

Supporting Information for Article

The Kinetic Behavior of Torrefied Biomass in an Oxidative Environment

Energy Fuels, 2013, 27, 1050-1060. doi: [10.1021/ef3019222](https://doi.org/10.1021/ef3019222)

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KEYWORDS Torrefied wood; beech; pine; thermogravimetry; distributed activation energy model; combustion; char burn-off; pyrolysis; kinetic regime.

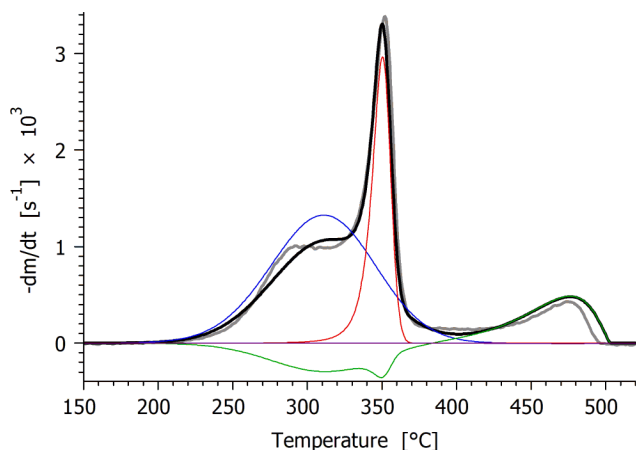
Scope of this document: The kinetic evaluation was based on the least squares evaluation of 36 TGA experiments by Evaluation 4. The fit quality and the partial curves were shown only on six experiments in the paper due to space restrictions. This Supporting information presents a whole version of Figure 3 displaying all the 36 experiments.

Figure caption: Results of Evaluation 8. Notation: experimental DTG curves normalized by the initial sample mass (gray —); their calculated counterpart (black —); the simulated partial curves: $-dm_{\text{cell}}/dt$ (red —); $-dm_{\text{other}}/dt$ (blue —); $-dm_{\text{char}}/dt$ (green —); $-dm_{\text{ash}}/dt$ (purple —); the temperature programs of the modulated and CRR experiments (gray —). In this representation the char formation rate (green line) appears below 0 because mass loss rates ($-dm/dt$) are plotted.

Textual information beneath the plots: The first row below each figure contains the name of the sample and a brief description of the experimental conditions. The date of the experiment is also shown in ISO 8601 format. The second row lists the fit quality for the given experiment: deviation ($\mu\text{g/s}$) and the deviation expressed as percent of the peak maxima (relative deviation, %). The further rows display the parameters for the partial processes.

The order of the plots (with the corresponding page numbers):

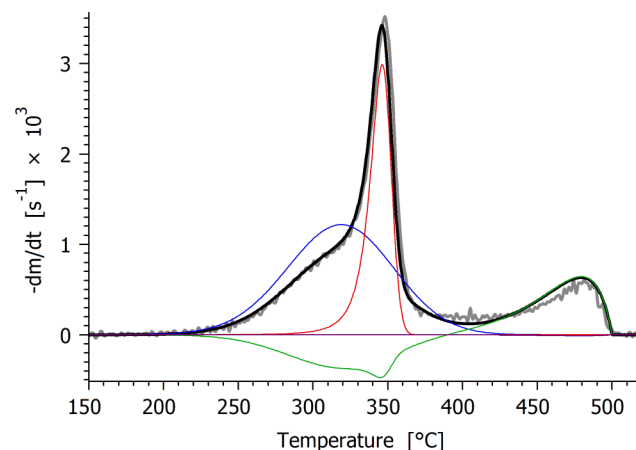
10°C/min experiments in 5% O ₂	2
10°C/min experiments in 20% O ₂	3
Modulated experiments in 5% O ₂	4
Modulated experiments in 20% O ₂	5
Constant reaction rate (CRR) experiments in 5% O ₂	6
Constant reaction rate (CRR) experiments in 20% O ₂	7

Untreated birch [O₂]=0.05 10°C/min 2012-05-03 0.34mg

Relative deviation: 2.89%, Deviation: 0.033 µg/s

1: $E_0=160.1$ $\log_{10} A=12.43$ $\sigma=8.14$ $v=0.245$ $yield=0.221$ 2: $E=135.0$ $\log_{10} A=9.97$ $n=0.93$ $z=0.00797$ $v=0.502$ $yield=0.070$ 3: $E=152.6$ $\log_{10} A=8.69$ $n=0.58$ $v=0.474$

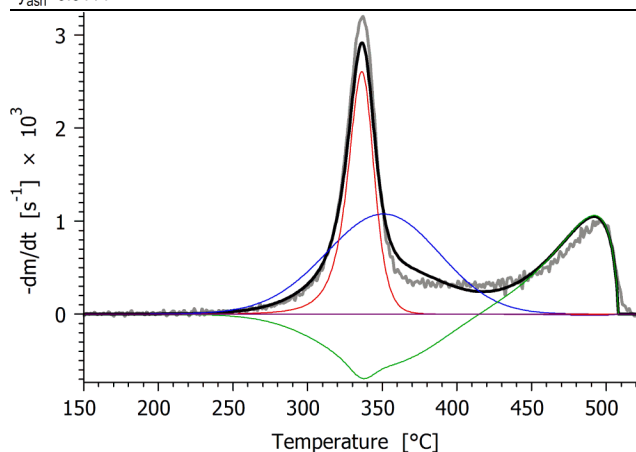
c: 0.70 0.30

 $y_{ash}=0.0114$ Birch 225°C [O₂]=0.05 10°C/min 2012-01-27 0.41mg

Relative deviation: 3.01%, Deviation: 0.044 µg/s

1: $E_0=160.1$ $\log_{10} A=12.23$ $\sigma=8.14$ $v=0.245$ $yield=0.296$ 2: $E=135.0$ $\log_{10} A=9.99$ $n=0.93$ $z=0.0178$ $v=0.502$ $yield=0.070$ 3: $E=152.6$ $\log_{10} A=8.62$ $n=0.48$ $v=0.474$

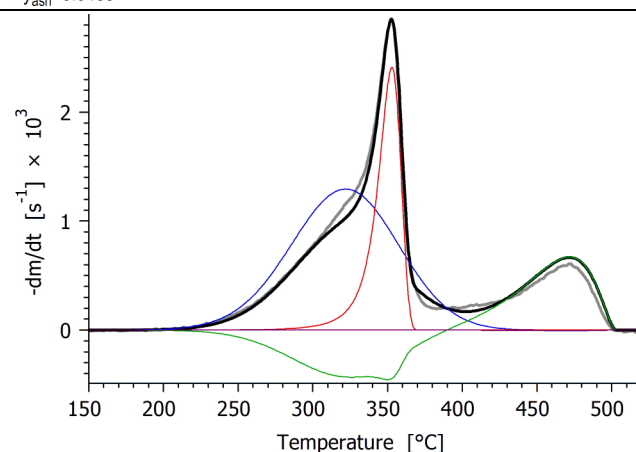
c: 0.65 0.35

 $y_{ash}=0.0183$ Birch 275°C [O₂]=0.05 10°C/min 2012-01-26 0.46mg

Relative deviation: 2.85%, Deviation: 0.042 µg/s

1: $E_0=160.1$ $\log_{10} A=11.47$ $\sigma=8.14$ $v=0.245$ $yield=0.511$ 2: $E=135.0$ $\log_{10} A=10.09$ $n=1.23$ $z=0.0249$ $v=0.502$ $yield=0.070$ 3: $E=152.6$ $\log_{10} A=8.50$ $n=0.39$ $v=0.474$

