



**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI



# Flammability of wood treated with DURAWOOD model systems

W.Ł. Grzeškowiak

Scots pine sapwood

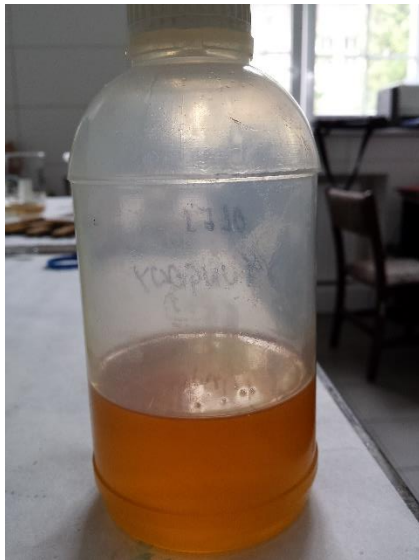
# Materials

Silanes: APTMOS 5%, APTEOS 5%, MTMOS 5%, AATMOS 5%,

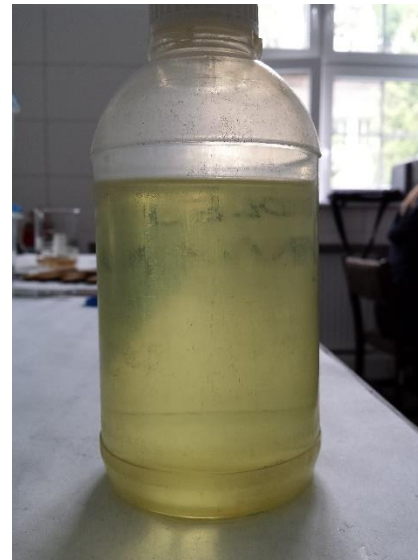
Oils: Linseed oil (LO), Tung oil (TO),

Solvents: water, ethanol, white spirit,

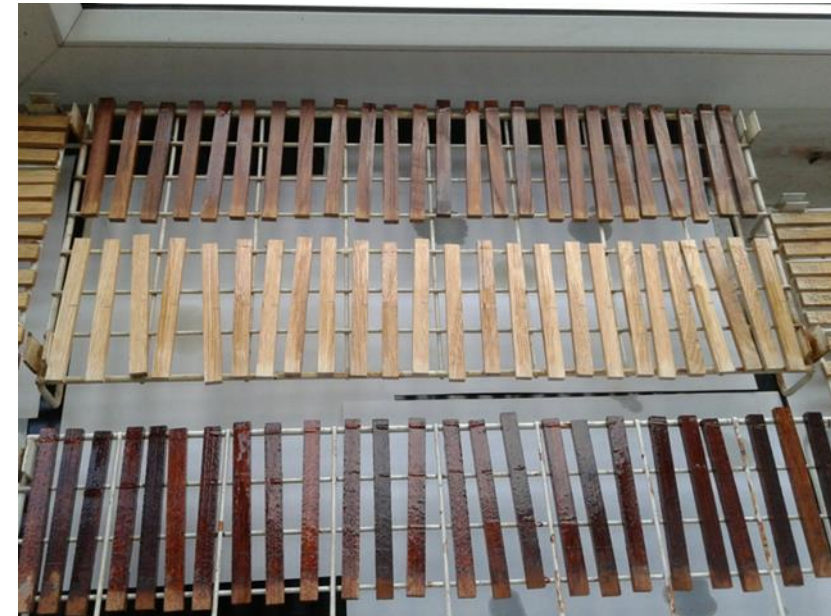
Other chemicals: potassium carbonate (PC), mixture of potassium carbonate and urea (PCU)



**TUNG OIL**



**LINSEED OIL**



# MFT methodology

## 1. Impregnation

### ➤ vaccum method:

- pressure 0,1 MPa/15min;
- atmospheric pressure 120 min

Scots pine sapwood  
(100 x 10 x 5 mm)



Soaking (24 h)

Leaching acc. EN-84





## Flammability test:

- Test time 10 min.
- Burner high 1,5 cm
- 5 samples for each variant

## Collected data:

- Temperature
- Mass loss



Scots pine sapwood (100 x 10 x 5 mm)



**AATMOS 5%**



**APTAMOS 5%**



**LINSEED  
OIL 20%**



**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI



| <b>Formulation</b> | <b>Solvent</b> | <b>Impregnation method</b> | <b>Mass loss</b> | <b>Mass loss (leached)</b> |
|--------------------|----------------|----------------------------|------------------|----------------------------|
| AATMOS 5%          | Water          | soaking 24h                | 80%              | 76%                        |
| AATMOS 5%          | Water          | vacuum 15 min              | 77%              | 73%                        |
| APTAMOS 5%         | Water          | soaking 24h                | 80%              | 78%                        |
| APTAMOS 5%         | Water          | vacuum 15 min              | 78%              | 73%                        |
| APTEOS 5%          | Water          | soaking 24h                | 80%              | 83%                        |
| APTEOS 5%          | Water          | vacuum 15 min              | 78%              | 82%                        |
| AATMOS 5%          | Ethanol        | soaking 24h                | 80%              | 84%                        |
| AATMOS 5%          | Ethanol        | vacuum 15 min              | 82%              | 80%                        |
| APTAMOS 5%         | Ethanol        | soaking 24h                | 81%              | 84%                        |
| APTAMOS 5%         | Ethanol        | vacuum 15 min              | 80%              | 81%                        |
| APTEOS 5%          | Ethanol        | soaking 24h                | 80%              | 84%                        |
| APTEOS 5%          | Ethanol        | vacuum 15 min              | 82%              | 82%                        |
| MTMOS 5%           | Ethanol        | soaking 24h                | 81%              | 85%                        |
| MTMOS 5%           | Ethanol        | vacuum 15 min              | 84%              | 93%                        |
| AATMOS 5%          | White spirit   | soaking 24h                | 81%              | 86%                        |
| AATMOS 5%          | White spirit   | vacuum 15 min              | 86%              | 82%                        |
| APTAMOS 5%         | White spirit   | soaking 24h                | -                | -                          |
| APTAMOS 5%         | White spirit   | vacuum 15 min              | 79%              | 82%                        |
| MTMOS 5%           | White spirit   | soaking 24h                | 86%              | 88%                        |
| MTMOS 5%           | White spirit   | vacuum 15 min              | 88%              | 94%                        |



