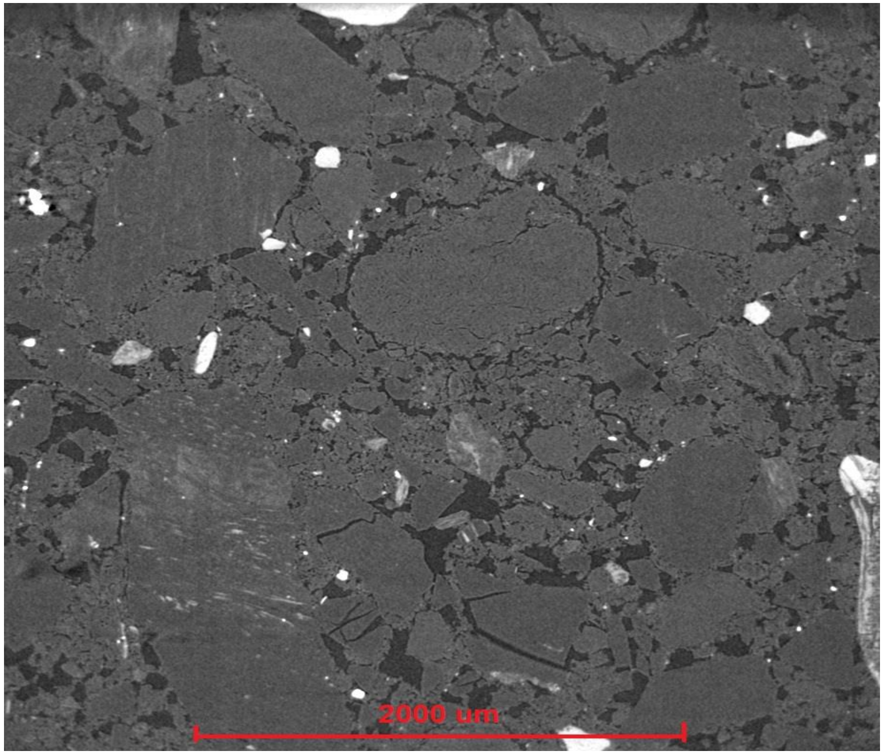
| | Olive stones | Woodchips | Anthracite |
|---|---|---|---|
| **Organic composition (wt. %, db)[1]** | | | |
| Cellulose | **25.4** | **42.6** | |
| Hemicellulose | 25.6 | 17.6 | |
| Lignin (Klason) | 30.5 | 27.3 | |
| Extractives | 4.6 | 3.8 | |
| Ash (550°C, %, db) | 0.8 | 0.5 | 9.9 |
| **Ash elemental analysis (mg $kg^{-1}$, db)** | | | |
| K | 1600 | 900 | 2000 |
| Si | **1800** | **500** | **41000** |
| Ca | 1650 | 1300 | 3500 |
| Na | 300 | 100 | 2000 |

