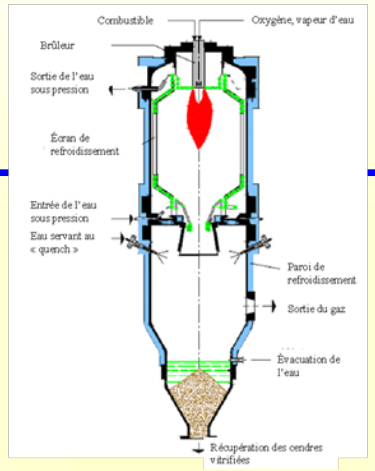
Torrefaction of biomass:
influence of operating conditions on products

Jean-Michel COMMANDRE

P. ROUSSET, G. LESUEUR, A. LEBOEUF, L. CHAFCHAOUNI

Context

Thermo-chemical conversion of biomass in entrained flow reactor (EFR)



Syngas (CO, H_2)
H_2

EFR

- High temperature (1400°C) → -High quality syngas
  -Small amounts of residual hydrocarbons and solid carbon
- Short residence time (≈ s) → Biomass must be ground finely (≈ 100µm) before injection

Grinding consumes large amounts of energy

Torrefaction: biomass pretreatment used to reduce mechanical properties

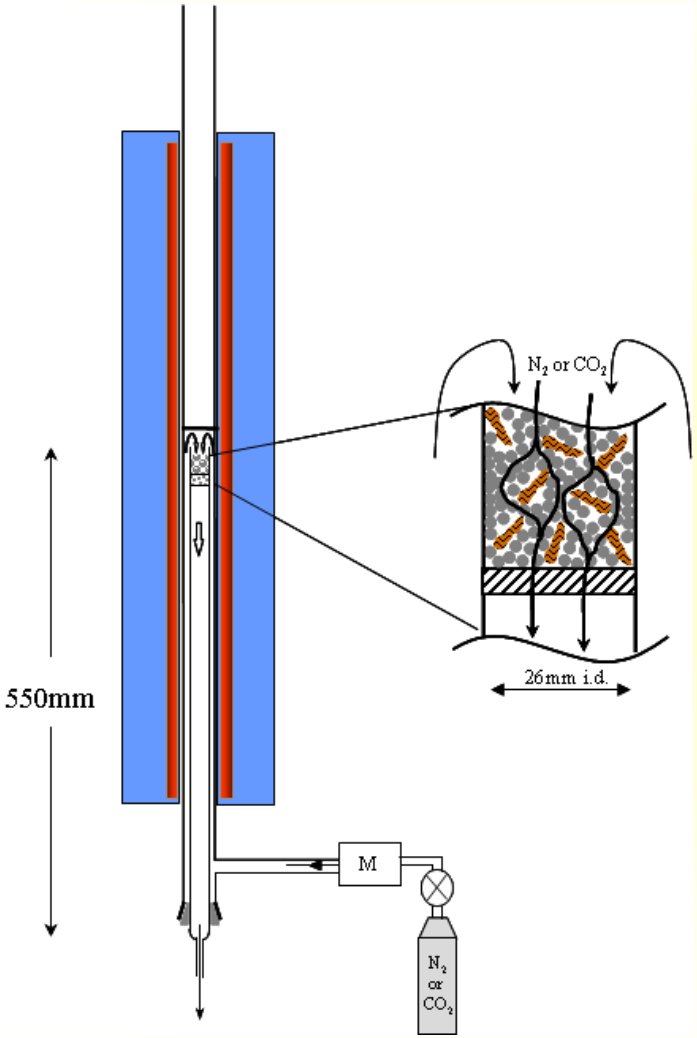
Objectives:

Characterisation of biomass torrefaction products,

from biomass analysis to precise mass balances,

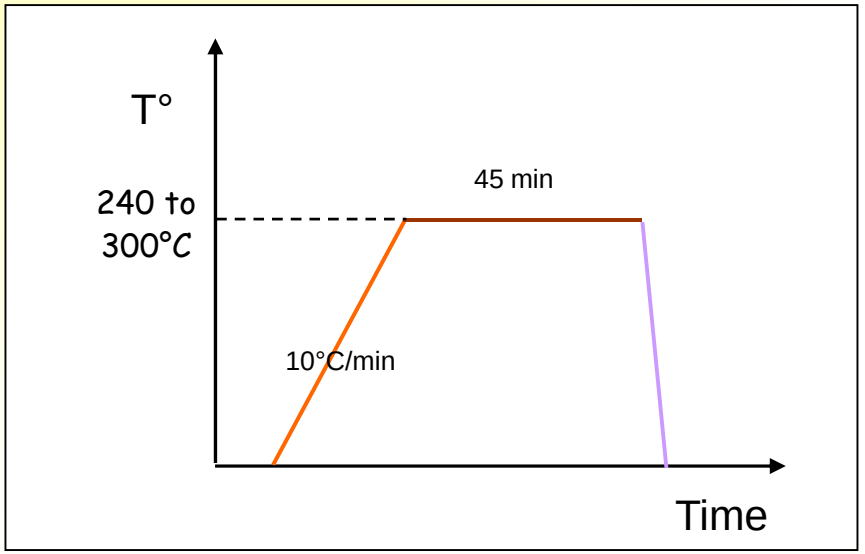
by the way of a complete quantification of the products released

Torrefaction at laboratory scale: Crossed fixed bed reactor



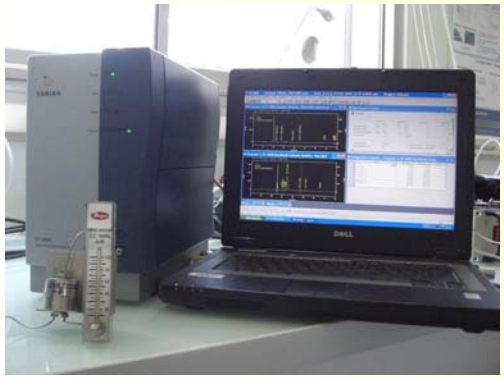
- control of gas and wood temperature
- control of gas nature and flow rate
- gas flow rate sufficiently high to avoid heterogeneous reactions
- wood particles mixed with glass balls to ensure:
  - good contact between gas and wood particles
  - homogeneous gas flow inside the bed