**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI

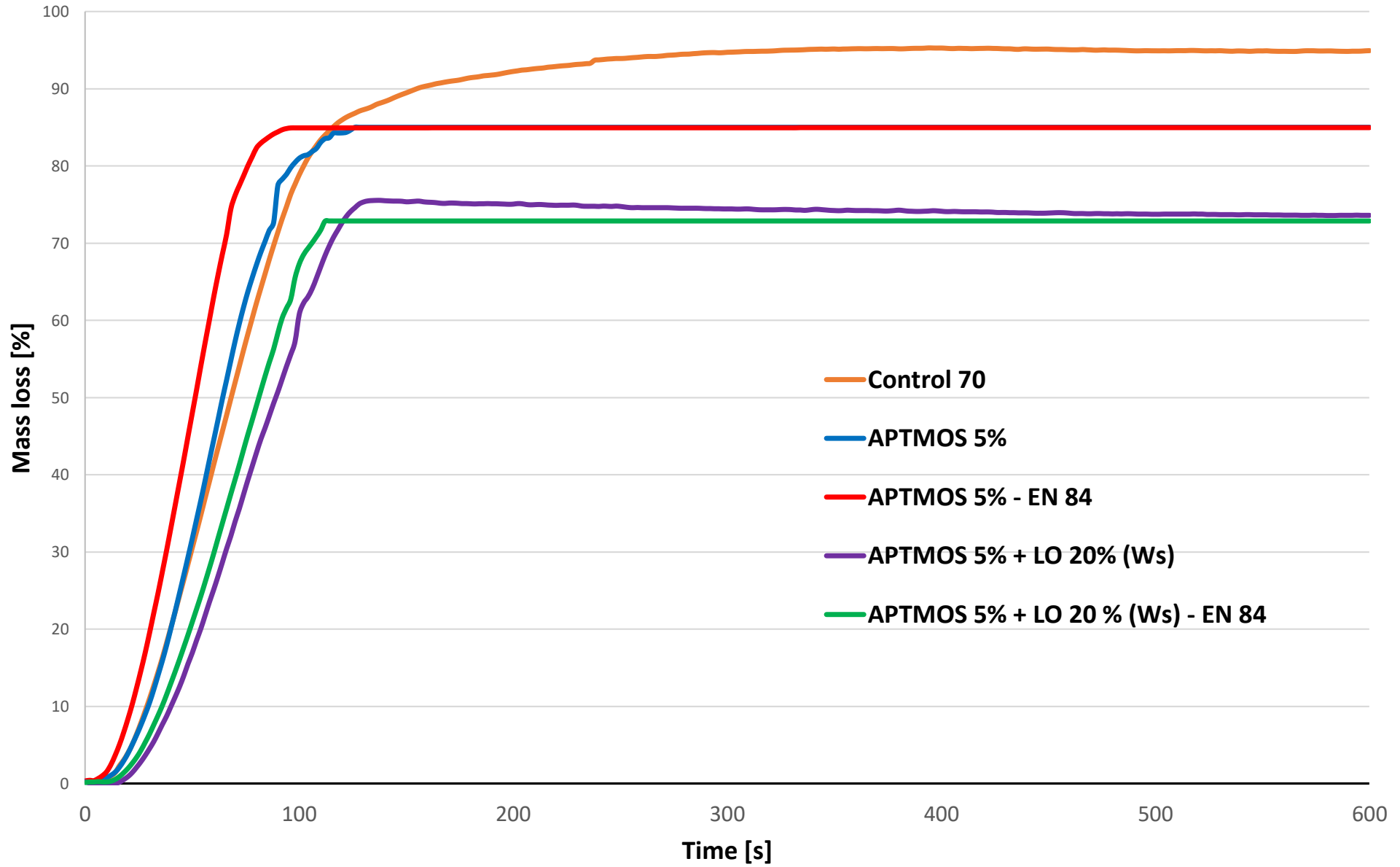


| Formulation                  | Solvent      | Impregnation method | Mass loss | Mass loss (leached) |
|------------------------------|--------------|---------------------|-----------|---------------------|
| AATMOS 5% + 20% PCU          | Water        | soaking 24h         | 28%       | 95%                 |
| AATMOS 5% + 20% PCU          | Water        | vacuum 15 min       | 26%       | 95%                 |
| APTAMOS 5% + 20% PCU         | Water        | soaking 24h         | 41%       | 98%                 |
| APTAMOS 5% + 20% PCU         | Water        | vacuum 15 min       | 26%       | 86%                 |
| AATMOS 5% + 10% PC           | Water        | soaking 24h         | 42%       | 86%                 |
| AATMOS 5% + 10% PC           | Water        | vacuum 15 min       | 38%       | 84%                 |
| APTAMOS 5% + 10% PC          | Water        | soaking 24h         | 58%       | 90%                 |
| APTAMOS 5% + 10% PC          | Water        | vacuum 15 min       | 39%       | 93%                 |
| APTEOS 5% + 10% PC           | Water        | soaking 24h         | 44%       | 99%                 |
| APTEOS 5% + 10% PC           | Water        | vacuum 15 min       | 32%       | 96%                 |
| AATMOS 5% + 20% PC           | Water        | soaking 24h         | 28%       | 92%                 |
| AATMOS 5% + 20% PC           | Water        | vacuum 15 min       | 23%       | 96%                 |
| APTAMOS 5% + 20% PC          | Water        | soaking 24h         | 30%       | 87%                 |
| APTAMOS 5% + 20% PC          | Water        | vacuum 15 min       | 24%       | 89%                 |
| APTEOS 5% + 20% PC           | Water        | soaking 24h         | 32%       | 92%                 |
| APTEOS 5% + 20% PC           | Water        | vacuum 15 min       | 26%       | 98%                 |
| APTAMOS 5% + 20% tung oil    | White spirit | soaking 24h         | 82%       | 83%                 |
| APTAMOS 5% + 20% tung oil    | White spirit | vacuum 15 min       | 84%       | 84%                 |
| APTAMOS 5% + 20% linseed oil | White spirit | soaking 24h         | 83%       | 84%                 |
| APTAMOS 5% + 20% linseed oil | White spirit | vacuum 15 min       | 72%       | 70%                 |