# Analysis with X-ray microtomography

**Torrefied olive stone briquette**



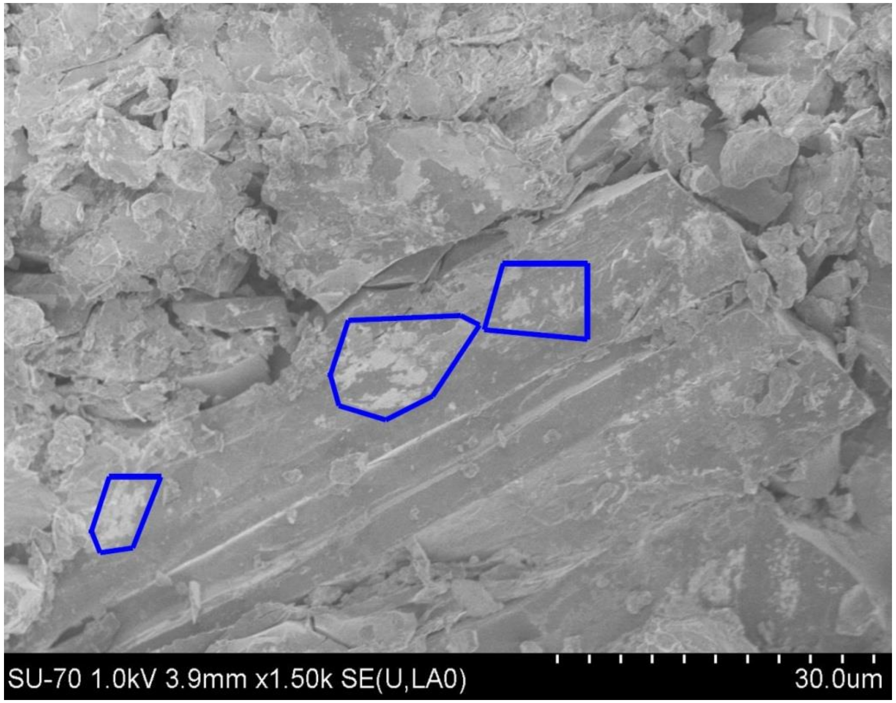

**Eco Coal briquette**



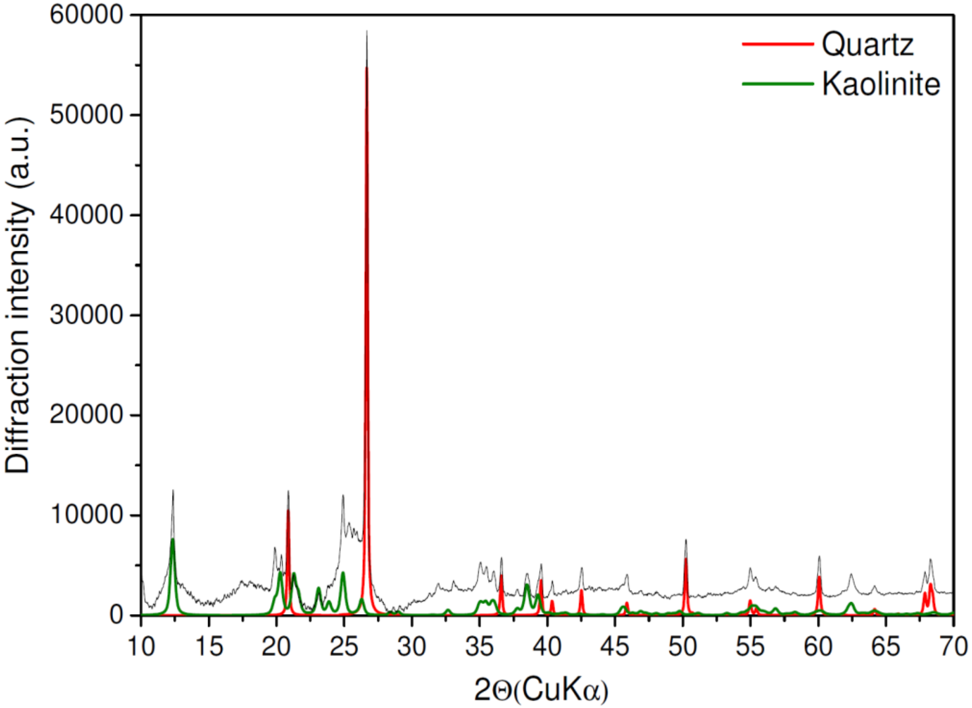

| Volume fractions of briquette phases | | | |
|---|---|---|---|
| XμCT | Feedstock | Binder | Inorganics |
| Olive stone briquette | 80.5 | 19 | 0.5 |
| Coal briquette (starch) | 91.6 | 7 | 1.5 |
| Coal briquette (resin) | 84.7 | 13.3 | 2 |