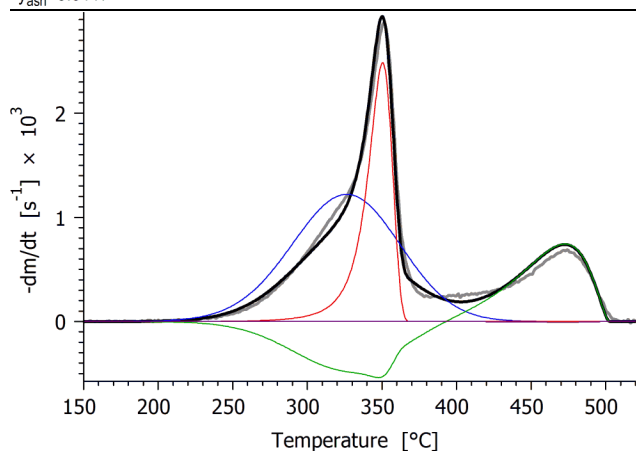
c: 0.62 0.38

 $y_{ash}=0.0117$ Untreated spruce [O₂]=0.05 10°C/min 2012-05-03 0.33mg

Relative deviation: 1.86%, Deviation: 0.017 µg/s

1: $E_0=160.1$ $\log_{10} A=12.16$ $\sigma=8.14$ $v=0.245$ $yield=0.326$ 2: $E=135.0$ $\log_{10} A=9.84$ $n=0.80$ $z=0.0352$ $v=0.502$ $yield=0.070$ 3: $E=152.6$ $\log_{10} A=8.86$ $n=0.64$ $v=0.474$

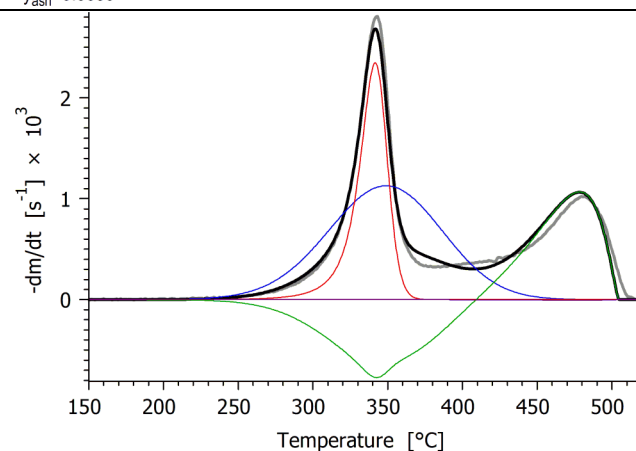
c: 0.70 0.30

 $y_{ash}=0.0080$ Spruce 225°C [O₂]=0.05 10°C/min 2012-02-01 0.43mg

Relative deviation: 2.05%, Deviation: 0.025 µg/s

1: $E_0=160.1$ $\log_{10} A=12.05$ $\sigma=8.14$ $v=0.245$ $yield=0.375$ 2: $E=135.0$ $\log_{10} A=9.86$ $n=0.81$ $z=0.0487$ $v=0.502$ $yield=0.070$ 3: $E=152.6$ $\log_{10} A=8.85$ $n=0.62$ $v=0.474$

c: 0.67 0.33

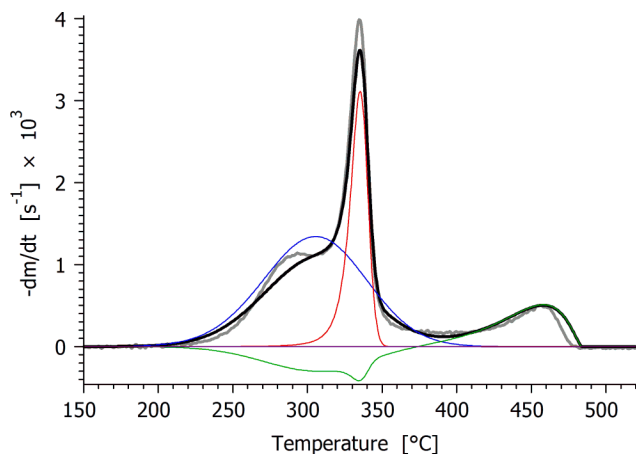
 $y_{ash}=0.0073$ Spruce 275°C [O₂]=0.05 10°C/min 2012-01-30 0.47mg

Relative deviation: 2.30%, Deviation: 0.030 µg/s

1: $E_0=160.1$ $\log_{10} A=11.51$ $\sigma=8.14$ $v=0.245$ $yield=0.553$ 2: $E=135.0$ $\log_{10} A=9.97$ $n=1.06$ $z=0.0422$ $v=0.502$ $yield=0.070$ 3: $E=152.6$ $\log_{10} A=8.80$ $n=0.57$ $v=0.474$

c: 0.65 0.35

 $y_{ash}=0.0052$



Untreated birch [O₂]=0.20 10°C/min 2012-05-02 0.32mg

Relative deviation: 2.20%, Deviation: 0.028 µg/s

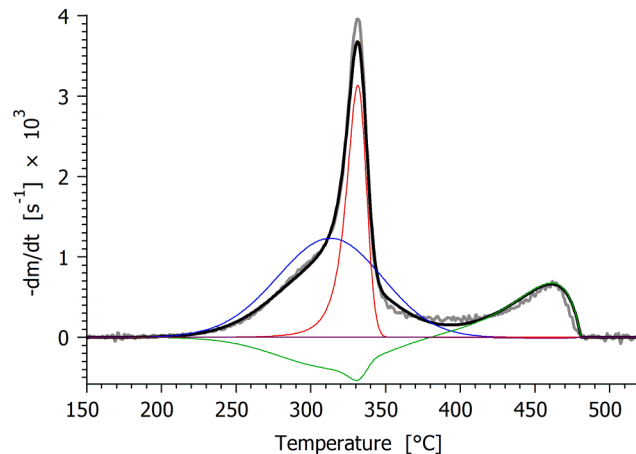
1: $E_0=160.1$ $\log_{10} A=12.43$ $\sigma=8.14$ $v=0.245$ $yield=0.221$

2: $E=135.0$ $\log_{10} A=9.97$ $n=0.93$ $z=0.00797$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.69$ $n=0.58$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0114$