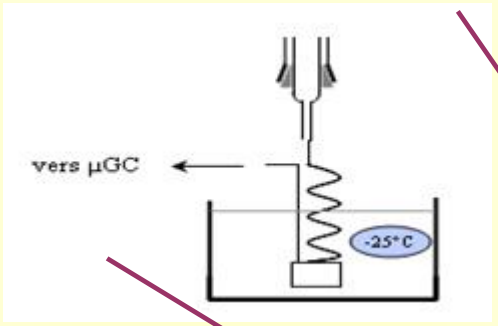
Operating conditions

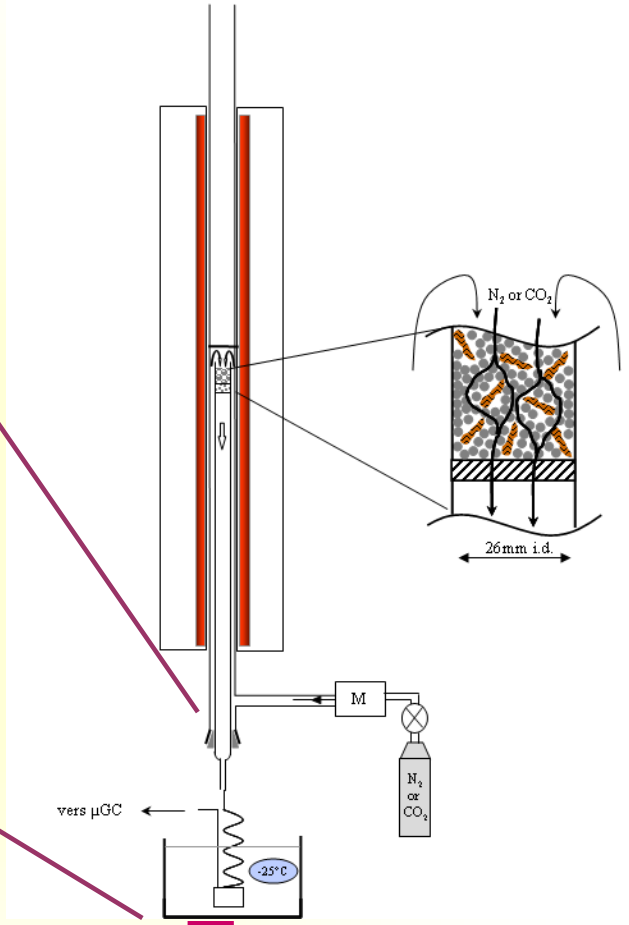


Analytical devices

µGC





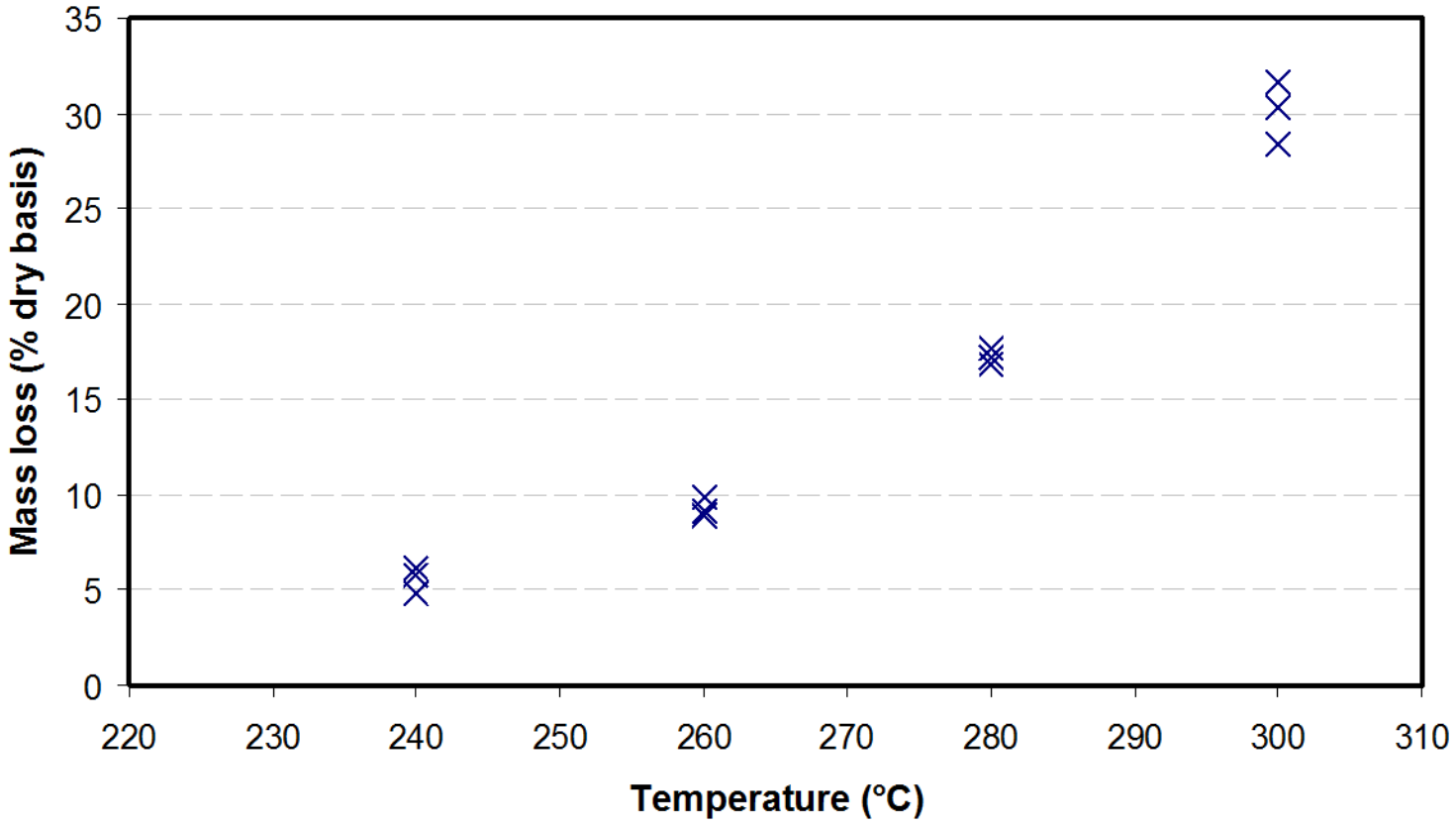


Karl-Fischer

GC-MS

Influence of torrefaction temperature

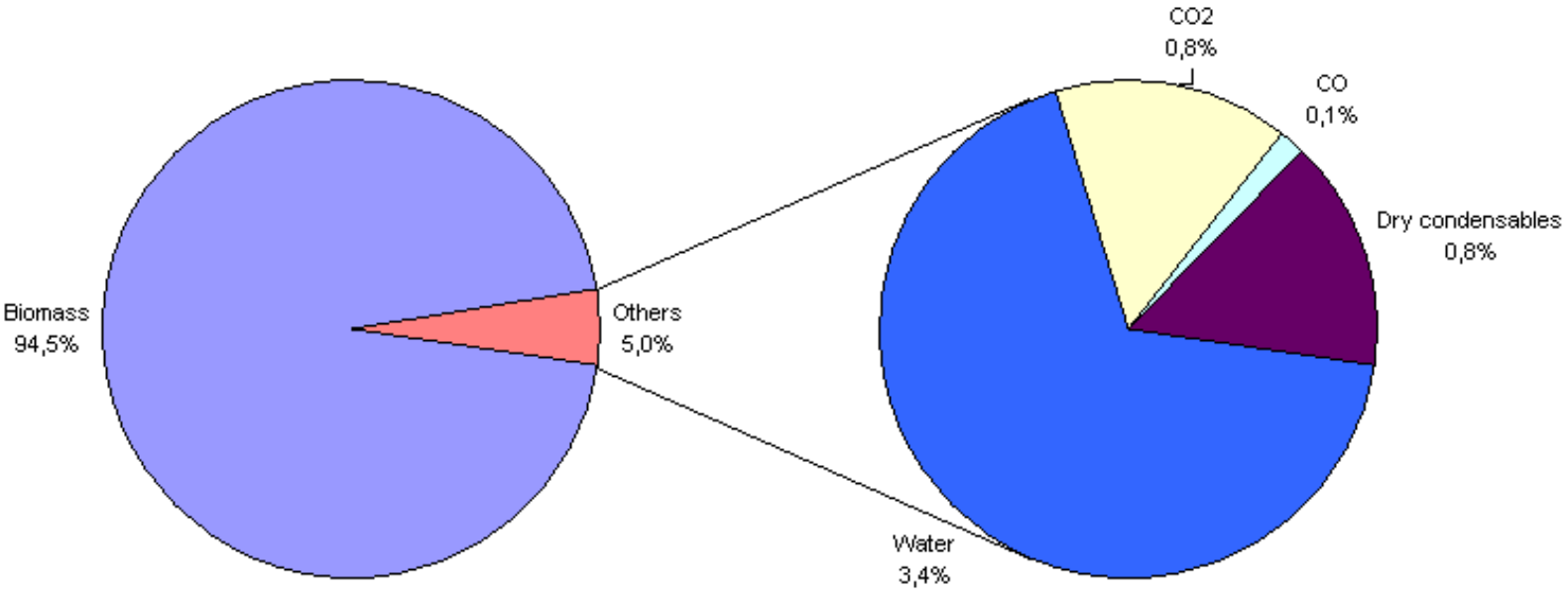