# Characterization of inorganics

## SEM-EDS of Eco Coal briquette



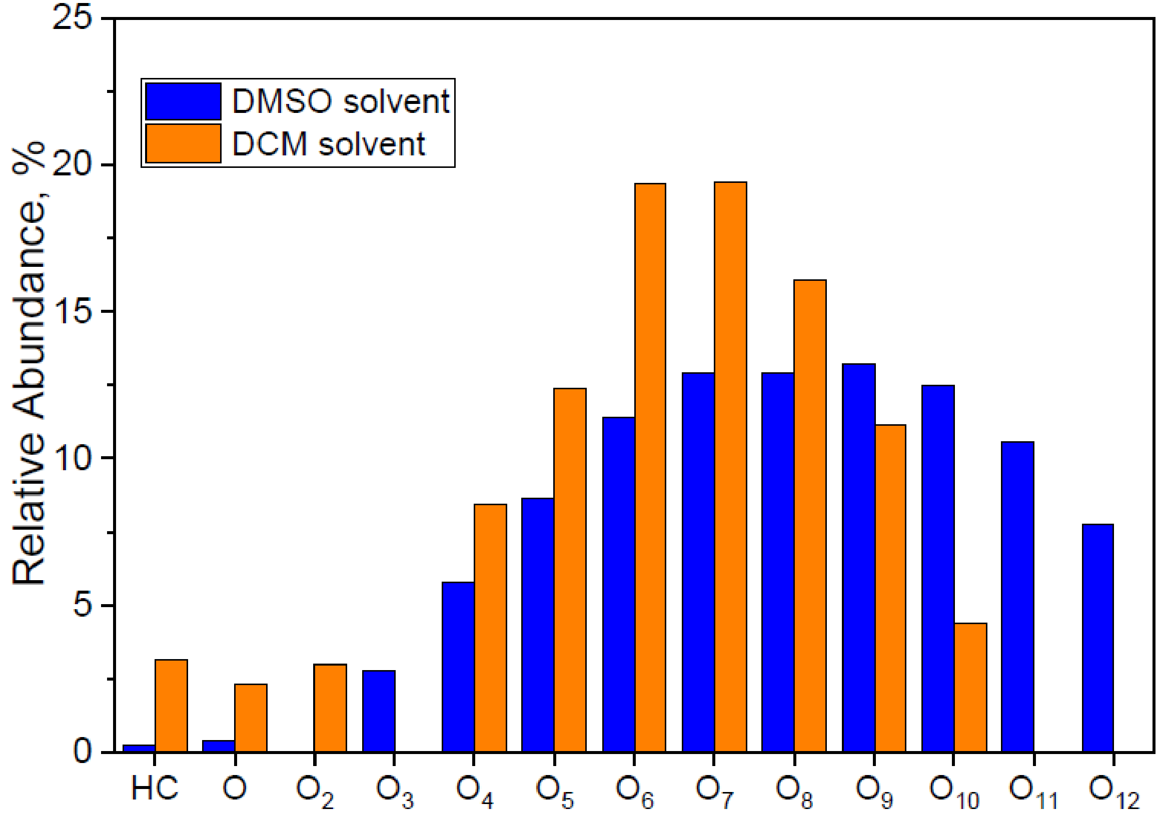

## X-ray diffraction of Eco Coal briquette




- The XRD results showed that torrefied olive stones and anthracite exhibit reflections from crystalline silicon oxides, retaining in particles from the original feedstock
- Olive stones and torrefied olive stones contain a few reflections from crystalline whewellite, whereas anthracite contains sharp and narrow reflections from kaolinite.