Birch 225°C [O₂]=0.20 10°C/min 2011-10-26 0.42mg

Relative deviation: 1.58%, Deviation: 0.027 µg/s

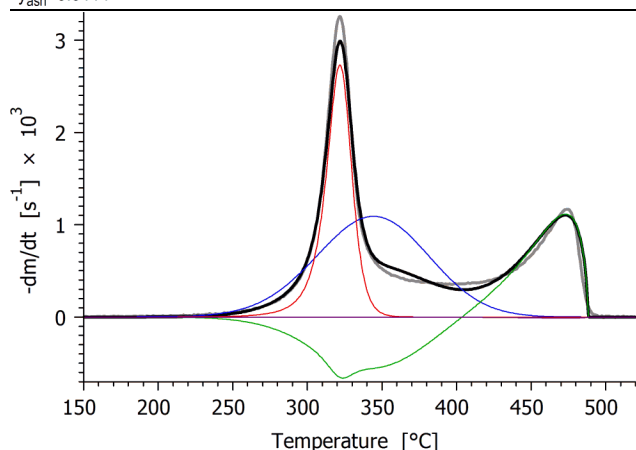
1: $E_0=160.1$ $\log_{10} A=12.23$ $\sigma=8.14$ $v=0.245$ $yield=0.296$

2: $E=135.0$ $\log_{10} A=9.99$ $n=0.93$ $z=0.0178$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.62$ $n=0.48$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0183$



Birch 275°C [O₂]=0.20 10°C/min 2011-10-25 0.52mg

Relative deviation: 2.02%, Deviation: 0.034 µg/s

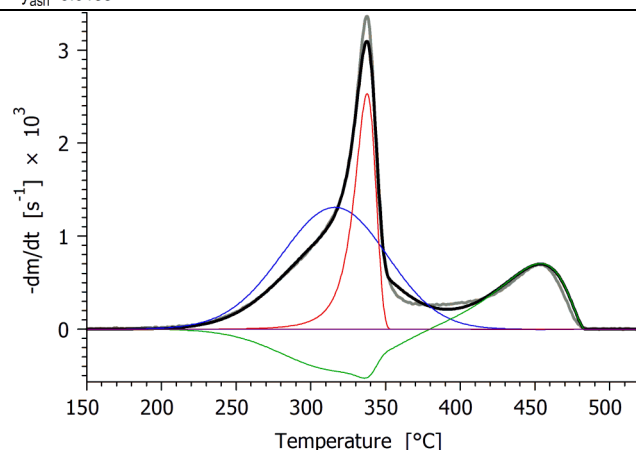
1: $E_0=160.1$ $\log_{10} A=11.47$ $\sigma=8.14$ $v=0.245$ $yield=0.511$

2: $E=135.0$ $\log_{10} A=10.09$ $n=1.23$ $z=0.0249$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.50$ $n=0.39$ $v=0.474$

c: 0.62 0.38

$y_{ash}=0.0117$



Untreated Spruce [O₂]=0.20 10°C/min 2011-11-04 0.41mg

Relative deviation: 1.45%, Deviation: 0.020 µg/s

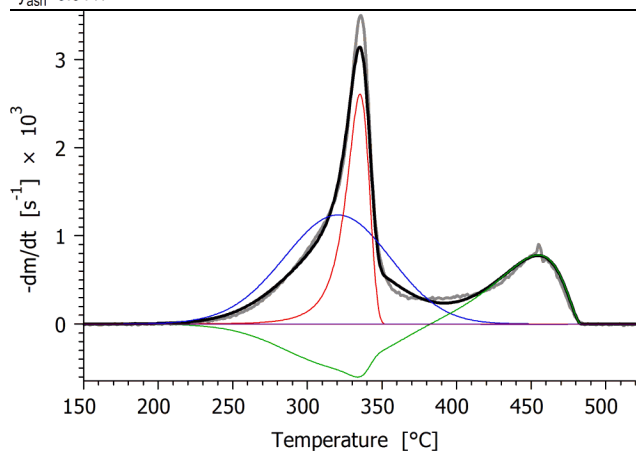
1: $E_0=160.1$ $\log_{10} A=12.16$ $\sigma=8.14$ $v=0.245$ $yield=0.326$

2: $E=135.0$ $\log_{10} A=9.84$ $n=0.80$ $z=0.0352$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.86$ $n=0.64$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0080$



Spruce 225°C [O₂]=0.20 10°C/min 2011-10-31 0.38mg

Relative deviation: 1.84%, Deviation: 0.025 µg/s

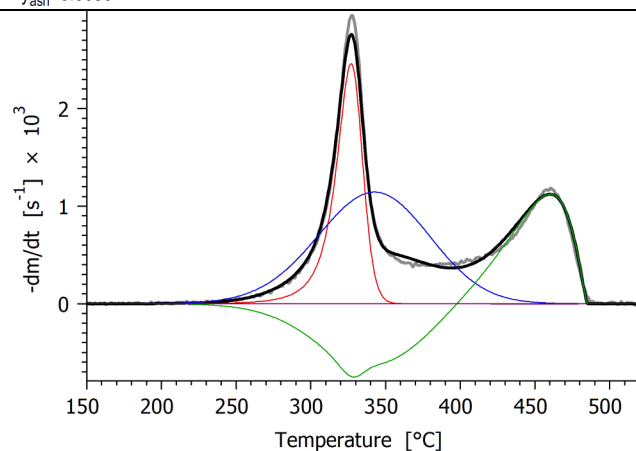
1: $E_0=160.1$ $\log_{10} A=12.05$ $\sigma=8.14$ $v=0.245$ $yield=0.375$

2: $E=135.0$ $\log_{10} A=9.86$ $n=0.81$ $z=0.0487$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.85$ $n=0.62$ $v=0.474$

c: 0.67 0.33

$y_{ash}=0.0073$



Spruce 275°C [O₂]=0.20 10°C/min 2011-10-27 0.38mg

Relative deviation: 1.47%, Deviation: 0.017 µg/s

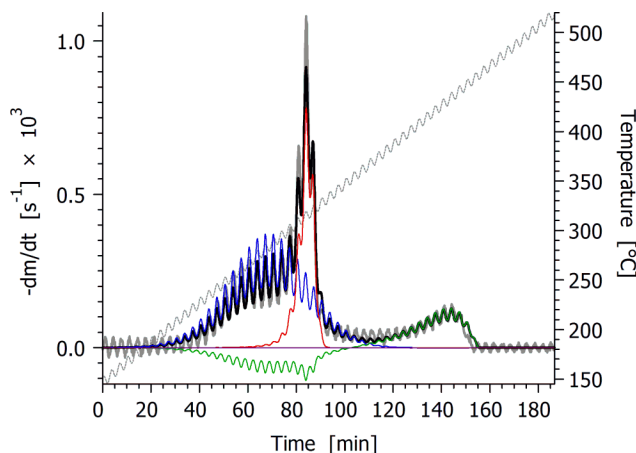
1: $E_0=160.1$ $\log_{10} A=11.51$ $\sigma=8.14$ $v=0.245$ $yield=0.553$