Pine wood



- Good reproducibility
- Increase of mass loss with temperature

Global mass balance

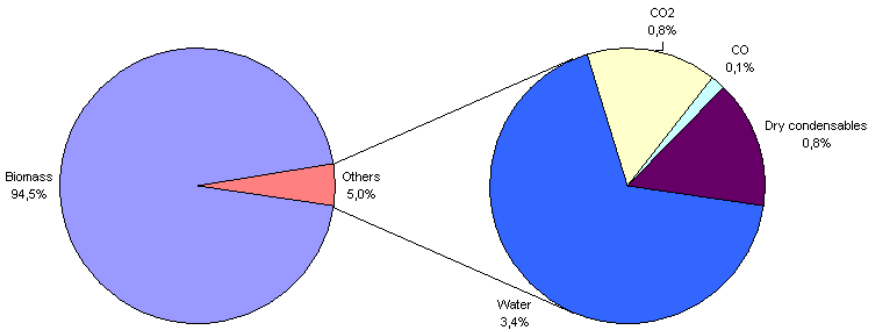
240°C



Mass balance = 99,4%

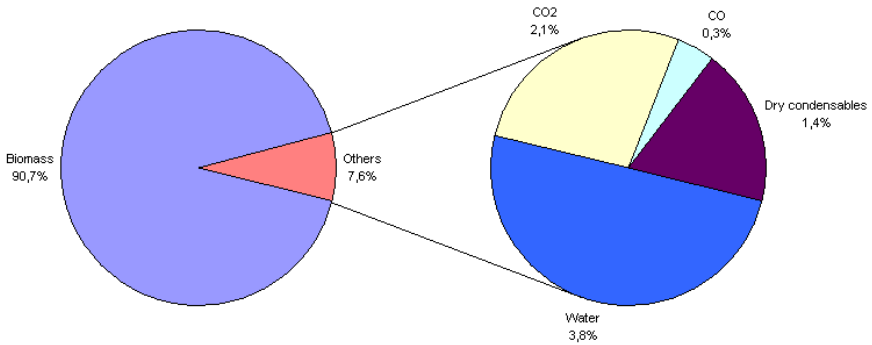
Global mass balance

240°C



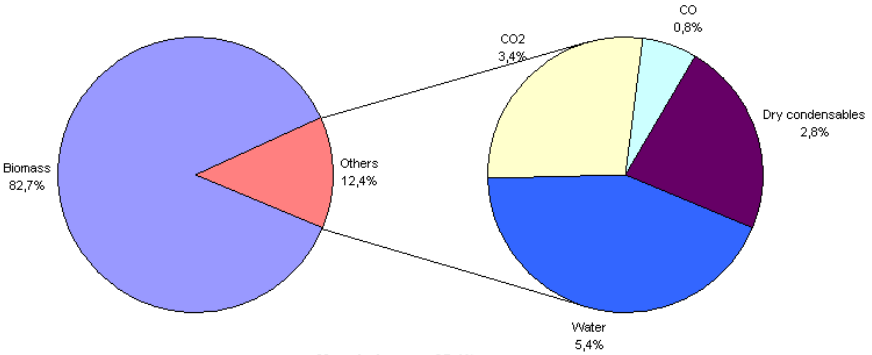