# Physicochemical characterization of tar

## High Resolution Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR MS)

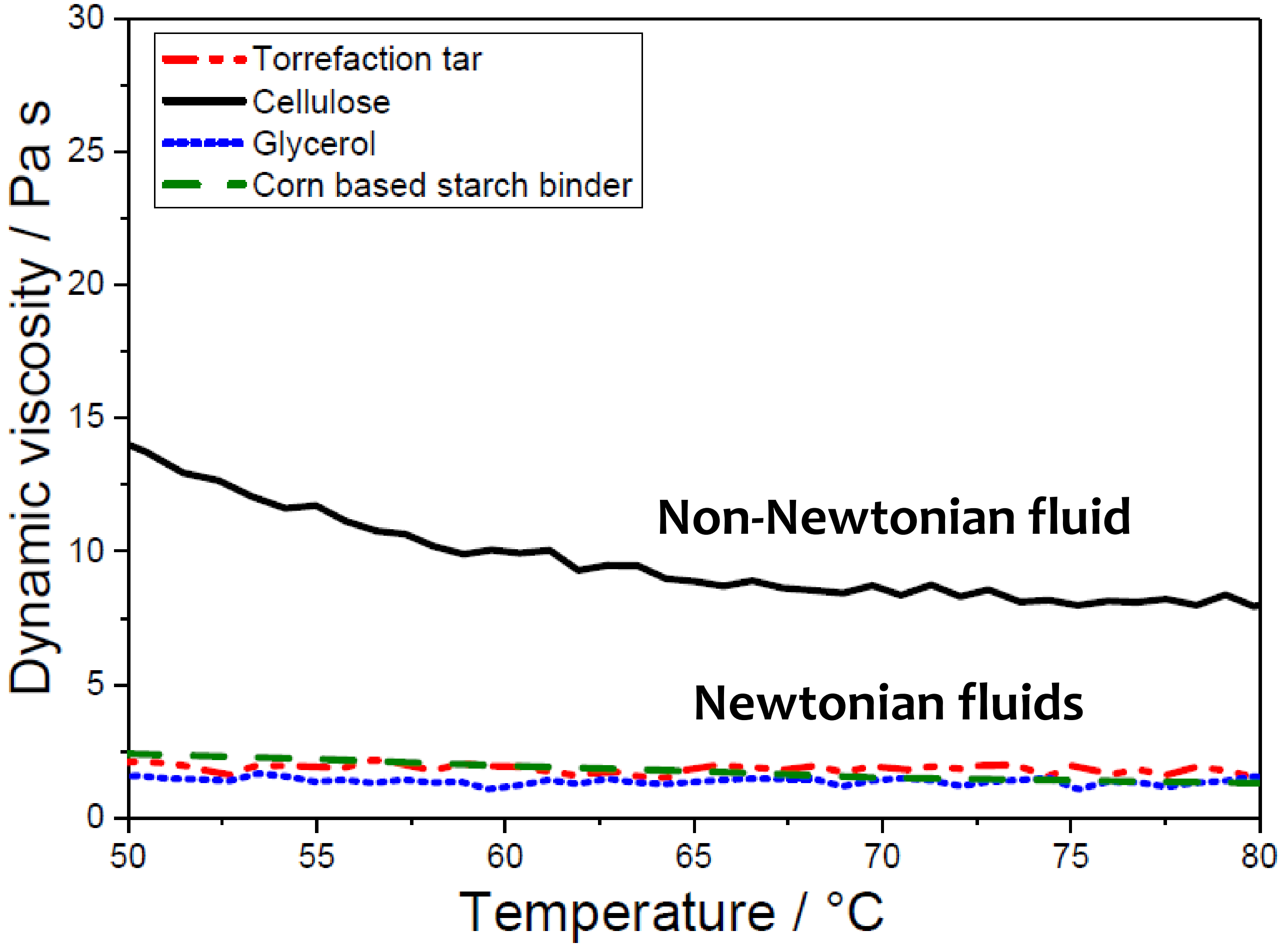



## Size exclusion chromatography (SEC) using THF as a