## The list of the most effective fire retardants – the results of MFT test for pine wood

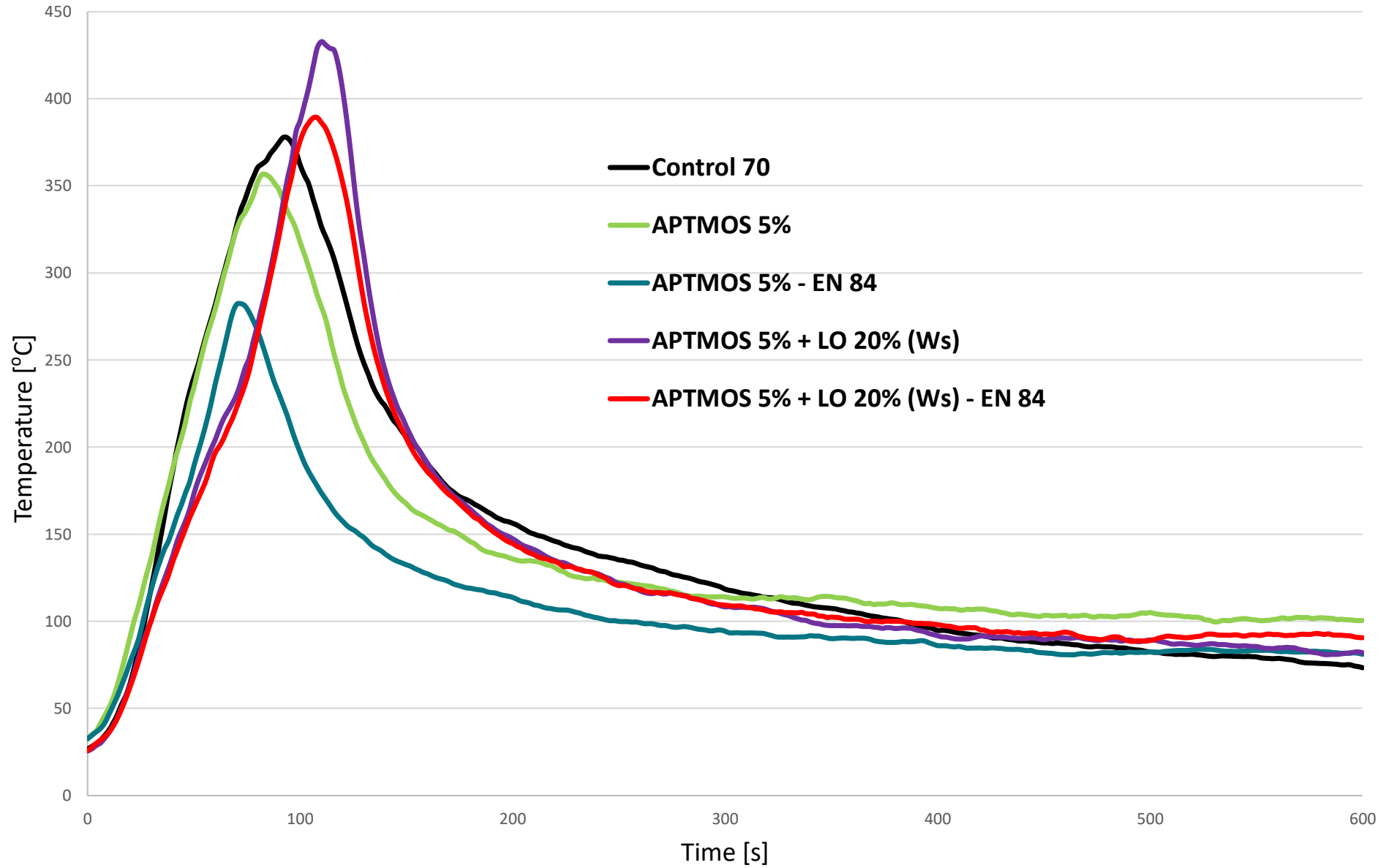
| Model protective system composition | Ratio of the components | Concentration (%) | Medium | Treatment method | Leaching | Mass loss [%] |
|-------------------------------------|-------------------------|-------------------|--------|------------------|----------|---------------|
| AATMOS                              | -                       | 5                 | WB     | V                | yes      | 72,95         |
| APTMO5                              | -                       | 5                 | WB     | V                | yes      | 73,46         |
| APTMO5+linseed oil                  | 1:4                     | 25                | SB     | V                | no       | 71,98         |
| APTMO5+linseed oil                  | 1:4                     | 25                | SB     | V                | yes      | 70,31         |
| AATMO5+PCU                          | 1:4                     | 25                | WB     | S                | no       | 28,14         |
| AATMO5+PCU                          | 1:4                     | 25                | WB     | V                | no       | 26,25         |
| APTMO5+PCU                          | 1:4                     | 25                | WB     | V                | no       | 26,41         |
| APTMO5+PC                           | 1:4                     | 25                | WB     | V                | no       | 23,76         |
| APTEOS+PC                           | 1:4                     | 25                | WB     | V                | no       | 26,13         |
| AATMO5+PC                           | 1:4                     | 25                | WB     | V                | no       | 23,16         |
| APTMO5+PC                           | 1:2                     | 15                | WB     | V                | no       | 39,29         |
| AATMO5+PC                           | 1:2                     | 15                | WB     | V                | no       | 38,31         |
| APTEOS+PC                           | 1:2                     | 15%               | WB     | V                | no       | 31,87         |
| APTMO5+PCU                          | 1:2                     | 15%               | WB     | S                | no       | 40,67         |