Mass balance = 99,4%

260°C



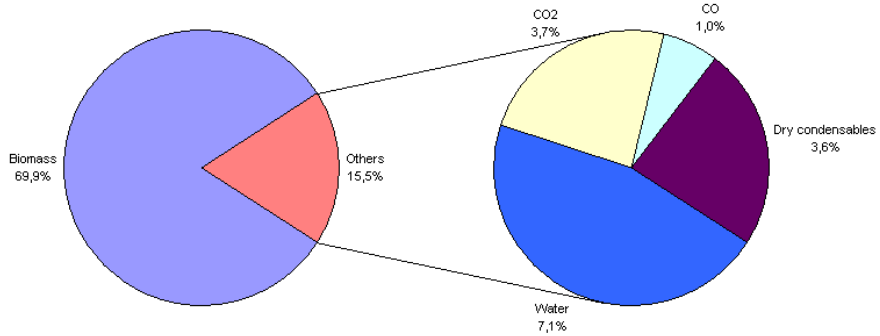
Mass balance = 98,3%

280°C



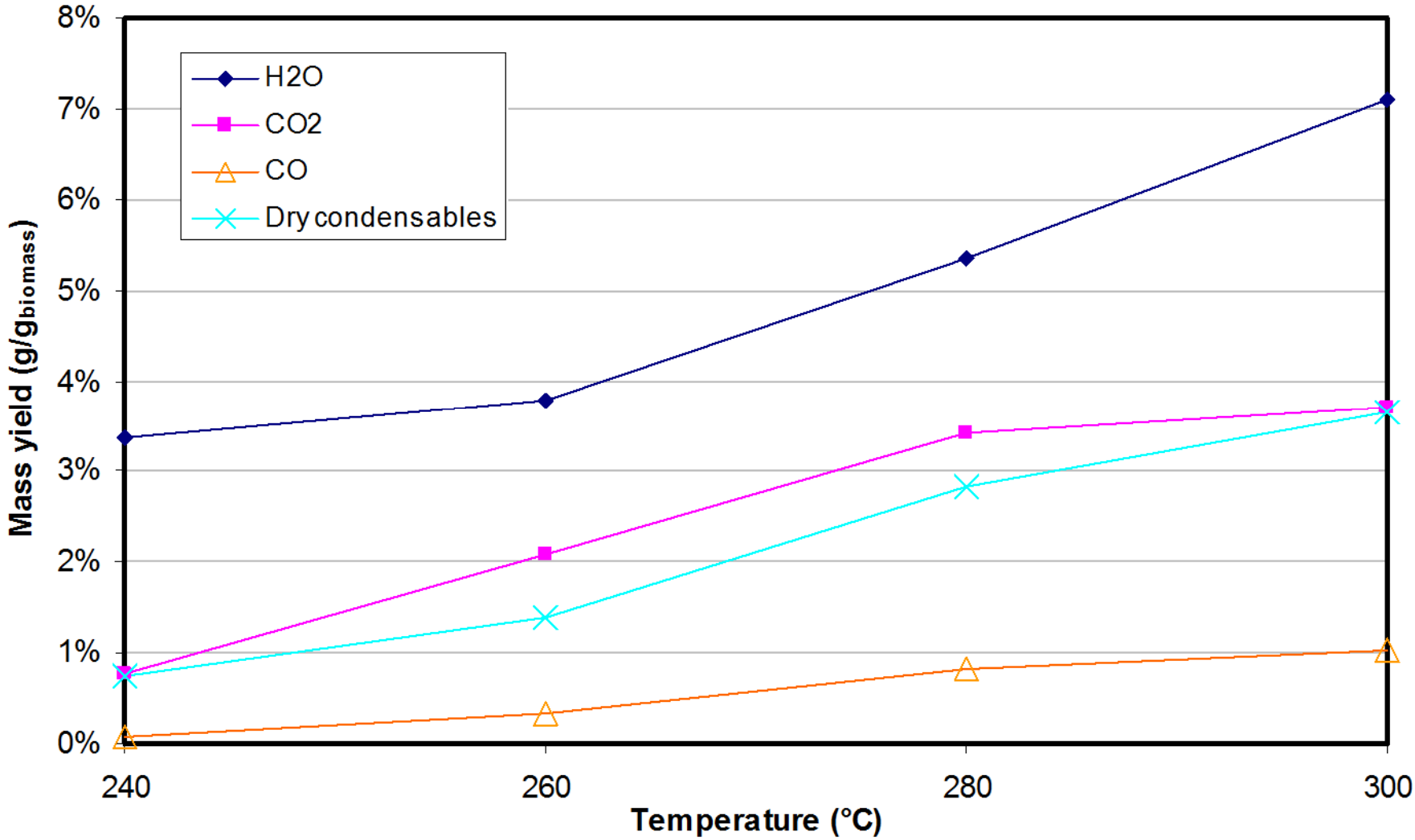
Mass balance = 95,1%

300°C



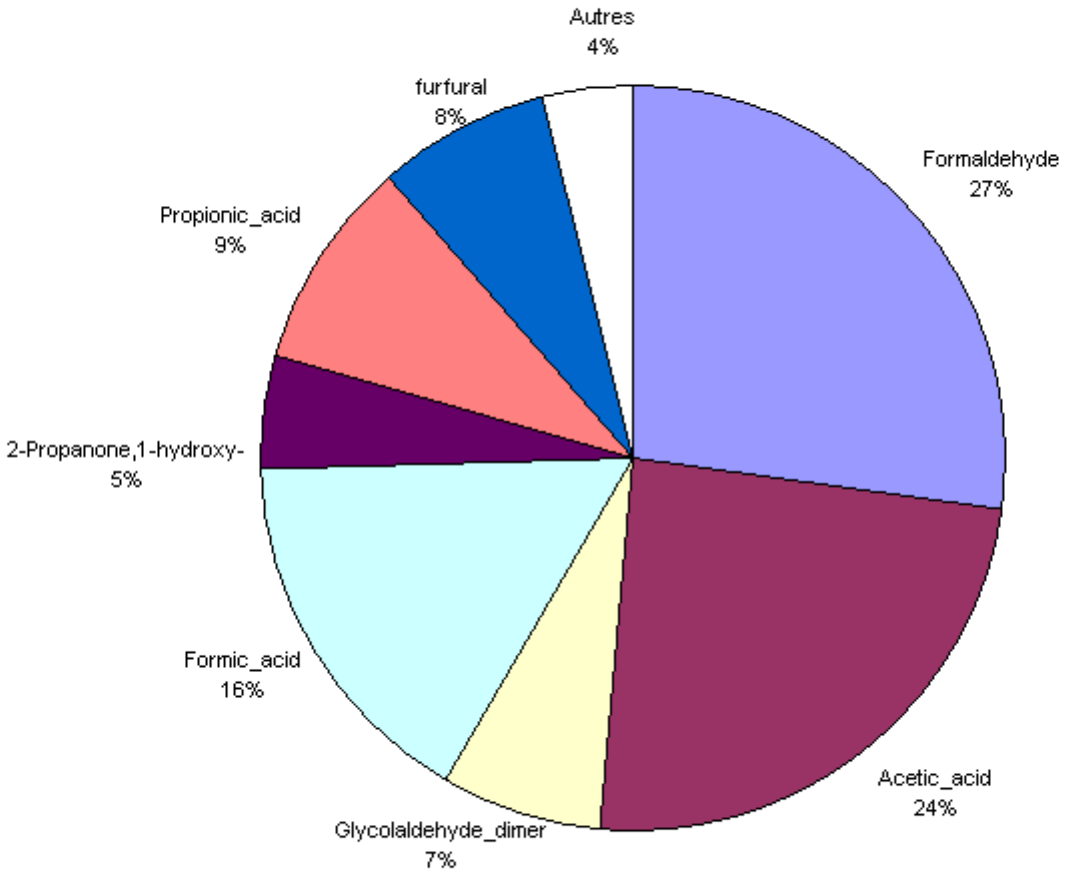
Mass balance = 85,4%

Global mass balance



