Rubber fires – composition of effluents and influence of parameters

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- Combustion simulation
- Macroscopic thermooxidative degradation of rubber
- High volatile combustion effluents
- Semi volatile combustion effluents
- Conclusion
Combustion and flame

- Oxygen
- Combustion products
- Ignition
- Heat
- Non-combustible gases
- Combustible gases
- Solid phase
- Surface/char
- Vapor phase
Combustion stages

- Initial stage
- Fully developed fire
- Fire decay

Temperature $T$

Time $t$

Ignition

Flash over
## Combustion stages - classification of fire types

<table>
<thead>
<tr>
<th>Fire type</th>
<th>Oxygen¹</th>
<th>Ratio CO₂/CO²</th>
<th>Temperature¹</th>
<th>Irradiance³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Decomposition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Smouldering (self-sustained)</td>
<td>21</td>
<td>N/A</td>
<td>&lt; 100</td>
<td>N/A</td>
</tr>
<tr>
<td>b) Non-flaming (oxidative)</td>
<td>5 to 21</td>
<td>N/A</td>
<td>&lt; 500</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>c) Non-flaming (pyrolytic)</td>
<td>&lt; 5</td>
<td>N/A</td>
<td>&lt; 1000</td>
<td>N/A</td>
</tr>
<tr>
<td>2 Developing fire (flaming)</td>
<td>10 to 15</td>
<td>100 to 200</td>
<td>400 to 600</td>
<td>20 to 40</td>
</tr>
<tr>
<td>3 Fully developed (flaming)</td>
<td>1 to 5</td>
<td>&lt; 10</td>
<td>600 to 900</td>
<td>40 to 70</td>
</tr>
<tr>
<td>a) Relatively low ventilation</td>
<td>5 to 10</td>
<td>&lt;100</td>
<td>600 to 1200</td>
<td>50 to 150</td>
</tr>
<tr>
<td>b) Relatively high ventilation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹) General environmental condition (average) within compartment.
²) Mean value in fire plume near to fire.
³) Incident irradiance on the sample (average).
N/A Not applicable.
Combustion simulation

- Thermogravimetric analyzer (TGA)
  - to determine the macroscopic degradation behaviour under the influence of an approaching flame front

- TGA-infrared spectroscope coupling (TGA-IR)
  - to determine the formation kinetic of high volatile fire effluents

- VCI-combustion oven with different sampling and analysis methods
  - to determine the composition of fire effluents and emission potentials in dependence of burned material and fire conditions
Flame spread

Flammenausbreitungsrichtung

Gas
Sauerstoff
Diffusionsflamme
Pyrolyse Produkte

Oberfläche
Wärme
Feststoff
Wärme
Flame spread simulation

\[ T_t - T_0 = 345 \cdot \lg (8t + 1) \]

- \( T_t \) = burning room temperature at time \( t \),
- \( T_0 \) = burning room temperature at begin,
- \( t \) = time [min]
Macroscopic degradation behaviour

Raw rubber

![Graph showing degradation behaviour of different types of rubber](image-url)
Macroscopic degradation behaviour

Passenger tire tread

Temperatur [°C]

- dm/dT [%/°C]
TGA-IR spectroscope coupling

1. synthetic air bottle with pressure controller,
2. high precision flow regulator,
3. flowmeter,
4. TGA furnace with control unit,
5. heated transfer line with filter unit,
6. IR spectrometer equipped with heated gas cell,
7. waste
Thermooxidative degradation kinetic

High volatile combustion effluents of NBR
VCI combustion oven

1 synthetic air bottle with pressure controller, 2 high precision flow regulator, 3 flowmeter, 4 VCI combustion chamber with digital temperature control unit, 5 sample inlet, 6 double wall burn tube with side outlet, 7 XAD-2 adsorption tube, 8 cooling, 9 charcoal adsorption tube, 10 aluminium-coated gas sampling bag
Composition of fire effluents
- GC-TCD chromatogram

SBR 1500

Intensität

Retentionszeit [min]

O₂, N₂, CO, CH₄, CO₂
Composition of fire effluents
- high volatile fraction

raw polymers
- $\text{CO}_2$, CO, alkanes, alkenes, aldehydes
- Cl containg: HCl, chlorinated alkanes and alkenes
- N containg: HCN, NH$_3$, NO$_x$

mixtures and vulcanizates
- additionally SO$_x$, H$_2$S, small amounts of NO$_x$, HCN depending on recipe and fire conditions
Composition of fire effluents - high volatile fraction

$\text{CO}_2$ emission of SBR in dependency of temperature and ventilation
Composition of fire effluents - high volatile fraction

CO emission of SBR in dependency of temperature and ventilation

![3D graph showing CO yield in dependency of temperature and ventilation](image)
Composition of fire effluents - high volatile fraction

CO/CO$_2$ emission of SBR in dependency of specific surface

@ 600 °C, 400 mL/min air ventilation
Passenger tire tread (SBR based) - semi volatile fraction at 800°C
Products of incomplete combustion - temperature dependency

SBR 1500

retention time [min]

intensity

temperature [°C]

5 10 15 20 25 30

400 600 800 1000
## Composition of fire effluents - semi volatile fraction

<table>
<thead>
<tr>
<th>Elastomer</th>
<th>Products at low temperatures</th>
<th>Products at high temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw polymers</td>
<td>Monomers, oligomers, partially oxygenated, low molecular ketones, aldehydes, products of cyclisation reactions of chain fragments</td>
<td>benzene and polynuclear aromatics, partially saturated, alkylated</td>
</tr>
<tr>
<td>CR additionally</td>
<td>hydrogen chloride, chlorine containing aromatics</td>
<td></td>
</tr>
<tr>
<td>NBR additionally</td>
<td>hydrogen cyanide, aromatics containing cyano groups</td>
<td></td>
</tr>
<tr>
<td>Mixtures and vulcanizates</td>
<td>fragments of additives; carbon black and zinc oxide remain as residue</td>
<td>S- and N-containing aromatics like benzothiazole; zinc oxide remains as residue</td>
</tr>
<tr>
<td>additionally</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- CR: Chloroprene
- NBR: Butyl rubber
Conclusion

- Rubber materials are easy ignitable and nearly inextinguishable.
- The composition of combustion effluents of rubber is strongly dependent on the burned material and the fire conditions (mainly temperature).
- Effluents of an uncontrolled rubber fire are acute toxic.
- Chlorine and nitrogen containing materials possess an additional toxicity.
- The lowest toxicity and the least problematic residues are produced at the fire stage of a relatively high ventilated fully developed fire.
Acknowledgement and references

Acknowledgment

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References

IRC `98 poster and this presentation:

http://www.buethe.onlinehome.de/research.htm


http://www.DIKautschuk.de