Mass Loss MFT - examples





Temperature distribution MFT - examples



## Mass Loss Calorimeter (MLC).

- heat flux of 35 kW/m<sup>2</sup>,
- temperature of 690°C.
- piloted ignition
- three samples for each variant
- dimensions 10 cm x 10 cm x 1,8 cm thick

## Wood species:

1. Scots pine
2. Spruce
3. Poplar
4. Beech



| No | Tested formulations (solvent)            |
|----|--|
|    | Control (air dried)                      |
|    | Control (dried at 70°C)                  |
|    | Control (dried at 105°C)                 |
| 3  | 6%AB (White spirit)                      |
| 4  | 6%WAB (Water)                            |
| 5  | 20% LO + 5% APTMOS (White spirit)        |
| 6  | 14% LO + 5% APTMOS - 6%AB (White spirit) |
| 7  | 5% AATMOS - (White spirit)               |
| 8  | 5% AATMOS - 6%AB (White spirit)          |
| 9  | 5% APTMOS (White spirit)                 |
| 10 | 5% APTMOS - 6%AB (White spirit)          |
| 11 | 5% AATMOS (Water)                        |
| 12 | 5% AATMOS + 6%WAB (Water)                |
| 18 | 5%AATMOS + 10%PC(Water)                  |
| 19 | 5%APTEOS +10%PC (Water)                  |
|    | 20% LO (White spirit)                    |
|    | 14% LO + 6%AB (White spirit)             |



LO – linseed oil  
 PC – potassium carbonate  
 AATMOS – [3-(2-aminoethyl amino)propyl]trimetoxysilane  
 APTMOS – (3-aminopropyl) trimethoxysilane  
 APTEOS - (3-aminopropyl) triethoxysilane  
 AB – solvent alkyd resin  
 WAB – waterborne alkyd resin