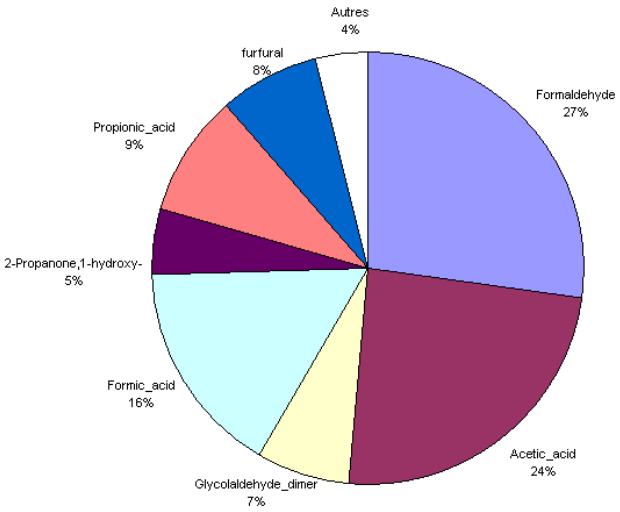
Detailed mass balance

240°C

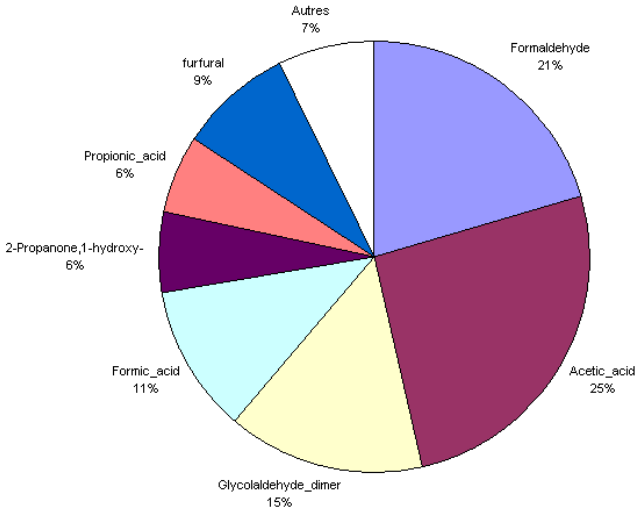


Detailed mass balance

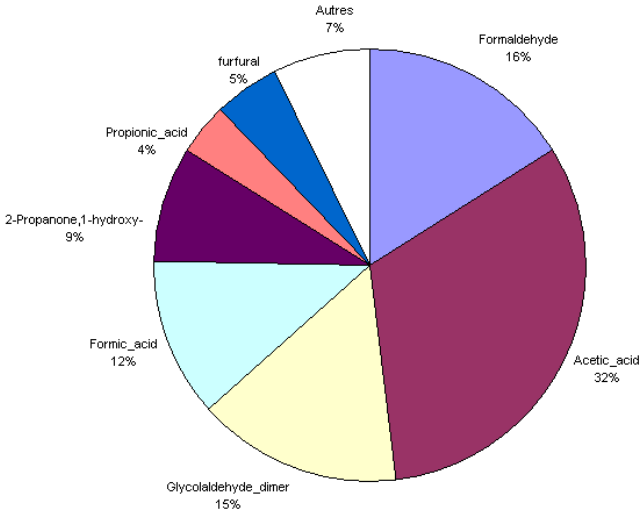
240°C



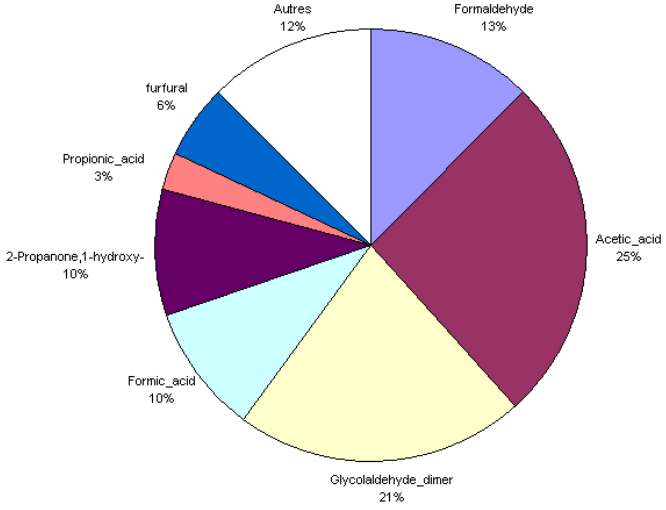
260°C



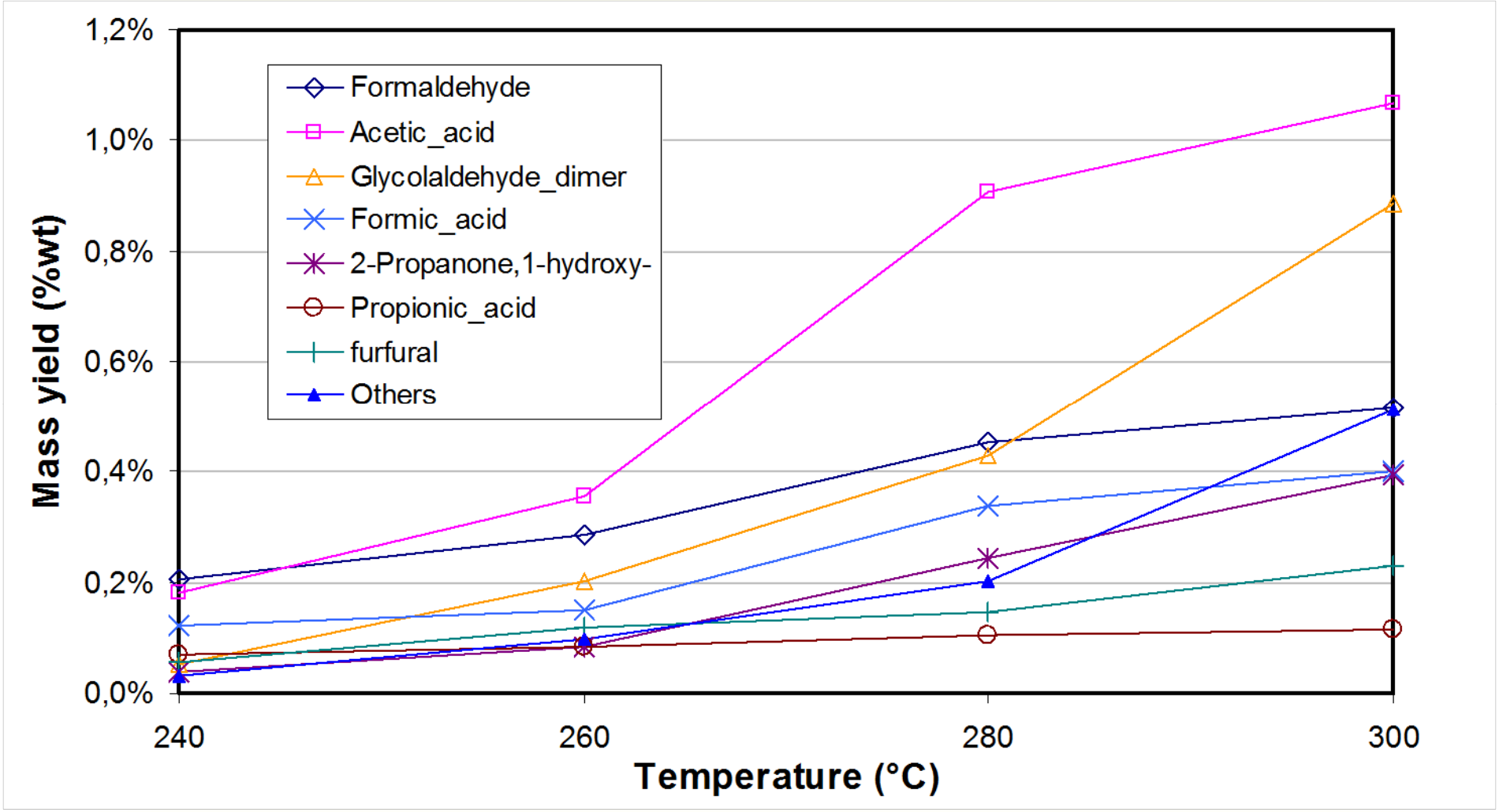
280°C