solvent

| Molecular weight, kDa | 6.0 | 19.7 | 26.1 | 96.3 |
|---|---|---|---|---|
| Concentration, mg $ml^{-1}$ | 0.2 | 0.04 | 0.08 | 0.09 |

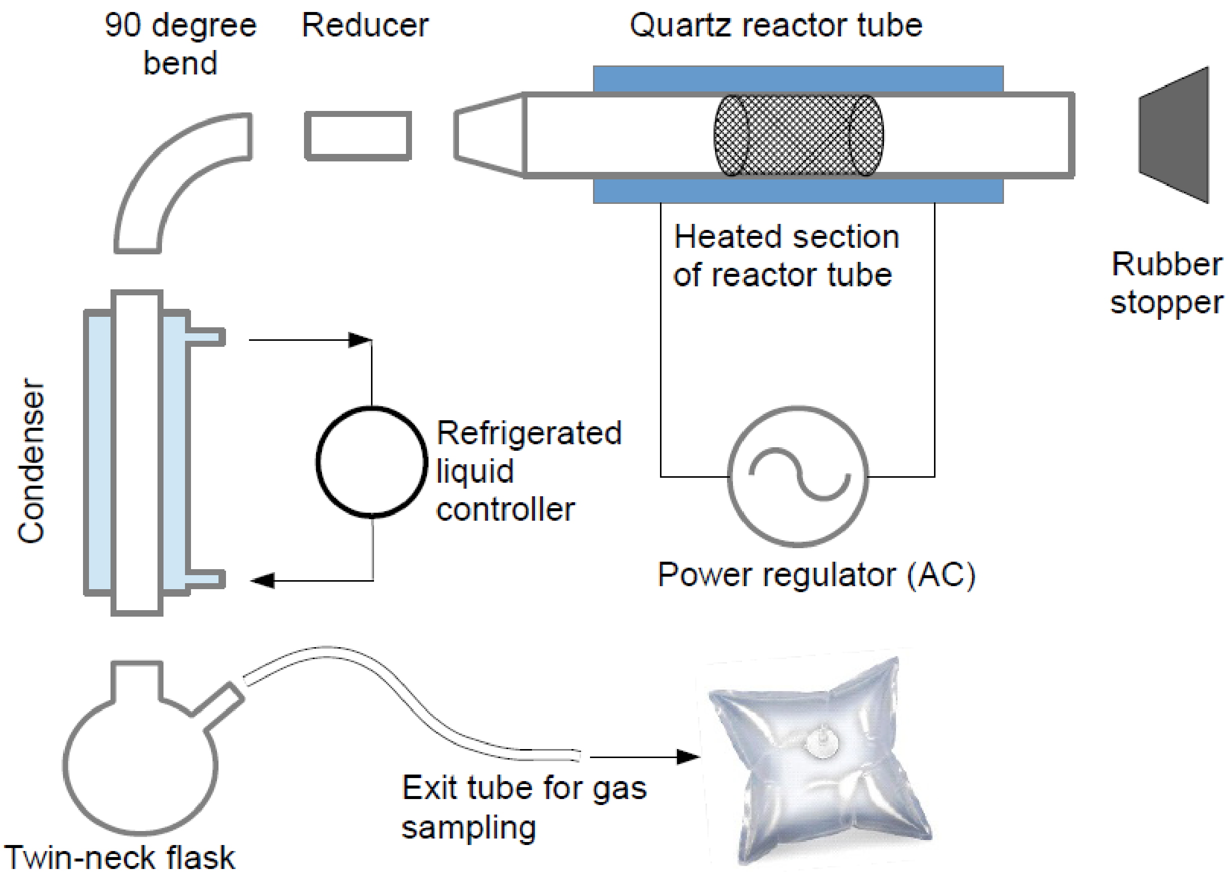
# Physicochemical characterization of tar