**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI



| Variant      | No | Parameter                | Pine        |             | Spruce      |             | Poplar      |             | Beech       |             |
|--------------|----|--------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|              |    |                          | no leached  | leached     | no leached  | leached     | no leached  | leached     | no leached  | leached     |
| control      |    | Mass loss [%]            | 80,64-82,36 | 78,42-79,35 | 78,69-79,35 | 78,50-79,25 | 77,47-80,43 | 79,45-80,66 | 77,81-78,13 | 77,67-78,82 |
|              |    | HRR [kW/m <sup>2</sup> ] | 182-218     | 213-223     | 154-156     | 116-119     | 134-159     | 127-160     | 301-321     | 237-274     |
| control 70   |    | Mass loss [%]            | 78,89-80,94 | 76,62-79,25 | 76,74-77,65 | 78,45-79,22 | 78,27-78,46 | 78,56-79,77 | 74,38-76,44 | 75,87-77,76 |
|              |    | HRR [kW/m <sup>2</sup> ] | 212-249     | 208-235     | 125-165     | 122-127     | 154-159     | 131-157     | 239-310     | 270-280     |
| control 100  |    | Mass loss [%]            | 77,43-79,68 | 75,21-77,30 | 75,39-79,17 | 75,44-78,19 | 75,49-78,31 | 77,35-78,86 | 74,04-77,15 | 75,54-77,03 |
|              |    | HRR [kW/m <sup>2</sup> ] | 202-221     | 222-240     | 158-172     | 121-130     | 172-214     | 121-171     | 224-302     | 226-240     |
| 5%AATMS      | 7  | Mass loss [%]            | 69,77-73,43 | 72,27-72,69 | 75,54-76,85 | 73,99-74,71 | 77,69-79,70 | 75,96-76,43 | 74,33-77,73 | 73,59-74,47 |
|              |    | HRR [kW/m <sup>2</sup> ] | 193-235     | 185-210     | 99-106      | 125-132     | 151-163     | 140-156     | 241-260     | 198-226     |
| AB           | 3  | Mass loss [%]            | 76,74-77,70 | 77,56-79,34 | 75,57-76,88 | 76,65-76,87 | 77,24-79,15 | 77,38-78,81 | 76,38-77,04 | 73,51-75,53 |
|              |    | HRR [kW/m <sup>2</sup> ] | 162-239     | 193-210     | 94-111      | 108-119     | 142-164     | 125-141     | 239-273     | 276-283     |
| WAB          | 4  | Mass loss [%]            | 77,05-77,86 | 77,38-78,71 | 76,45-78,06 | 76,79-77,43 | 78,57-79,85 | 77,37-80,05 | 74,32-76,24 | 75,45-76,70 |
|              |    | HRR [kW/m <sup>2</sup> ] | 206-219     | 196-206     | 94-131      | 101-123     | 127-129     | 177-187     | 226-264     | 221-245     |
| AATMS+WAB    | 12 | Mass loss [%]            | 74,27-74,33 | 76,21-77,07 | 75,44-75,50 | 75,06-76,73 | 75,00-75,96 | 77,20-78,01 | 74,07-74,73 | 73,54-75,22 |
|              |    | HRR [kW/m <sup>2</sup> ] | 193-211     | 138-158     | 107-119     | 100-109     | 119-166     | 140-161     | 222-241     | 218-224     |
| AATMS + AB   | 8  | Mass loss [%]            | 75,76-77,26 | 75,45-77,59 | 73,21-75,89 | 76,16-76,50 | 76,48-77,52 | 75,96-76,43 | 73,94-76,07 | 75,66-76,22 |
|              |    | HRR [kW/m <sup>2</sup> ] | 144-152     | 131-141     | 107-116     | 118-132     | 118-170     | 140-156     | 187-248     | 195-228     |
| AATMS+ PC    | 18 | Mass loss [%]            | 63,93-65,07 | 69,03-70,62 | 66,88-67,61 | 70,03-70,95 | 70,47-76,85 | 71,29-74,48 | 66,48-67,84 | 71,51-72,85 |
|              |    | HRR [kW/m <sup>2</sup> ] | 157-211     | 210-229     | 112-138     | 109-157     | 131-198     | 128-202     | 276-327     | 263-298     |
| LO+APTMS+ AB | 6  | Mass loss [%]            | 75,27-77,37 | 77,02-78,55 | 75,13-75,49 | 75,48-78,29 | 76,08-77,52 | 76,46-77,27 | 75,11-76,91 | 76,08-78,59 |
|              |    | HRR [kW/m <sup>2</sup> ] | 161-217     | 172-201     | 94-116      | 105-121     | 165-166     | 160-165     | 246-276     | 239-263     |
| APTMS +AB    | 10 | Mass loss [%]            | 74,84-77,16 | 75,45-77,59 | 72,67-74,81 | 75,25-77,15 | 77,33-78,82 | 76,90-80,00 | 74,49-76,58 | 75,14-75,45 |
|              |    | HRR [kW/m <sup>2</sup> ] | 145-167     | 131-141     | 97-119      | 106-130     | 122-130     | 140-150     | 181-194     | 201-246     |