2: $E=135.0$ $\log_{10} A=9.97$ $n=1.06$ $z=0.0422$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.80$ $n=0.57$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0052$



Untreated birch [O₂]=0.05 modulated (2°C/min) 2012-03-18 0.45mg

Relative deviation: 2.48%, Deviation: 0.012 µg/s

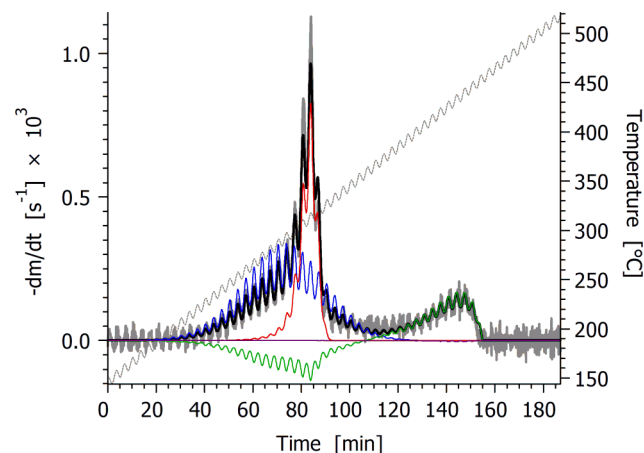
1: $E_0=160.1$ $\log_{10} A=12.43$ $\sigma=8.14$ $v=0.245$ $yield=0.221$

2: $E=135.0$ $\log_{10} A=9.97$ $n=0.93$ $z=0.00797$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.69$ $n=0.58$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0114$



Birch 225°C [O₂]=0.05 modulated (2°C/min) 2012-01-27 0.39mg

Relative deviation: 2.59%, Deviation: 0.011 µg/s

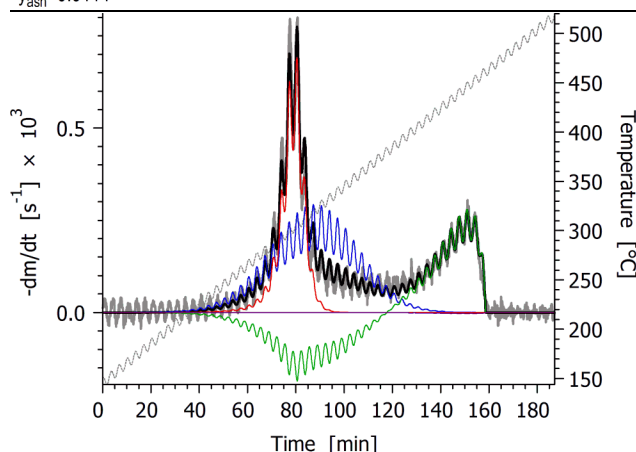
1: $E_0=160.1$ $\log_{10} A=12.23$ $\sigma=8.14$ $v=0.245$ $yield=0.296$

2: $E=135.0$ $\log_{10} A=9.99$ $n=0.93$ $z=0.0178$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.62$ $n=0.48$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0183$



Birch 275°C [O₂]=0.05 modulated (2°C/min) 2012-01-25 0.39mg

Relative deviation: 3.09%, Deviation: 0.0097 µg/s

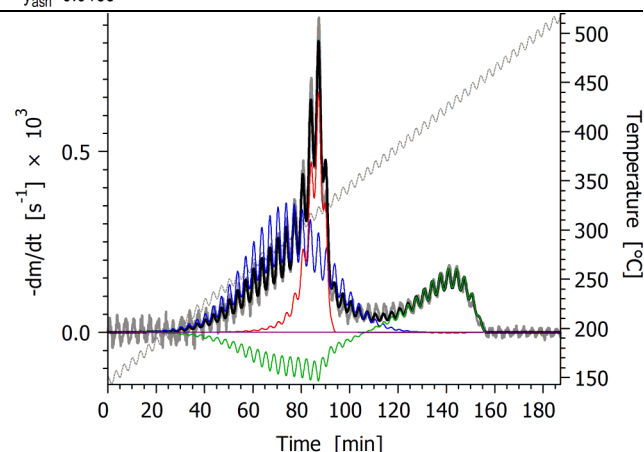
1: $E_0=160.1$ $\log_{10} A=11.47$ $\sigma=8.14$ $v=0.245$ $yield=0.511$

2: $E=135.0$ $\log_{10} A=10.09$ $n=1.23$ $z=0.0249$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.50$ $n=0.39$ $v=0.474$

c: 0.62 0.38

$y_{ash}=0.0117$



Untreated spruce [O₂]=0.05 modulated (2°C/min) 2012-03-19 0.44mg

Relative deviation: 2.45%, Deviation: 0.0094 µg/s

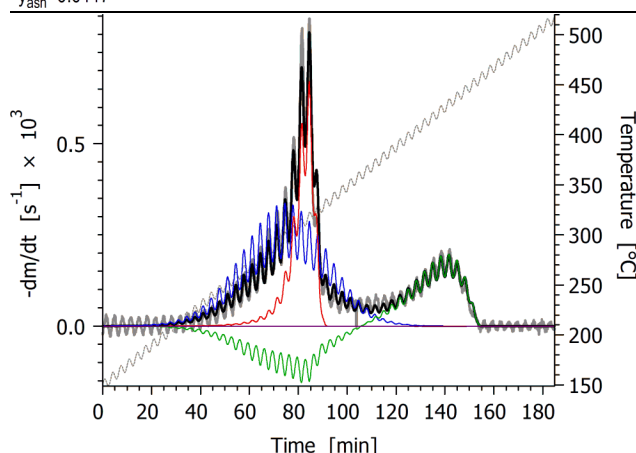
1: $E_0=160.1$ $\log_{10} A=12.16$ $\sigma=8.14$ $v=0.245$ $yield=0.326$

2: $E=135.0$ $\log_{10} A=9.84$ $n=0.80$ $z=0.0352$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.86$ $n=0.64$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0080$



Spruce 225°C [O₂]=0.05 modulated (2°C/min) 2012-01-31 0.45mg

Relative deviation: 2.67%, Deviation: 0.010 µg/s

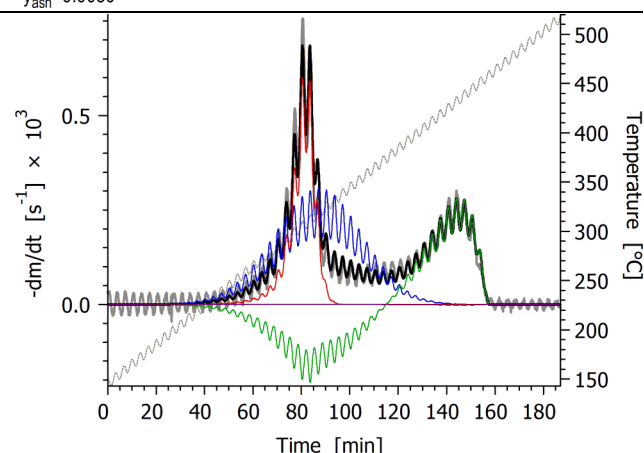
1: $E_0=160.1$ $\log_{10} A=12.05$ $\sigma=8.14$ $v=0.245$ $yield=0.375$