## Tar rheology




- Tar samples from 270-300°C behave like Newtonian fluids
- Calorific heating value of the torrefaction tar ≈ **26 MJ kg$^{-1}$**

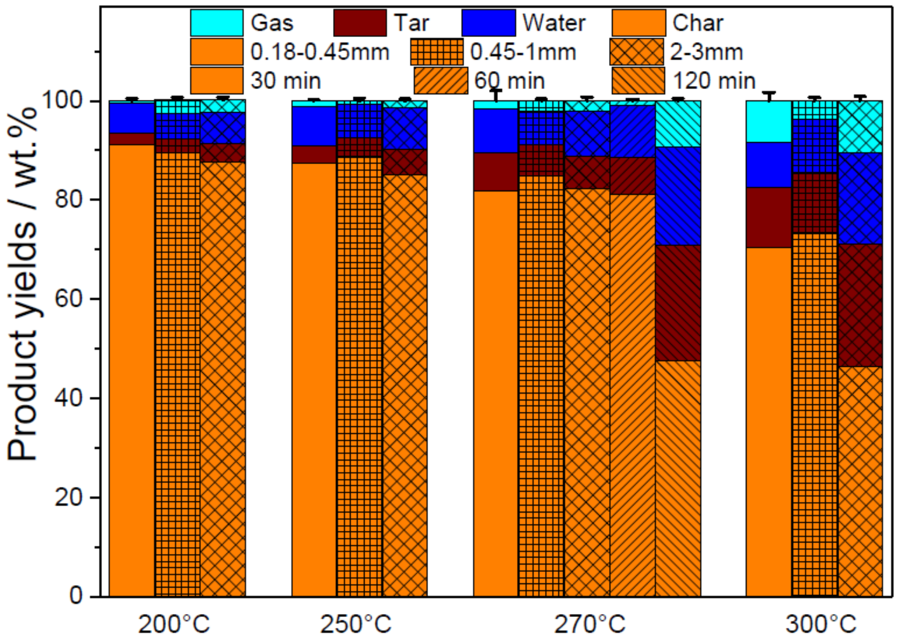
# Lab-scale slow heating rate reactor



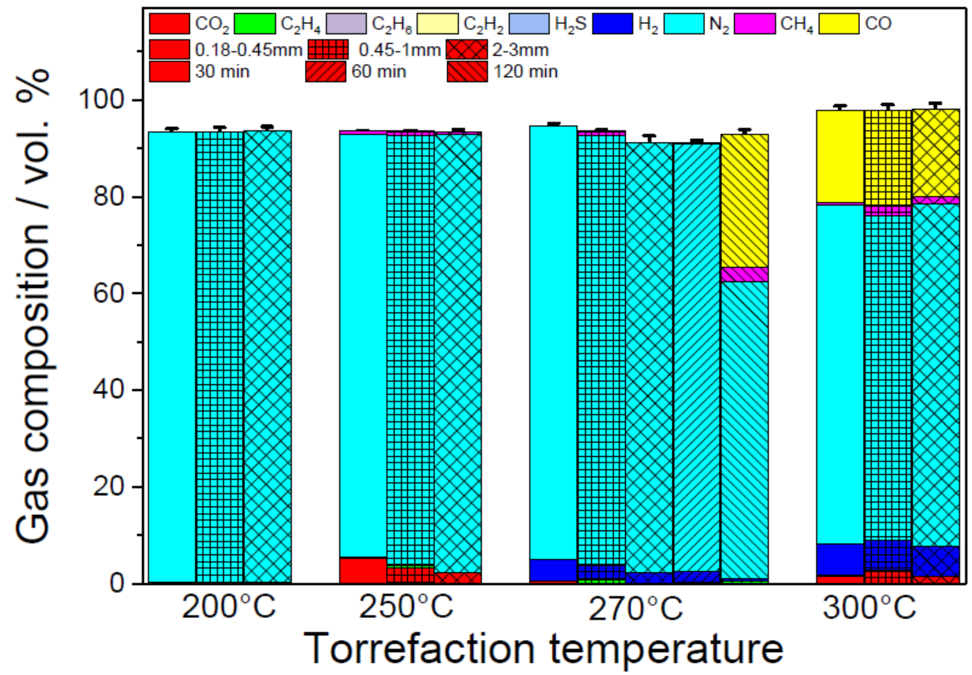

- Temperature range 30-900°C
- Heating rate 5-20 °C min$^{-1}$
- Particle size 0.08-3 mm (316L mesh)

# Lab scale pyrolysis experiments

**Product yields**



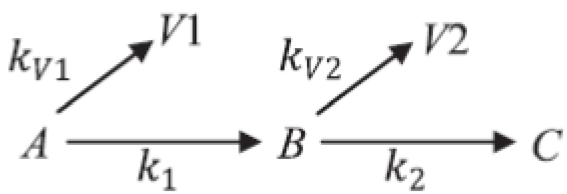

**Gas composition**




- The olive stones of larger particle size produced more liquid and gaseous products than smaller particles in a fixed bed reactor
- Particle size had significantly less influence on the product yields than residence time and heat treatment temperature
- CO and $H_2$ gas yields significantly increased in the temperature range 270 to 300°C

# Modeling (work in progress with MIT group of Prof. A. Ghoniem)

**Kinetic submodel (modified version of Ranzi model, Ghoniem et al. 2010, 2014,2017)**




**Conservation of species/mass**

$$\frac{d\rho_A}{dt} = -(k_1 + k_{V1}) \cdot \rho_A$$

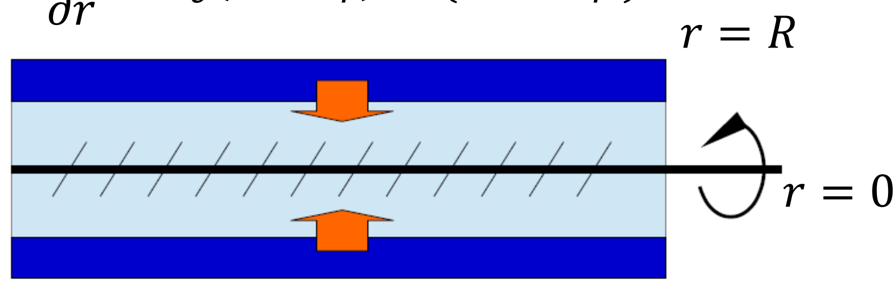
$$\frac{d\rho_B}{dt} = k_1\rho_A - (k_2 + k_{V2}) \cdot \rho_B$$