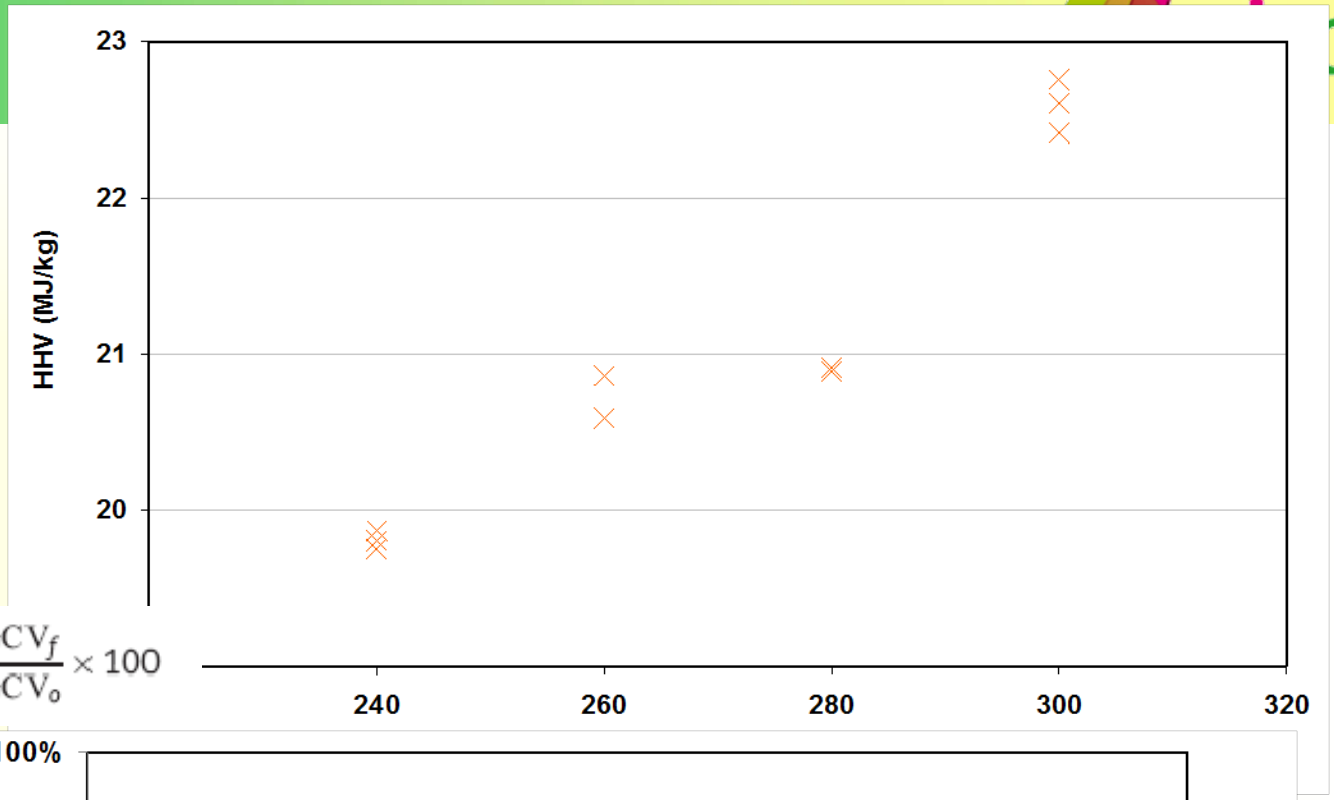
300°C



Detailed mass balance

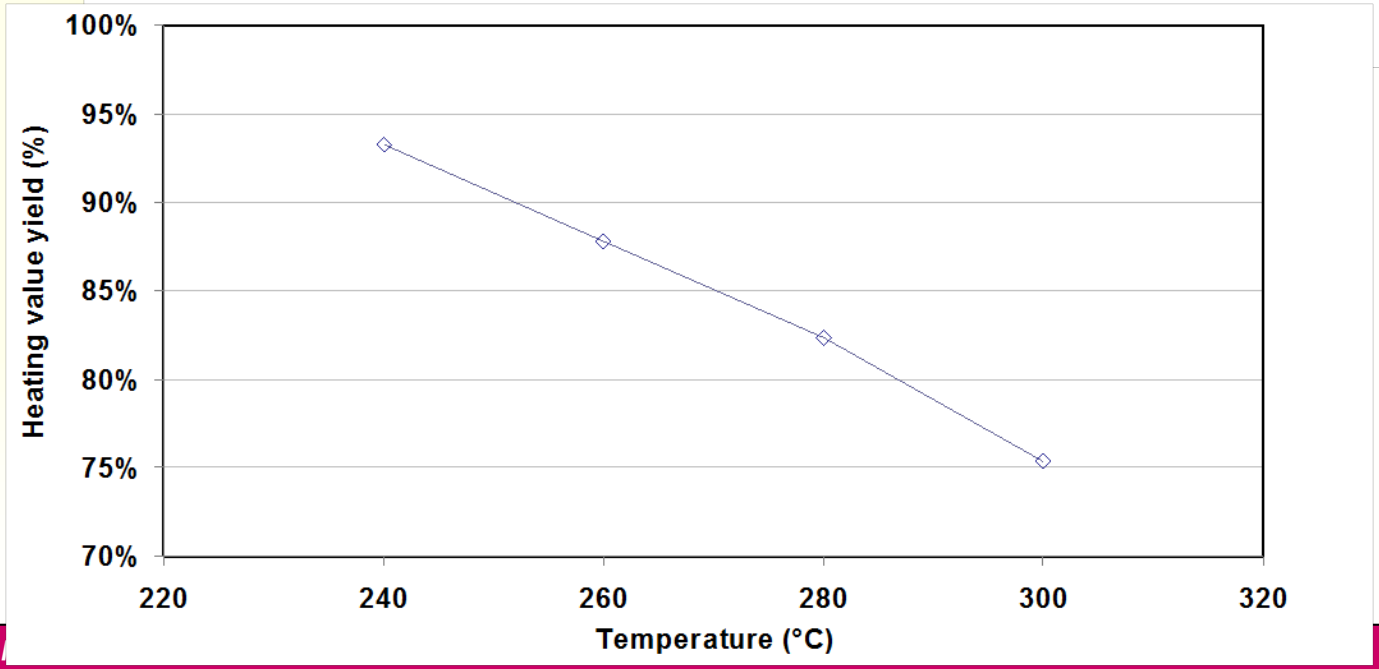


Heating value



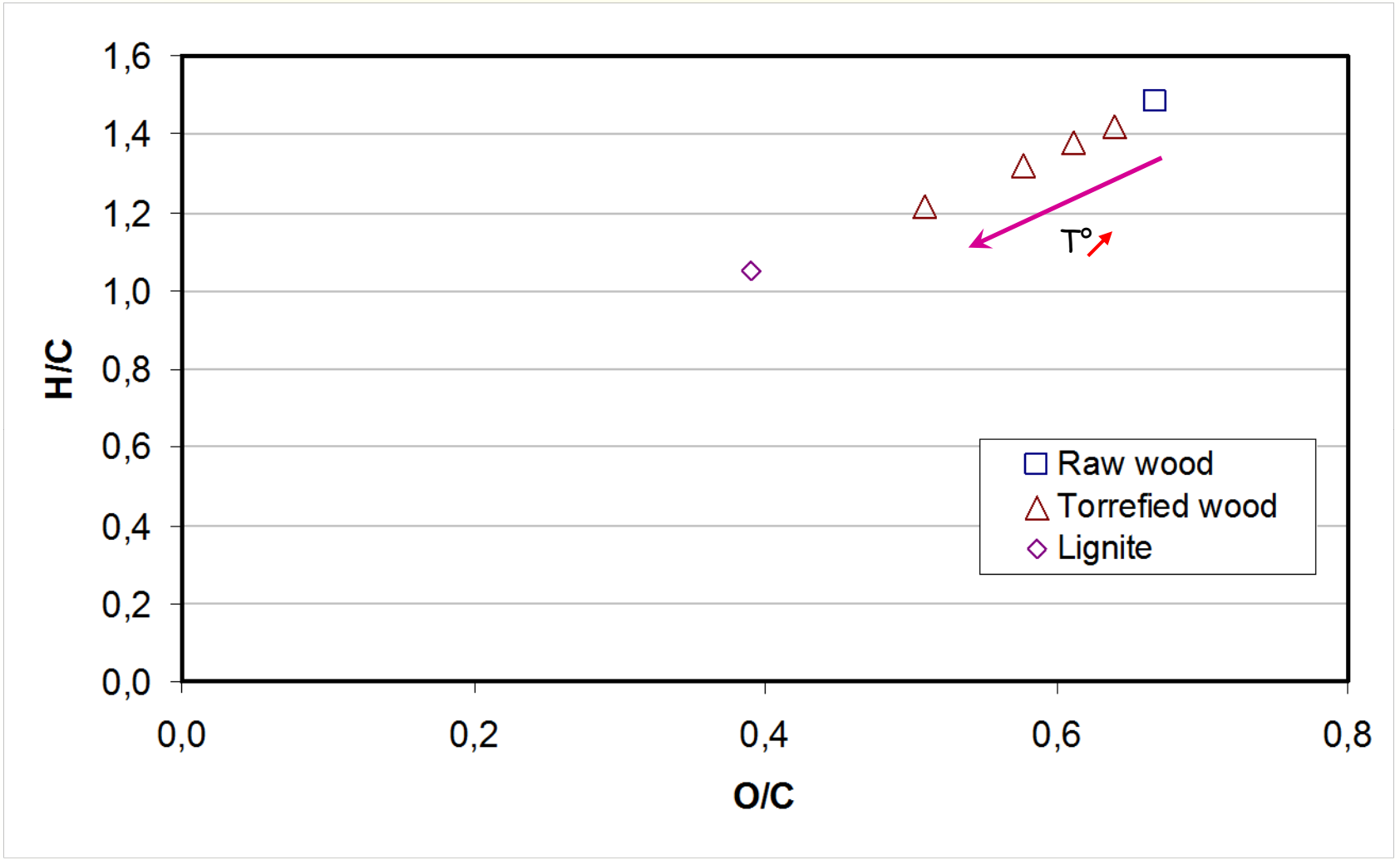
$$\text{Heating value yield}(\%) = \frac{M_f}{M_o}\frac{GCV_f}{GCV_o} \times 100$$

(Arias, 2008)