2: $E=135.0$ $\log_{10} A=9.86$ $n=0.81$ $z=0.0487$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.85$ $n=0.62$ $v=0.474$

c: 0.67 0.33

$y_{ash}=0.0073$



Spruce 275°C [O₂]=0.05 modulated (2°C/min) 2012-01-30 0.39mg

Relative deviation: 2.90%, Deviation: 0.0085 µg/s

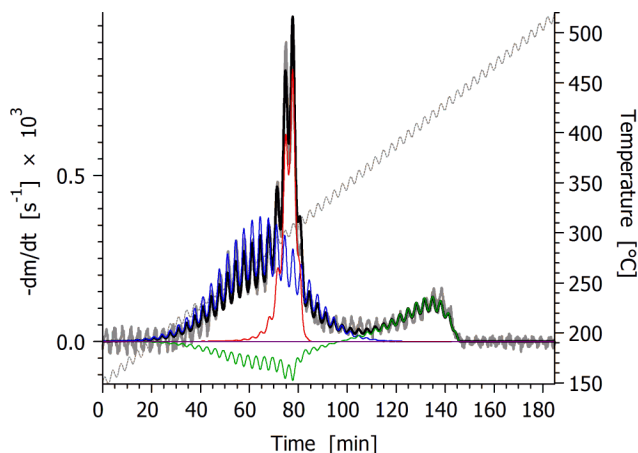
1: $E_0=160.1$ $\log_{10} A=11.51$ $\sigma=8.14$ $v=0.245$ $yield=0.553$

2: $E=135.0$ $\log_{10} A=9.97$ $n=1.06$ $z=0.0422$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.80$ $n=0.57$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0052$



Untreated birch [O₂]=0.20 modulated (2°C/min) 2012-03-22 0.41mg

Relative deviation: 2.75%, Deviation: 0.011 µg/s

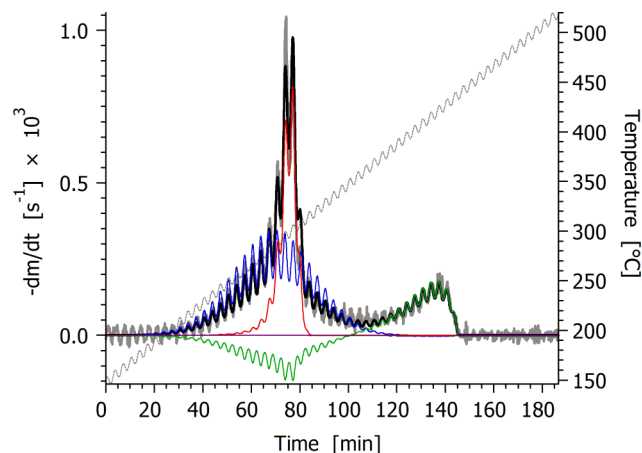
1: $E_0=160.1$ $\log_{10} A=12.43$ $\sigma=8.14$ $v=0.245$ $yield=0.221$

2: $E=135.0$ $\log_{10} A=9.97$ $n=0.93$ $z=0.00797$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.69$ $n=0.58$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0114$



Birch 225°C [O₂]=0.20 modulated (2°C/min) 2011-10-26 0.43mg

Relative deviation: 2.80%, Deviation: 0.013 µg/s

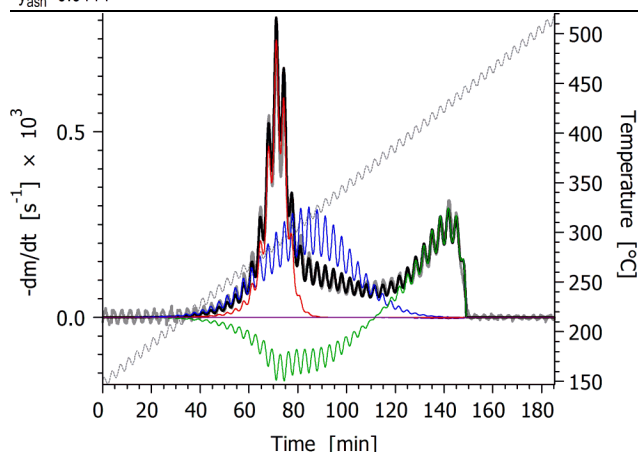
1: $E_0=160.1$ $\log_{10} A=12.23$ $\sigma=8.14$ $v=0.245$ $yield=0.296$

2: $E=135.0$ $\log_{10} A=9.99$ $n=0.93$ $z=0.0178$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.62$ $n=0.48$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0183$



Birch 275°C [O₂]=0.20 modulated (2°C/min) 2011-10-25 0.56mg

Relative deviation: 2.81%, Deviation: 0.012 µg/s

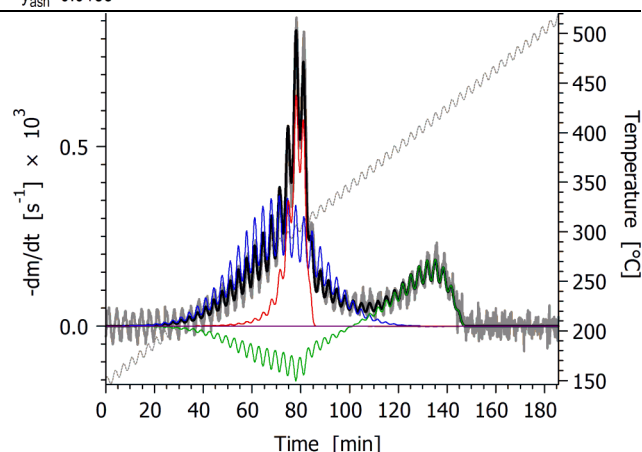
1: $E_0=160.1$ $\log_{10} A=11.47$ $\sigma=8.14$ $v=0.245$ $yield=0.511$