$$\frac{d\rho_C}{dt} = k_2\rho_B$$

$$\frac{d\rho_{MC}}{dt} = k_d\rho_{moisture}, \qquad if\ T > T_{vaporization}$$

**Multiphysics including a mixing effect**

$$k\frac{\partial T}{\partial r} = h_c(T - T_r) + (T^4 - T_r^4)$$

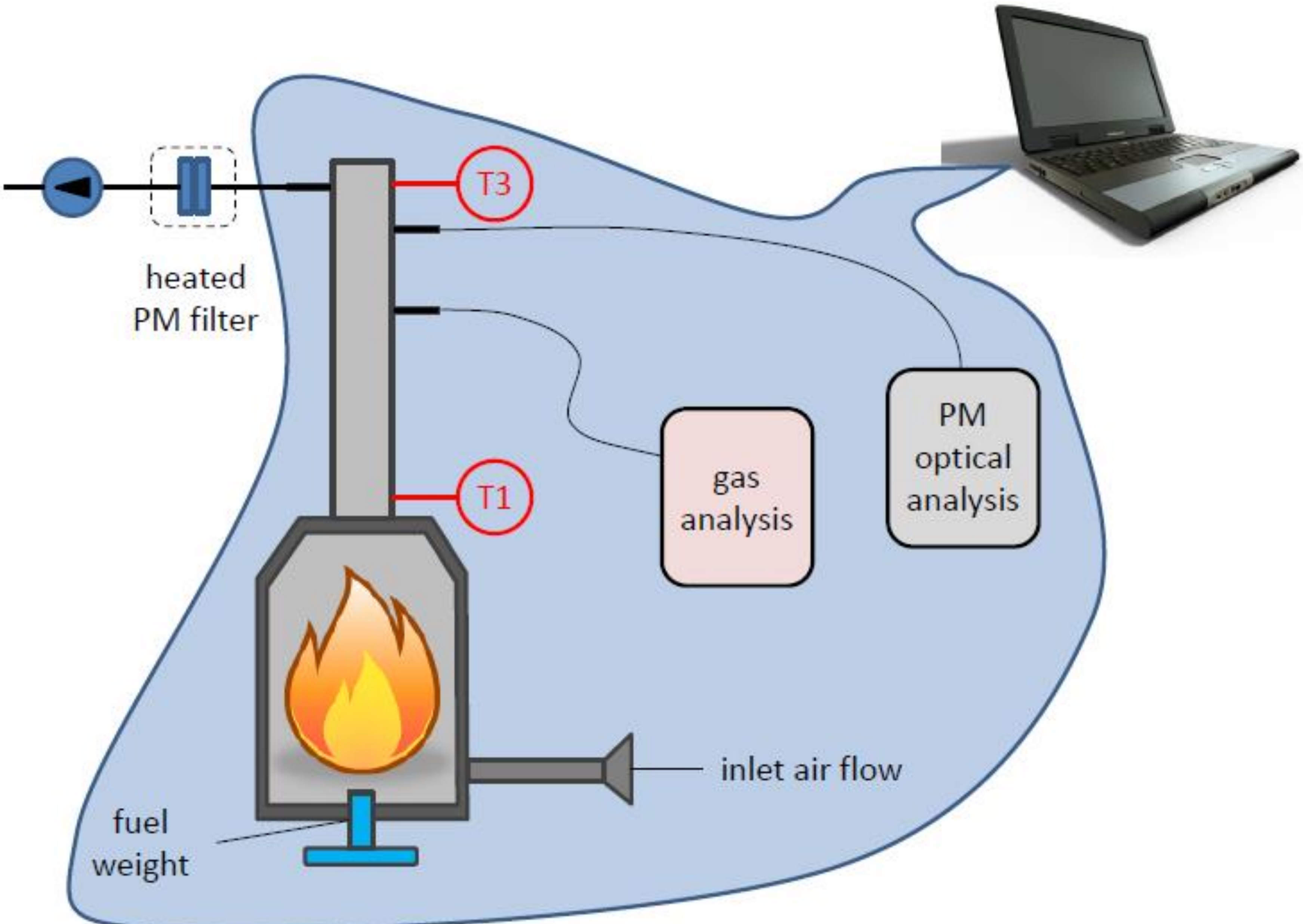



$$\frac{\partial T}{\partial r} = 0$$

$T(r,t)$= Particle temperature (K)
$T_r$(t) = Reactor temperature (K)