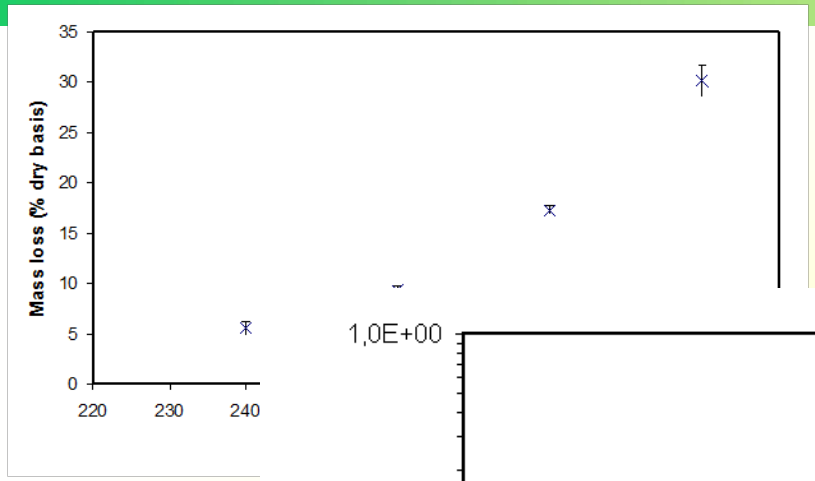


Ultimate analysis

Van Krevelen diagram



Torrefaction at high heating rate

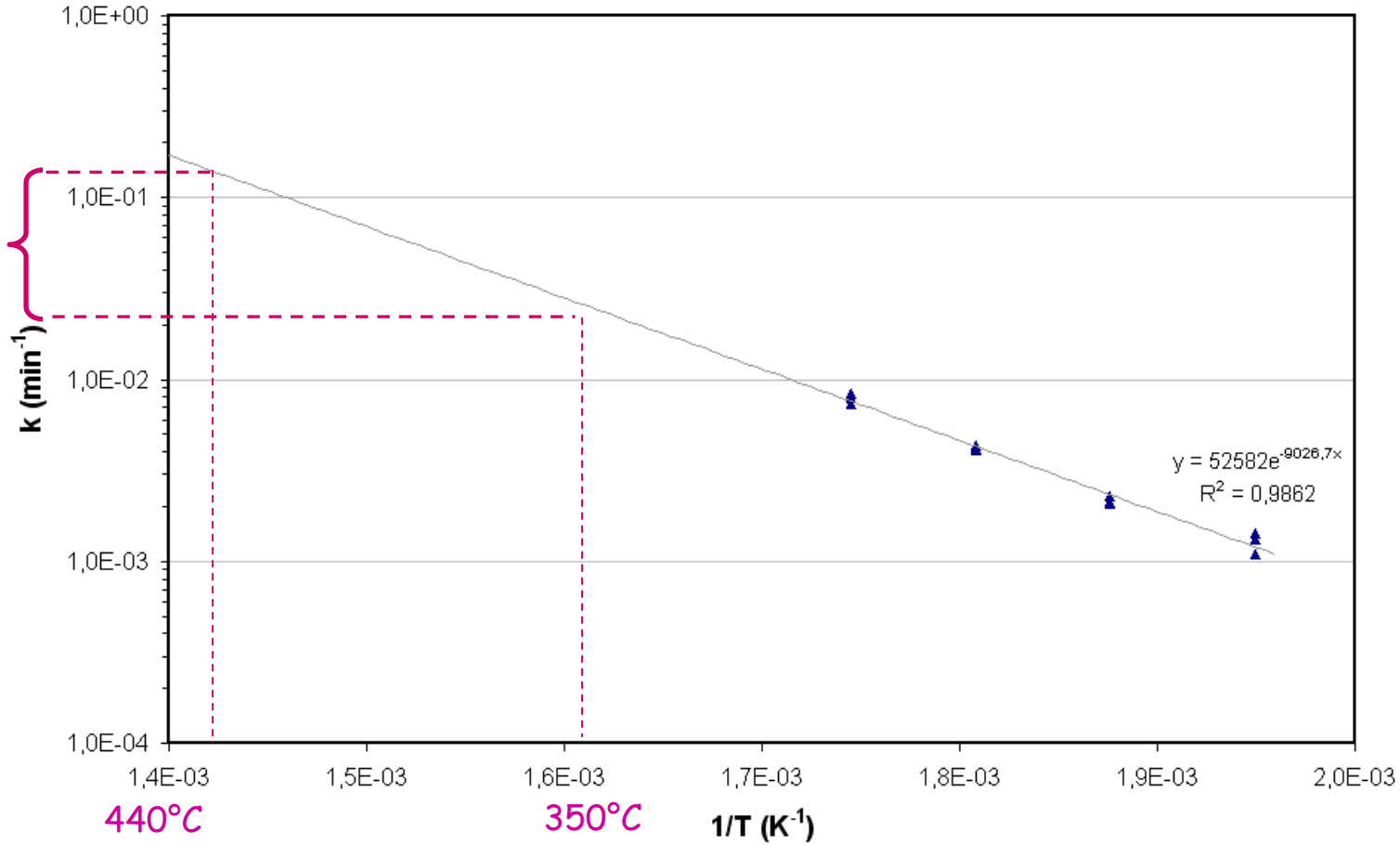


Simple first-order kinetic model

$$\frac{dm}{dt} = -k.m$$

Mass loss ≈ 20%

Resid. time ≈ min

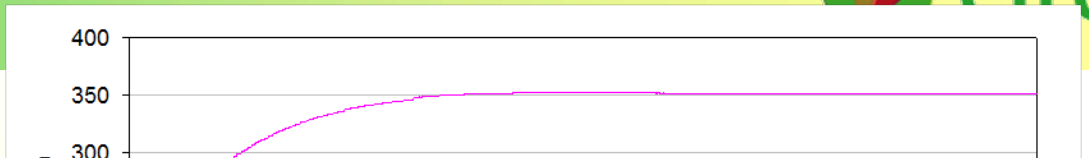


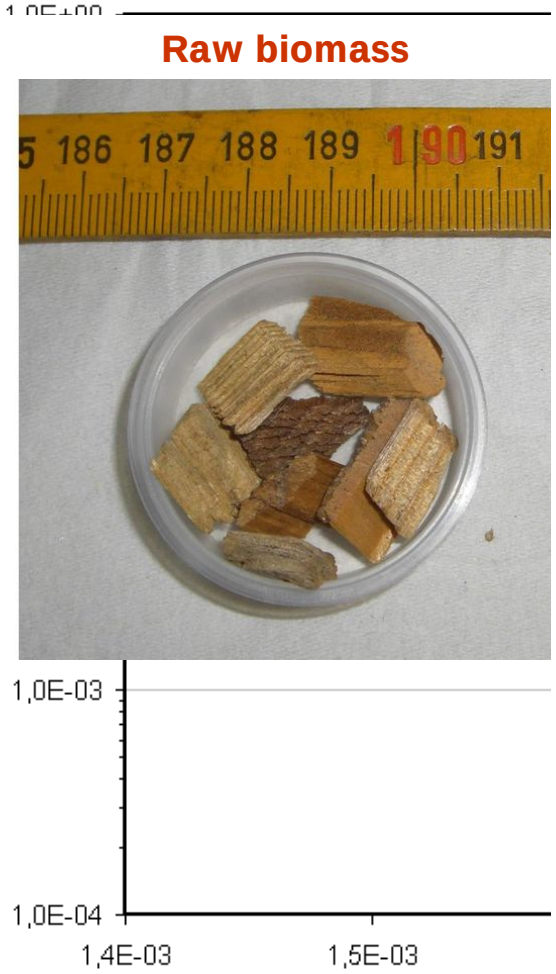
Torrefaction at high heating rate

Operating conditions:

Temperature = **350°C**

Residence time: **5 min**





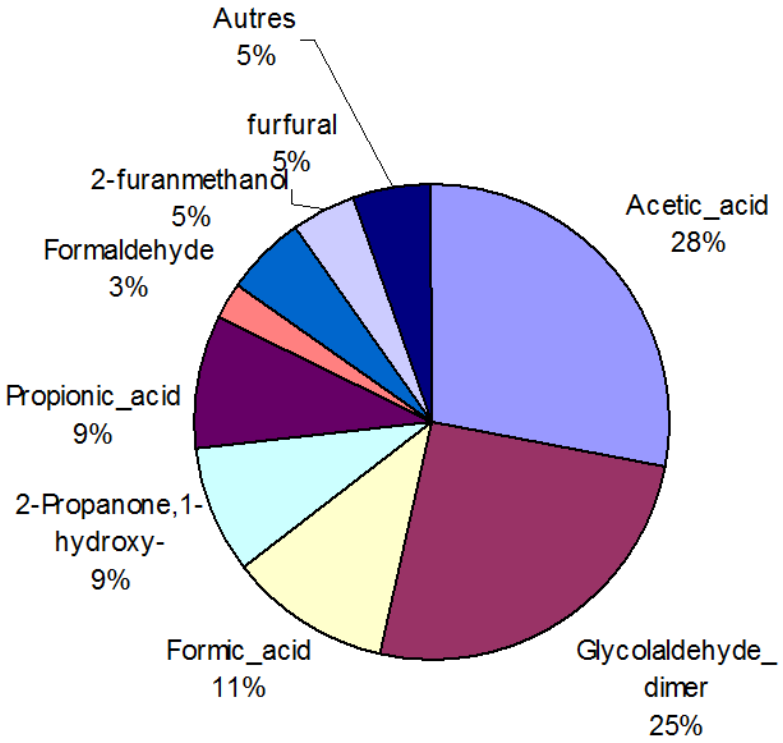
Raw biomass

Torrefied biomass

« Crushed » Torrefied biomass

Torrefaction at high heating rate

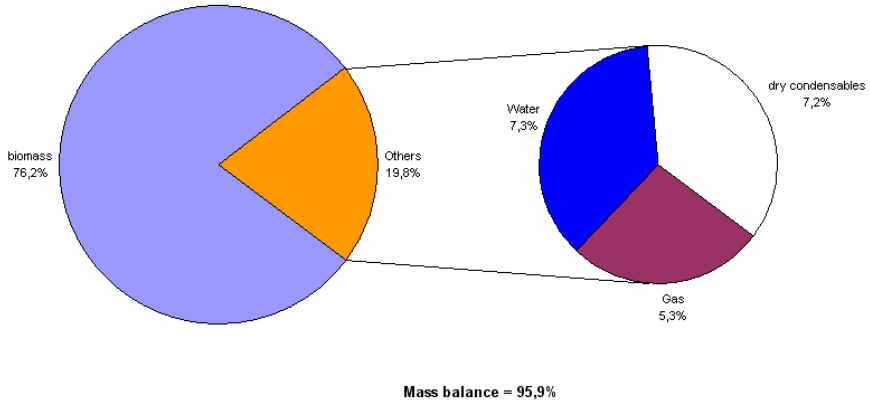
Detailed mass balance

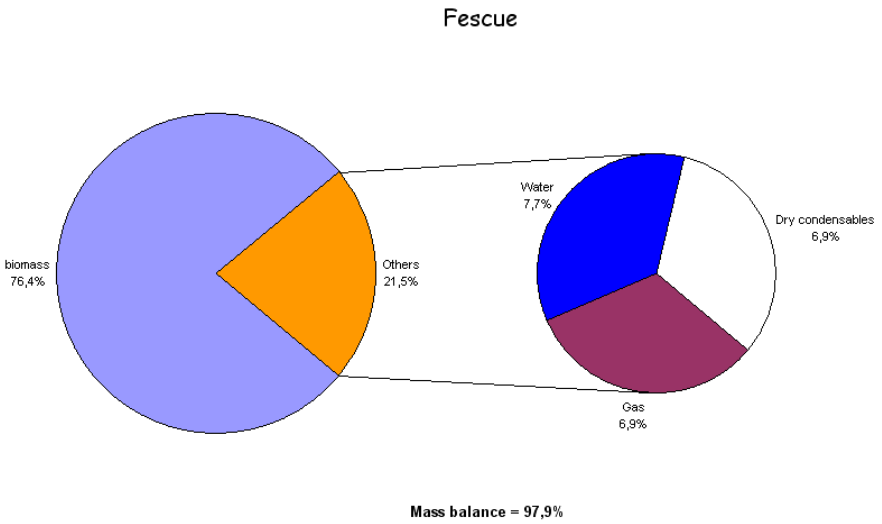


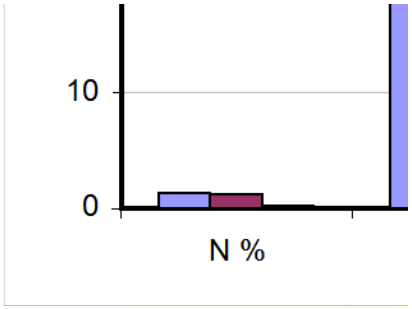
Compared to 280 and 300°C:

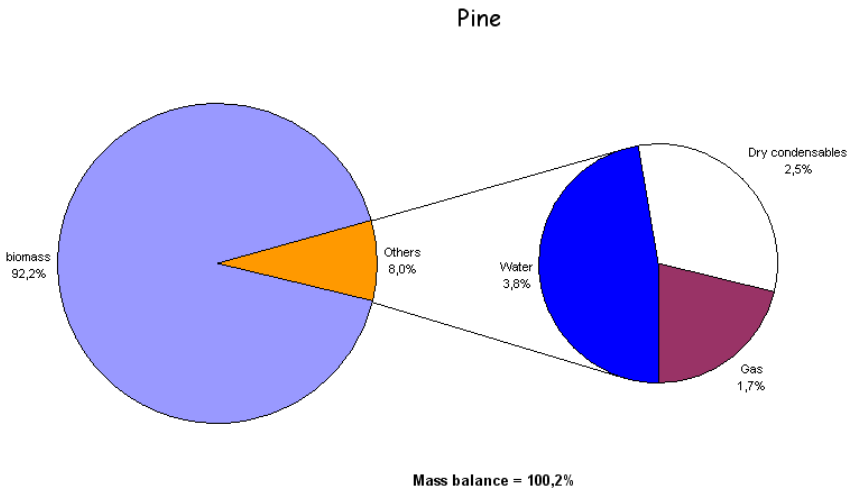
- Less formaldehyde
- Much more propionic acid
- Slightly similar acetic acid and glycolaldehyde contents

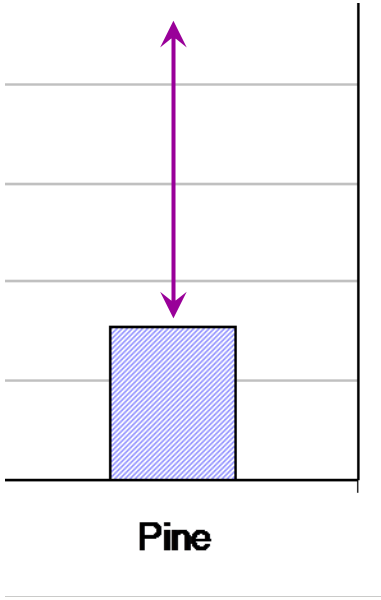
Nature of biomass











Conclusions

- **A complete characterisation of products of biomass torrefaction has been realised**
- **Volatile matters released mainly contain water, dry condensable species, CO_2 and CO**
- **Dry Condensable species mainly contain acids, aldehydes and ketones**
- **High heating rate influences significantly the torrefaction products**
- **Significant influence of the nature of biomass**
- **Work in progress:**
  - → **Cellulose, Hemicellulose and Lignin contents**
  - → **Grindability: energy consumption during grinding**