| APTES + PC   | 19 | Mass loss [%]            | 63,75-64,53 | 68,49-70,34 | 67,64-69,23 | 69,17-70,15 | 67,68-74,49 | 72,64-74,46 | 66,39-67,27 | 72,33-73,03 |
|              |    | HRR [kW/m <sup>2</sup> ] | 186-202     | 214-252     | 108-143     | 105-150     | 111-153     | 172-190     | 223-260     | 245-253     |
| LO+APTMS     | 5  | Mass loss [%]            | 73,44-76,59 | 77,82-80,18 | 76,04-77,44 | 75,88-77,21 | 77,50-80,44 | 75,48-76,83 | 76,72-79,10 | 74,87-76,37 |
|              |    | HRR [kW/m <sup>2</sup> ] | 198-240     | 161-175     | 111-113     | 110-127     | 198-218     | 185-197     | 214-315     | 204-247     |

## Results for control samples

| wariant         | Parameter                    | pine          |               | spruce        |               | poplar        |               | beech         |               |
|-----------------|------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                 |                              |               | Leach.        |               | Leach.        |               | Leach.        |               | Leach.        |
| Control air dry | Mass loss [%]                | 81,79         | 78,77         | 78,99         | 78,76         | 80,02         | 80,04         | 77,93         | 78,41         |
|                 | Max HRR [kW/m <sup>2</sup> ] | 202,79        | 219,33        | 155,31        | 117,75        | 147,50        | 147,83        | 313,31        | 258,54        |
| Control 70      | Mass loss [%]                | <b>79,93</b>  | <b>77,72</b>  | <b>77,14</b>  | <b>78,80</b>  | <b>78,39</b>  | <b>79,30</b>  | <b>75,44</b>  | <b>76,65</b>  |
|                 | Max HRR [kW/m <sup>2</sup> ] | <b>228,95</b> | <b>223,08</b> | <b>147,77</b> | <b>124,77</b> | <b>156,93</b> | <b>146,14</b> | <b>272,75</b> | <b>275,87</b> |
| Control 105     | Mass loss [%]                | 78,34         | 76,44         | 76,30         | 70,63         | 78,26         | 72,51         | 76,03         | 72,03         |
|                 | Max HRR [kW/m <sup>2</sup> ] | 211,41        | 230,27        | 126,73        | 133,39        | 153,56        | 173,03        | 211,78        | 277,31        |





**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI



# Best variants results

| Variant      | Parameter                    | pine          |               | spruce        |               | poplar        |               | beech         |               |
|--------------|------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|              |                              |               | Leach.        |               | Leach.        |               | Leach.        |               | Leach.        |
| AATMOS/PC    | Mass loss [%]                | 64,34         | 69,81         | 67,26         | 70,63         | 73,17         | 72,51         | 67,31         | 72,03         |
|              | Max HRR [kW/m <sup>2</sup> ] | 177,55        | 220,32        | 122,61        | 133,39        | 194,40        | 173,03        | 308,74        | 277,31        |
| APTEOS/PC    | Mass loss [%]                | <b>64,19</b>  | <b>69,17</b>  | <b>68,54</b>  | <b>69,80</b>  | <b>71,39</b>  | <b>73,68</b>  | <b>66,95</b>  | <b>72,73</b>  |
|              | Max HRR [kW/m <sup>2</sup> ] | <b>191,98</b> | <b>231,56</b> | <b>123,42</b> | <b>132,69</b> | <b>131,88</b> | <b>181,17</b> | <b>240,02</b> | <b>249,44</b> |
| OL/APTMOS/AB | Mass loss [%]                | <b>76,18</b>  | <b>77,68</b>  | <b>75,30</b>  | <b>74,31</b>  | <b>76,67</b>  | <b>76,24</b>  | <b>75,74</b>  | <b>74,06</b>  |
|              | Max HRR [kW/m <sup>2</sup> ] | <b>189,99</b> | <b>186,95</b> | <b>106,51</b> | <b>128,84</b> | <b>165,98</b> | <b>148,81</b> | <b>259,64</b> | <b>208,99</b> |
| AATMOS/AB    | Mass loss [%]                | 76,27         | 76,74         | 74,82         | 76,30         | 77,02         | 78,26         | 75,12         | 76,03         |
|              | Max HRR [kW/m <sup>2</sup> ] | 149,40        | 136,11        | 111,56        | 126,73        | 137,31        | 153,56        | 222,23        | 211,78        |