**No ash effect on the product yield and composition**

# Experimental setup at University College Dublin

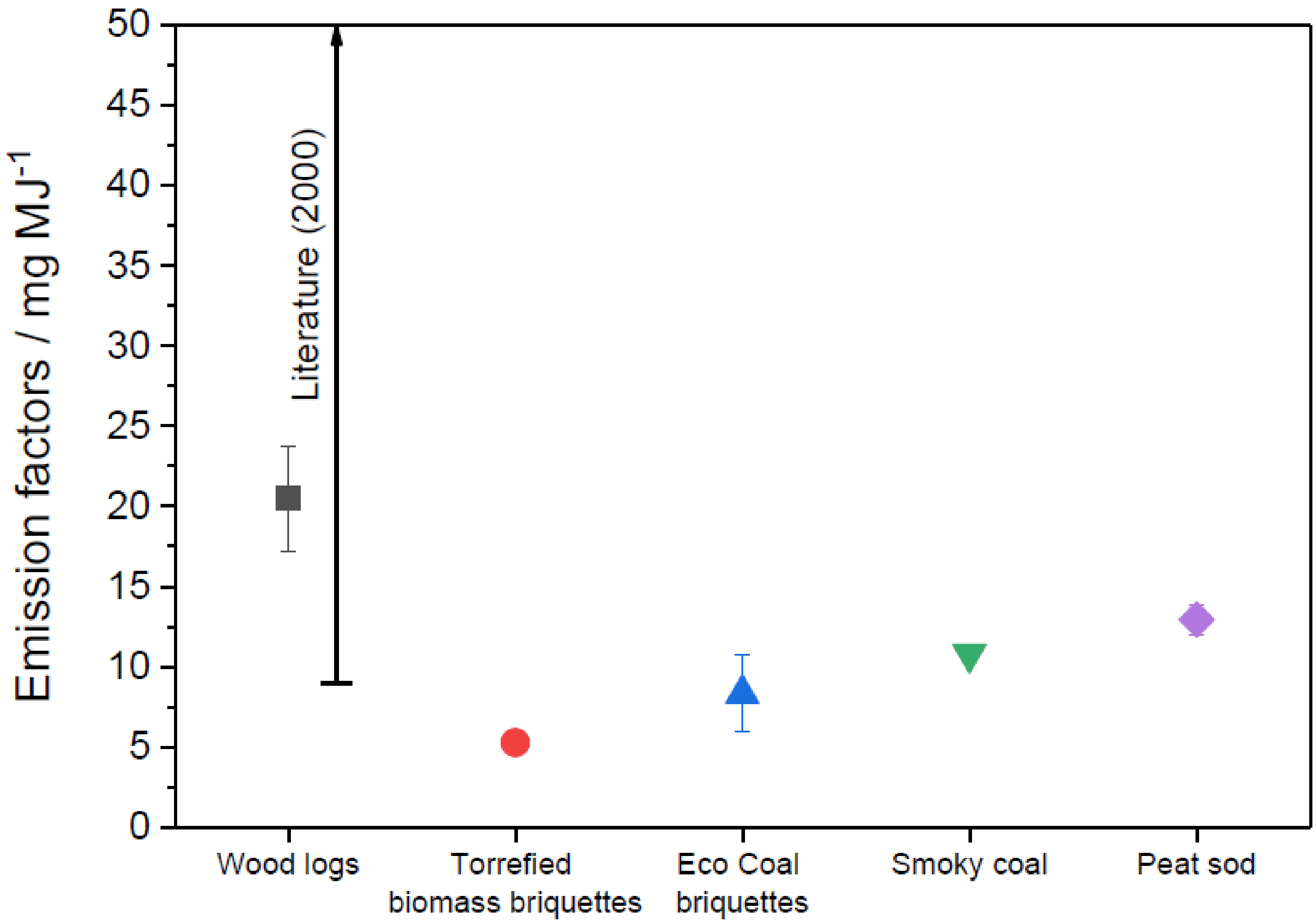


# Measurement apparatus

| PM and other parameter measurements | Gas analysis |
|---|---|
| PM mass:<br>- Gravimetric filter, 100°C, 0.2 µm PTFE, isokinetic flow<br><br>Tar content:<br>- Impinger bottles with methanol (cooled to -25°C)<br>- GC-FID and GC-MS<br><br>LabView:<br>- Mass loss<br>- Inlet air flow rate<br>- Stove pressure<br>- Flue Temperature | TESTO 350 XL<br><br>$O_2$<br><br>$CO_2$<br><br>CO<br><br>$NO_x$<br><br>$SO_2$ |

- 3.5 kg feedstock + 0.1 kg firelighter
- 12 Pa pressure drop across stove
- No refuelling, Test 4-6 hours, 3-8 Tests/feedstock
- All data (except filter) was sampled every 10 s

# PM emission factors




- PM EF for wood logs is significantly higher than for other feedstocks
- PM EF for all feedstocks are lower than EF values reported in the literature, but in line with the previous UCD study.

# Conclusion

- ❖ The XμCT analysis showed that the briquette structure contains carbon, binder and inorganic matter that mainly consists of quartz
- ❖ Importantly from a technological standpoint, the torrefaction tar can be used as a binder in olive stone briquettes
- ❖ Longer residence times led to the generation of more liquid products
- ❖ Smokeless torrefied biomass briquettes generated less PM emissions than other feedstocks
- ❖ Future plan is to extend our model with the data from the pilot plant and add a mixing effect on the product yields and composition

MaREI
Centre for Marine and Renewable Energy

Arigna Fuels

UCD DUBLIN

# Thank you!

testo

BRISK2
BIOFUELS RESEARCH INFRASTRUCTURE

Science Foundation Ireland sfi For what's next

OÉ Gaillimh
NUI Galway