2: $E=135.0$ $\log_{10} A=10.09$ $n=1.23$ $z=0.0249$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.50$ $n=0.39$ $v=0.474$

c: 0.62 0.38

$y_{ash}=0.0117$



Untreated spruce [O₂]=0.20 modulated (2°C/min) 2012-04-04 0.35mg

Relative deviation: 3.43%, Deviation: 0.010 µg/s

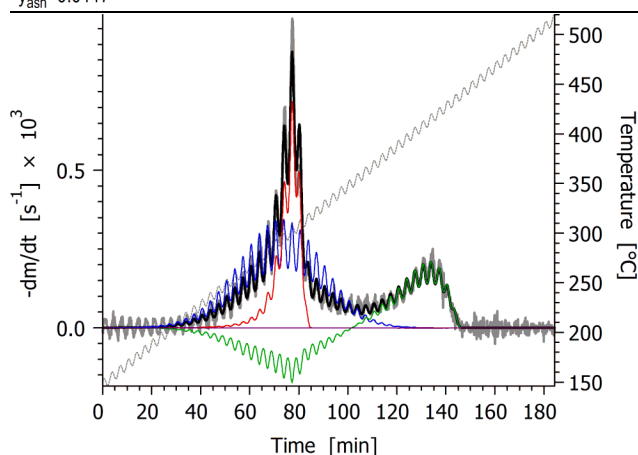
1: $E_0=160.1$ $\log_{10} A=12.16$ $\sigma=8.14$ $v=0.245$ $yield=0.326$

2: $E=135.0$ $\log_{10} A=9.84$ $n=0.80$ $z=0.0352$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.86$ $n=0.64$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0080$



Spruce 225°C modulated (2°C/min) [O₂]=0.20 2011-10-28 0.41mg

Relative deviation: 2.49%, Deviation: 0.0099 µg/s

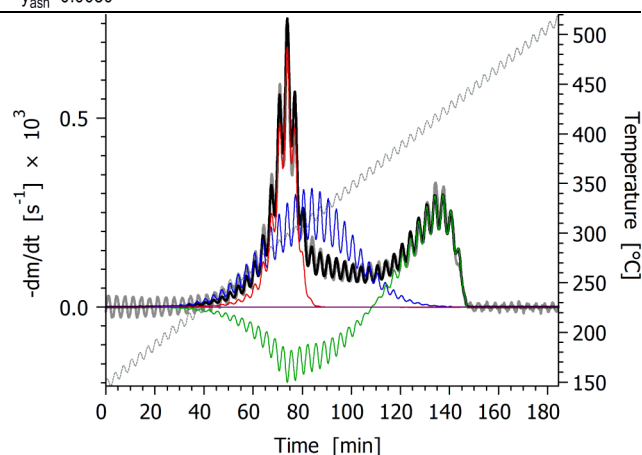
1: $E_0=160.1$ $\log_{10} A=12.05$ $\sigma=8.14$ $v=0.245$ $yield=0.375$

2: $E=135.0$ $\log_{10} A=9.86$ $n=0.81$ $z=0.0487$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.85$ $n=0.62$ $v=0.474$

c: 0.67 0.33

$y_{ash}=0.0073$



Spruce 275°C [O₂]=0.20 modulated (2°C/min) 2011-10-27 0.39mg

Relative deviation: 2.87%, Deviation: 0.0080 µg/s

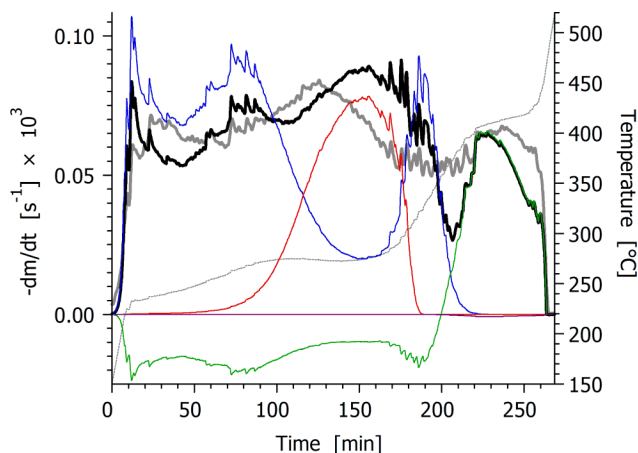
1: $E_0=160.1$ $\log_{10} A=11.51$ $\sigma=8.14$ $v=0.245$ $yield=0.553$

2: $E=135.0$ $\log_{10} A=9.97$ $n=1.06$ $z=0.0422$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.80$ $n=0.57$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0052$



Untreated birch [O₂]=0.05 CRR (10°C/min) 2012-03-17 0.83mg

Relative deviation: 14.73%, Deviation: 0.010 µg/s

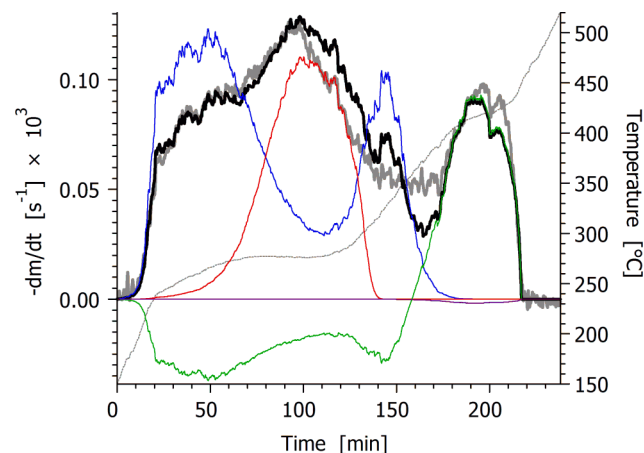
1: $E_0=160.1$ $\log_{10} A=12.43$ $\sigma=8.14$ $v=0.245$ $yield=0.221$

2: $E=135.0$ $\log_{10} A=9.97$ $n=0.93$ $z=0.00797$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.69$ $n=0.58$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0114$



Birch 225°C [O₂]=0.05 CRR (10°C/min) 2012-02-02 0.45mg

Relative deviation: 7.31%, Deviation: 0.0042 µg/s

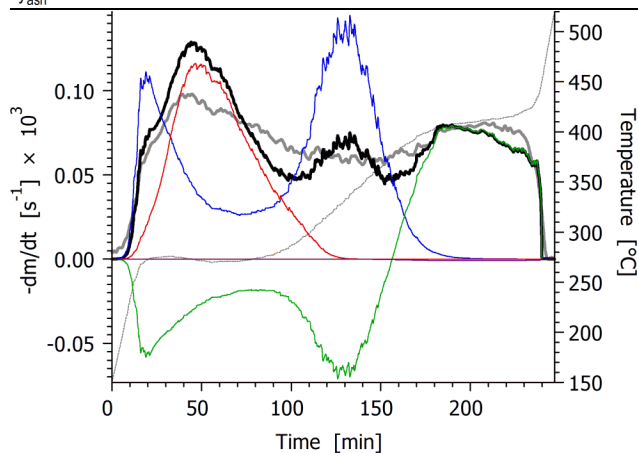
1: $E_0=160.1$ $\log_{10} A=12.23$ $\sigma=8.14$ $v=0.245$ $yield=0.296$

2: $E=135.0$ $\log_{10} A=9.99$ $n=0.93$ $z=0.0178$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.62$ $n=0.48$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0183$