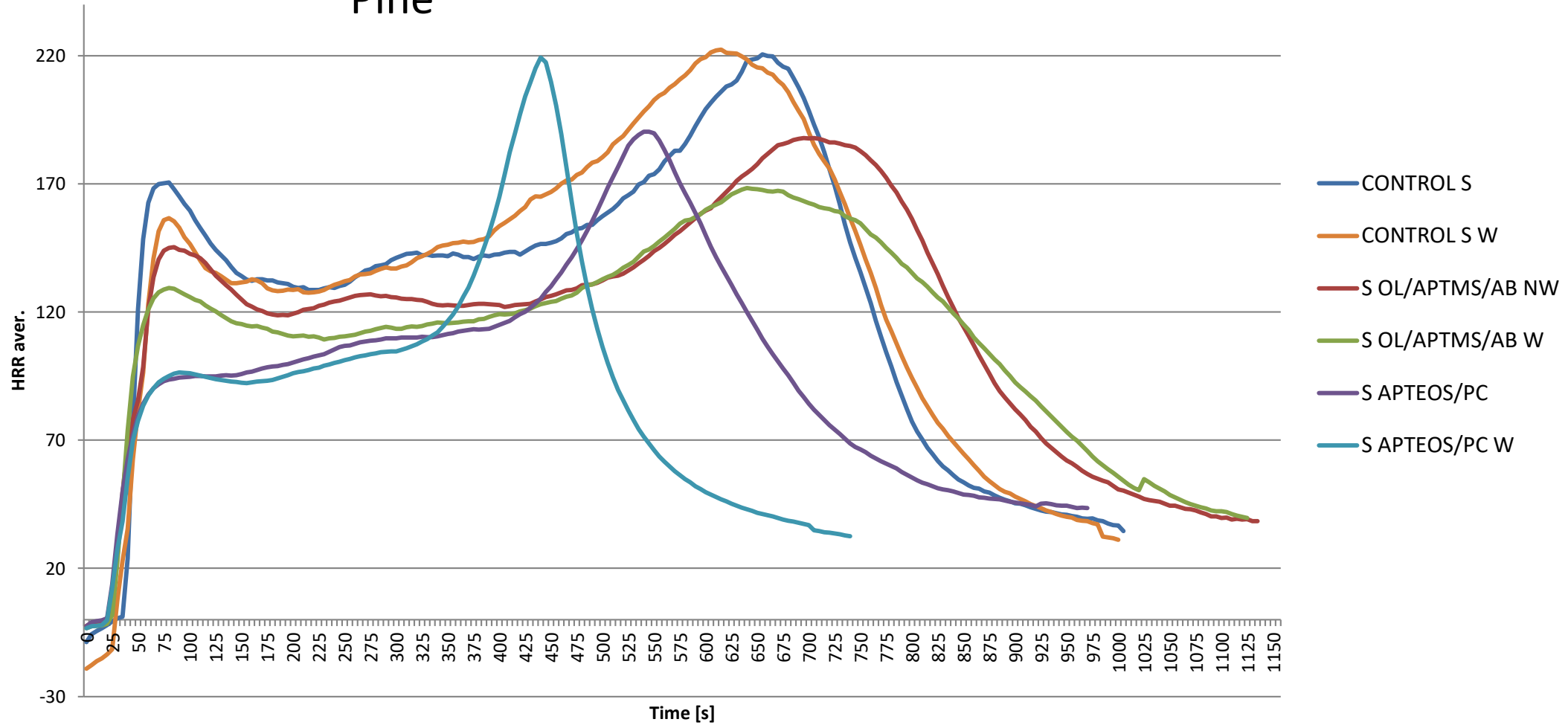


**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI



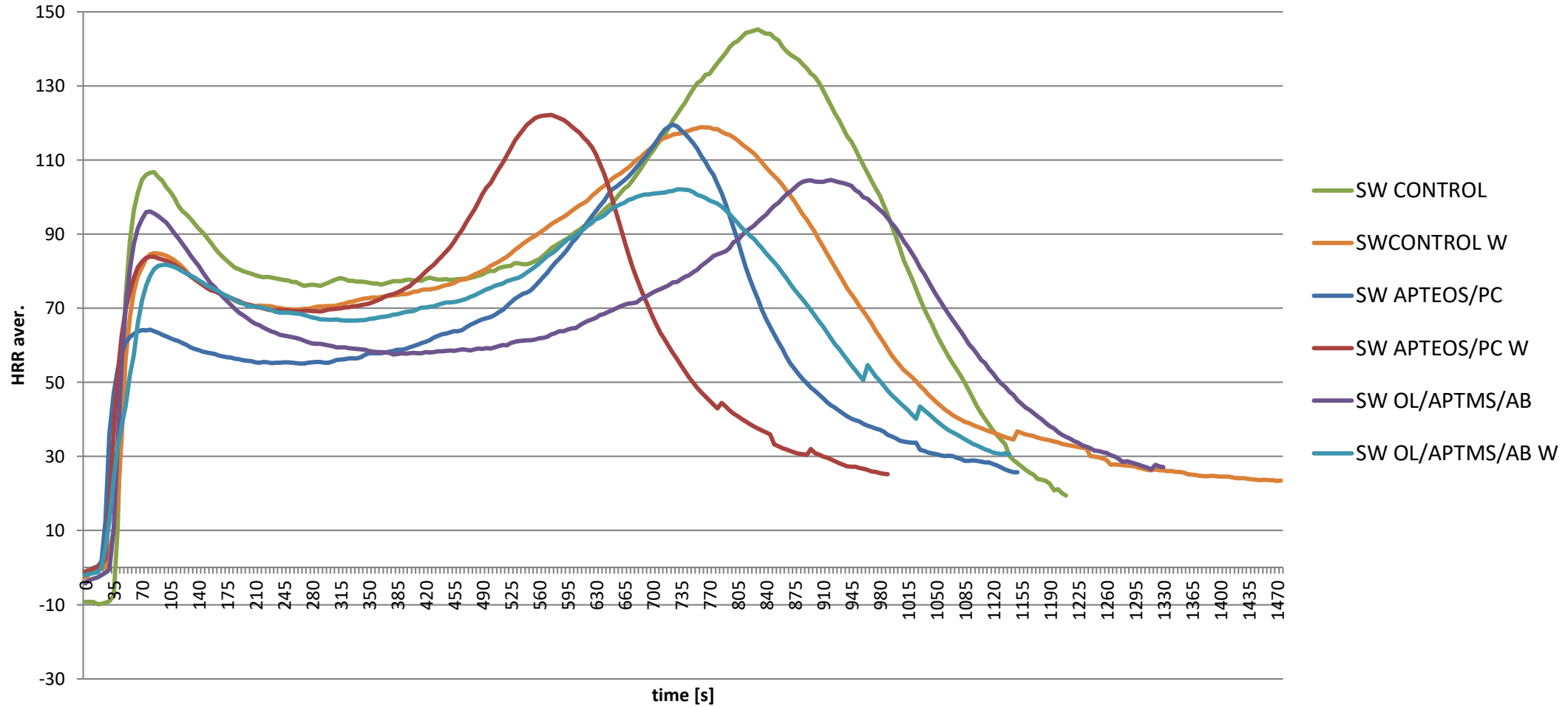
| Formulation            | Retention [kg/m <sup>3</sup> ] |         |        |         |        |         |        |         |
|------------------------|--------------------------------|---------|--------|---------|--------|---------|--------|---------|
|                        | Pine                           |         | Spruce |         | Poplar |         | Beech  |         |
| <b>LO + APTMS + AB</b> | 12,892                         | ± 1,014 | 9,315  | ± 0,670 | 9,831  | ± 0,828 | 14,311 | ± 1,432 |
| <b>AATMOS + AB</b>     | 8,442                          | ± 0,498 | 3,114  | ± 0,560 | 3,476  | ± 0,177 | 8,512  | ± 0,801 |
| <b>AATMOS + PC</b>     | 87,525                         | ± 5,525 | 34,634 | ± 3,101 | 72,436 | ± 4,905 | 88,209 | ± 0,945 |
| <b>APTEOS + PC</b>     | 98,511                         | ± 6,539 | 27,006 | ± 1,660 | 80,105 | ± 5,102 | 89,504 | ± 0,517 |

# Pine



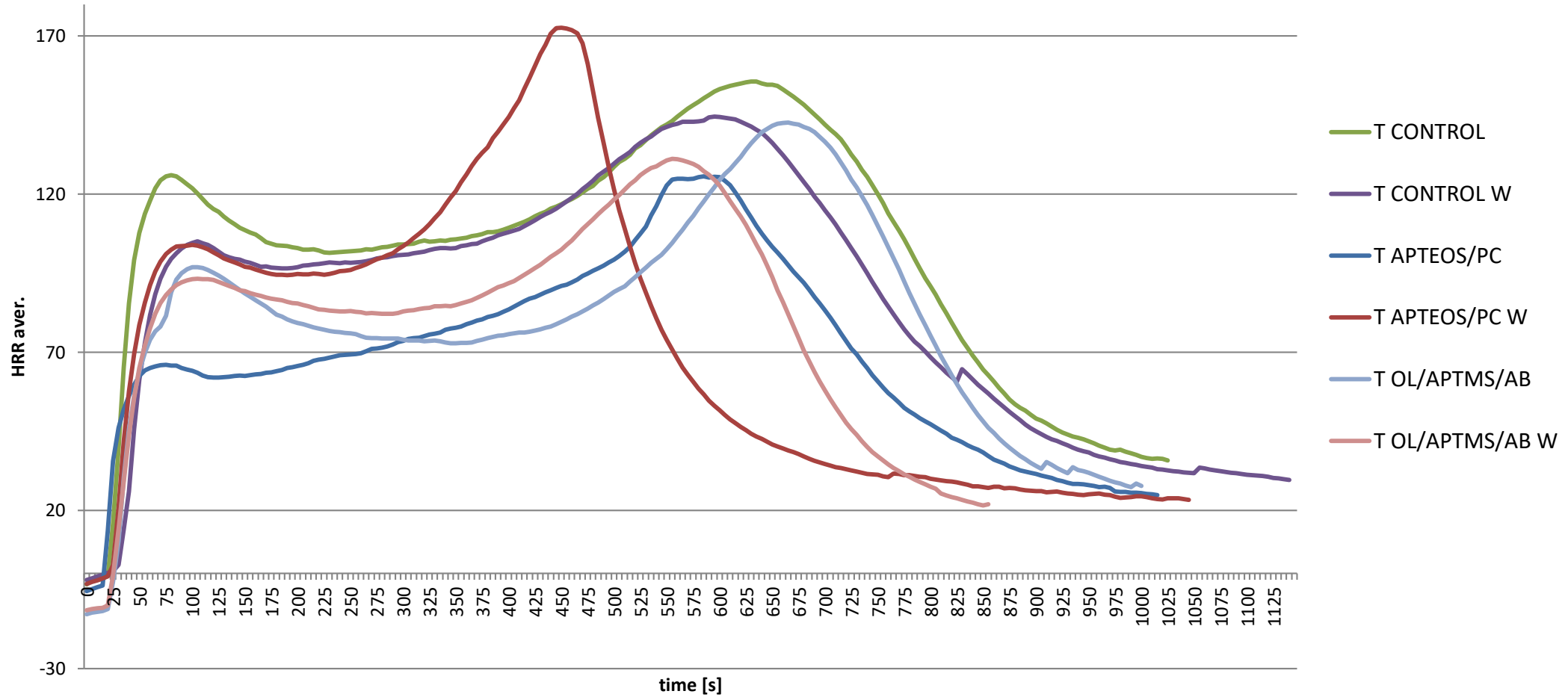
Legend: s – pine, w- leached

## Spruce



Legend: sw – spruce, w- leached

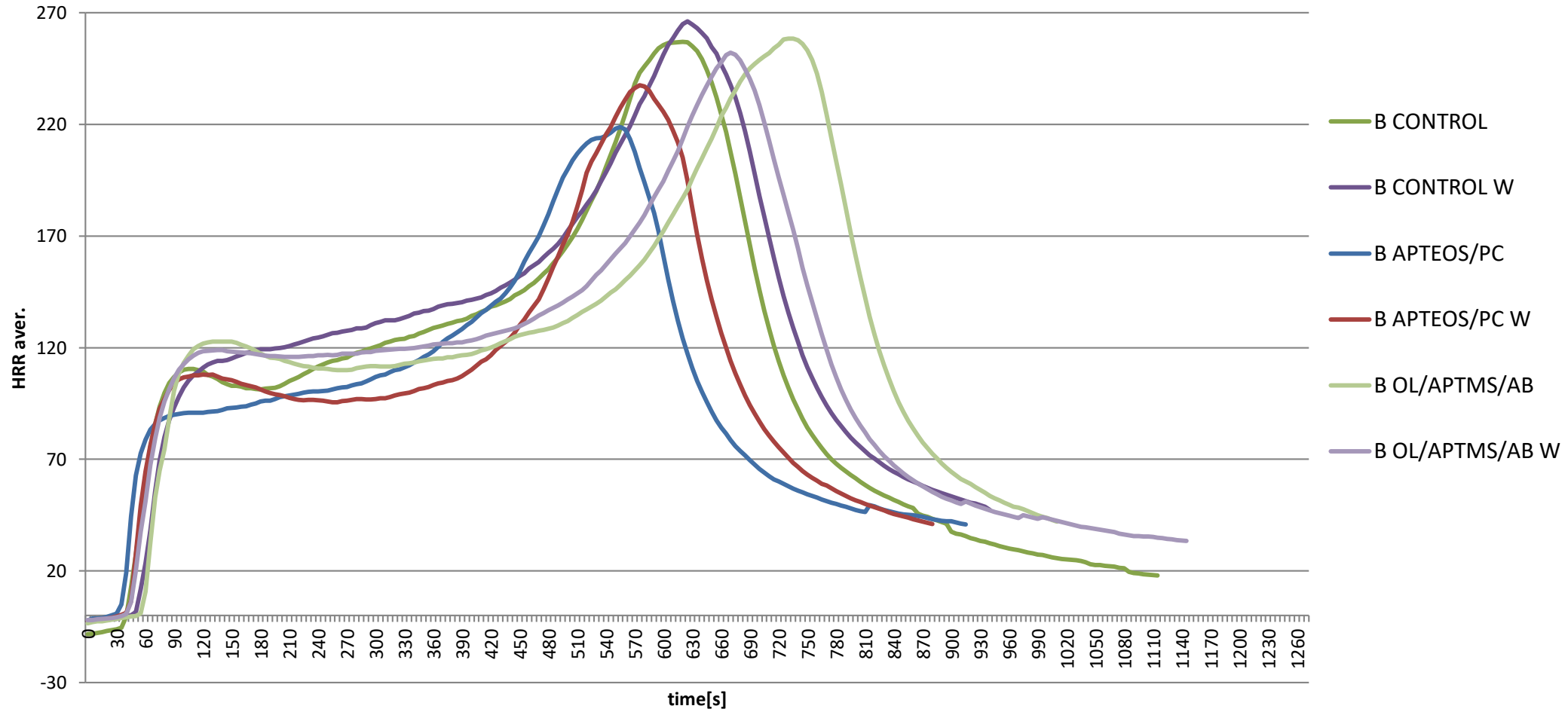
# Poplar



Legend: t – aspen, w- leached



# Beech



Legend: b – beech, w- leached



**NIBIO**  
NORSK INSTITUTT FOR  
BIOØKONOMI



## Summary

Initial investigations of the flammability parameters were made in order to choose on the most effective variants in terms of impact on the flammability protection. Into account were taken the following flammability parameters: mass loss, max. HRR value and the time to ignition.

For the determination of CO and CO<sub>2</sub> emissions during combustion and the extension of the flammability parameters, the tests of APTEOS/PC and OL/APTMOS/AB will be carried out on a full scale cone calorimeter acc. to ISO 5660-1 together with the analysis of the smoke extinction and the consumption of oxygen during combustion.

# THANK YOU FOR ATTENTION



I LIKE WORK IN FIRE LAB 😊