Birch 275°C [O₂]=0.05 CRR (10°C/min) 2012-03-19 0.55mg

Relative deviation: 13.04%, Deviation: 0.0071 µg/s

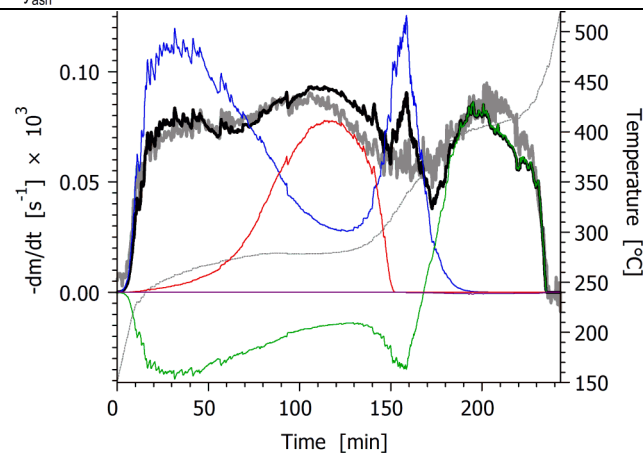
1: $E_0=160.1$ $\log_{10} A=11.47$ $\sigma=8.14$ $v=0.245$ $yield=0.511$

2: $E=135.0$ $\log_{10} A=10.09$ $n=1.23$ $z=0.0249$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.50$ $n=0.39$ $v=0.474$

c: 0.62 0.38

$y_{ash}=0.0117$



Untreated spruce [O₂]=0.05 CRR (10°C/min) 2012-03-18 0.57mg

Relative deviation: 9.23%, Deviation: 0.0050 µg/s

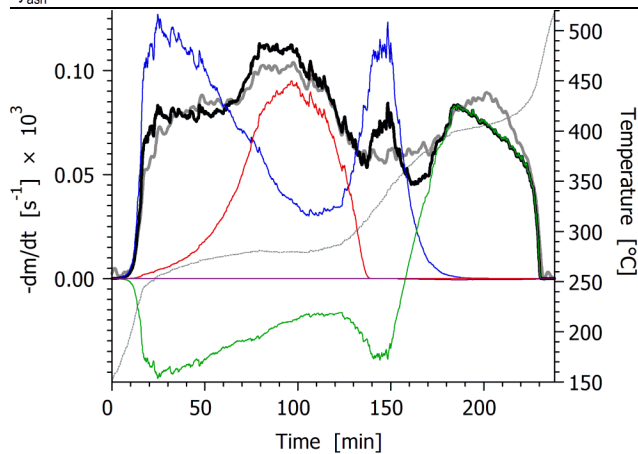
1: $E_0=160.1$ $\log_{10} A=12.16$ $\sigma=8.14$ $v=0.245$ $yield=0.326$

2: $E=135.0$ $\log_{10} A=9.84$ $n=0.80$ $z=0.0352$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.86$ $n=0.64$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0080$



Spruce 225°C [O₂]=0.05 CRR (10°C/min) 2012-03-20 0.42mg

Relative deviation: 7.78%, Deviation: 0.0034 µg/s

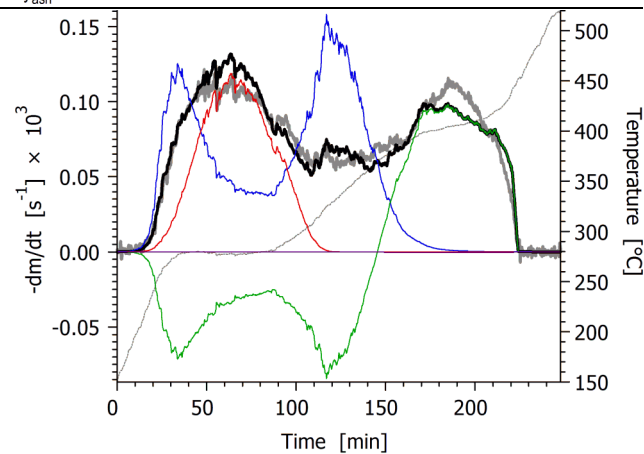
1: $E_0=160.1$ $\log_{10} A=12.05$ $\sigma=8.14$ $v=0.245$ $yield=0.375$

2: $E=135.0$ $\log_{10} A=9.86$ $n=0.81$ $z=0.0487$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.85$ $n=0.62$ $v=0.474$

c: 0.67 0.33

$y_{ash}=0.0073$



Spruce 275°C [O₂]=0.05 CRR (10°C/min) 2012-02-03 0.47mg

Relative deviation: 6.96%, Deviation: 0.0040 µg/s

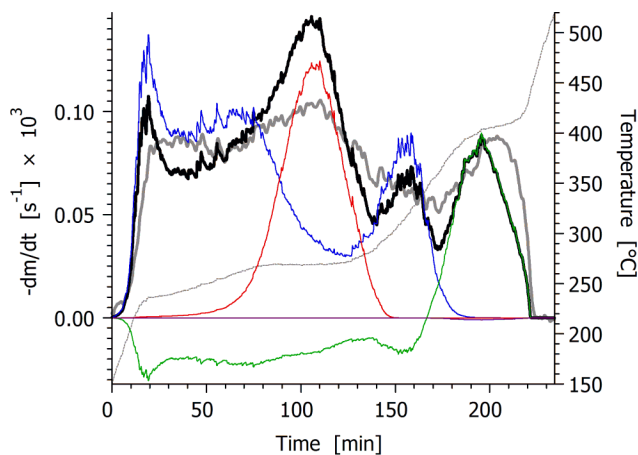
1: $E_0=160.1$ $\log_{10} A=11.51$ $\sigma=8.14$ $v=0.245$ $yield=0.553$

2: $E=135.0$ $\log_{10} A=9.97$ $n=1.06$ $z=0.0422$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.80$ $n=0.57$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0052$



Untreated birch [O₂]=0.20 CRR (10°C/min) 2012-04-03 0.39mg

Relative deviation: 16.81%, Deviation: 0.0069 µg/s

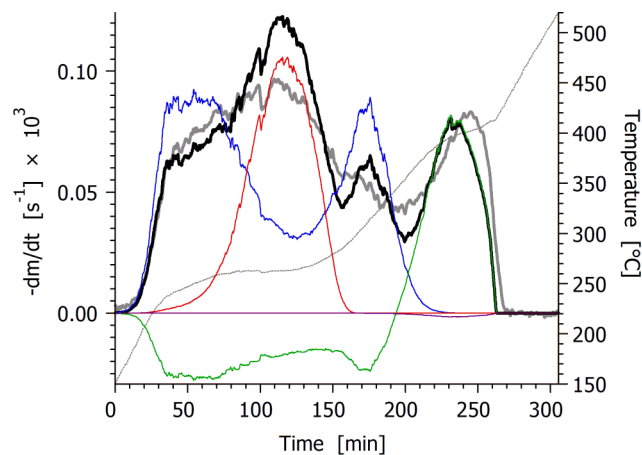
1: $E_0=160.1$ $\log_{10} A=12.43$ $\sigma=8.14$ $v=0.245$ $yield=0.221$

2: $E=135.0$ $\log_{10} A=9.97$ $n=0.93$ $z=0.00797$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.69$ $n=0.58$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0114$



Birch 225°C [O₂]=0.20 CRR (5°C/min) 2011-11-09 0.48mg

Relative deviation: 11.80%, Deviation: 0.0055 µg/s

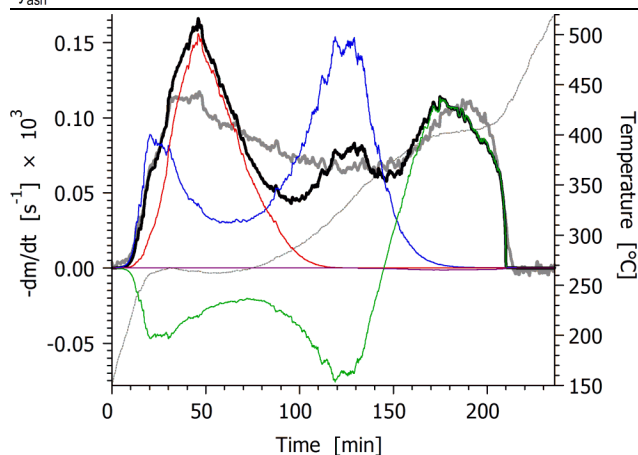
1: $E_0=160.1$ $\log_{10} A=12.23$ $\sigma=8.14$ $v=0.245$ $yield=0.296$

2: $E=135.0$ $\log_{10} A=9.99$ $n=0.93$ $z=0.0178$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.62$ $n=0.48$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0183$



Birch 275°C [O₂]=0.20 CRR (10°C/min) 2011-11-29 0.61mg

Relative deviation: 14.56%, Deviation: 0.010 µg/s

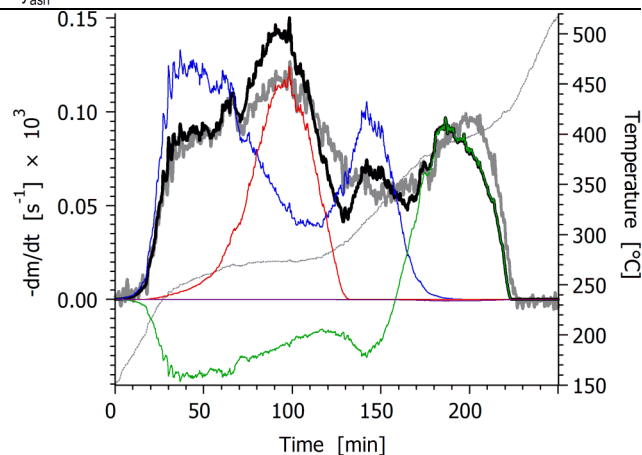
1: $E_0=160.1$ $\log_{10} A=11.47$ $\sigma=8.14$ $v=0.245$ $yield=0.511$

2: $E=135.0$ $\log_{10} A=10.09$ $n=1.23$ $z=0.0249$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.50$ $n=0.39$ $v=0.474$

c: 0.62 0.38

$y_{ash}=0.0117$



Untreated spruce [O₂]=0.20 CRR (10°C/min) 2012-04-04 0.32mg

Relative deviation: 9.75%, Deviation: 0.0039 µg/s

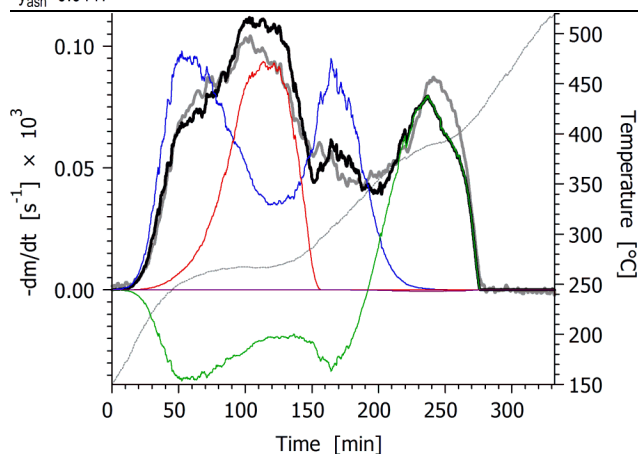
1: $E_0=160.1$ $\log_{10} A=12.16$ $\sigma=8.14$ $v=0.245$ $yield=0.326$

2: $E=135.0$ $\log_{10} A=9.84$ $n=0.80$ $z=0.0352$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.86$ $n=0.64$ $v=0.474$

c: 0.70 0.30

$y_{ash}=0.0080$



Spruce 225°C [O₂]=0.20 CRR (5°C/min) 2011-11-11 0.44mg

Relative deviation: 6.97%, Deviation: 0.0032 µg/s

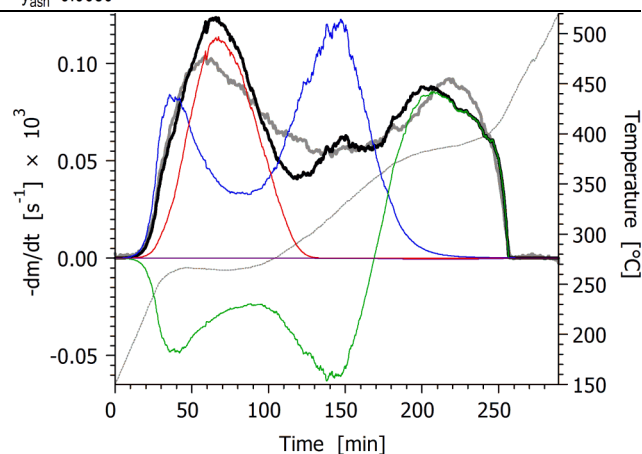
1: $E_0=160.1$ $\log_{10} A=12.05$ $\sigma=8.14$ $v=0.245$ $yield=0.375$

2: $E=135.0$ $\log_{10} A=9.86$ $n=0.81$ $z=0.0487$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.85$ $n=0.62$ $v=0.474$

c: 0.67 0.33

$y_{ash}=0.0073$



Spruce 275°C [O₂]=0.20 CRR (5°C/min) 2011-11-10 0.52mg

Relative deviation: 9.36%, Deviation: 0.0050 µg/s

1: $E_0=160.1$ $\log_{10} A=11.51$ $\sigma=8.14$ $v=0.245$ $yield=0.553$

2: $E=135.0$ $\log_{10} A=9.97$ $n=1.06$ $z=0.0422$ $v=0.502$ $yield=0.070$

3: $E=152.6$ $\log_{10} A=8.80$ $n=0.57$ $v=0.474$

c: 0.65 0.35

$y_{ash}=0.0052$