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Off-gassing from thermally treated lignocellulosic biomass

Eleonora Borén

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Fakultetsopponent: Hab. PhD Capucine Dupont, Environmental Engineering and Water Technology, IHE Delft Institute of Water Education, The Netherlands.

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Author

Eleonora Borén

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Abstract

Off-gassing of hazardous compounds is, together with self-heating and dust explosions, the main safety hazards within large-scale biomass storage and handling. Formation of CO, CO₂, and VOCs with concurrent O₂ depletion can occur to hazardous levels in enclosed stored forest products. Several incidents of CO poisoning and suffocation of oxygen depletion have resulted in fatalities and injuries during cargo vessel discharge of forest products and in conjunction with wood pellet storage rooms and silos. Technologies for torrefaction and steam explosion for thermal treatment of biomass are under development and approaching commercialization, but their off-gassing behavior is essentially unknown.

The overall objective of this thesis was to provide answers to one main question: “*What is the off-gassing behaviour of thermally treated lignocellulosic biomass during storage?*”. This was achieved by experimental studies and detailed analysis of off-gassing compounds sampled under realistic conditions, with special emphasis on the VOCs.

Presented results show that off-gassing behavior is influenced by numerous factors, in the following ways. CO, CO₂ and CH₄ off-gassing levels from torrefied and steam-exploded biomass and pellets, and accompanying O₂ depletion, are comparable to or lower than corresponding from untreated biomass. The treatments also cause major compositional shifts in VOCs; emissions of terpenes and native aldehydes decline, but levels of volatile cell wall degradation products (notably furans and aromatics) increase. The severity of the thermal treatment is also important; increases in torrefaction severity increase CO off-gassing from torrefied pine to levels comparable to emissions from conventional pellets, and increase O₂ depletion for both torrefied chips and pellets. Both treatment temperature and duration also influence degradation rates and VOC composition. The product cooling technique is influential too; water spraying in addition to heat exchange increased CO₂ and VOCs off-gassing from torrefied pine chips, as well as O₂ depletion. Moreover, the composition of emitted gases co-varied with pellets’ moisture content; pellets of more severely treated material retained less moisture, regardless of their pre-conditioning moisture content. However, no covariance was found between off-gassing and pelletization settings, the resulting pellet quality, or storage time of torrefied chips before pelletization. Pelletization of steam-exploded bark increased subsequent VOC off-gassing, and induced compositional shifts relative to emissions from un-pelletized steam-exploded material. In addition, CO, CO₂ and CH₄ off-gassing, and O₂ depletion, were positively correlated with the storage temperature of torrefied softwood. Similarly, CO and CH₄ emissions from steam-exploded softwood increased with increases in storage temperature, and VOC off-gassing from both torrefied and steam-exploded softwood was more affected by storage temperature than by treatment severity. Levels of CO, CO₂ and CH₄ increased, while levels of O₂ and most VOCs decreased, during storage of both torrefied and steam-exploded softwood. CO, CO₂ and O₂ levels were more affected by storage time than by treatment severity. Levels of VOCs were not significantly decreased or altered by nitrogen purging of storage spaces of steam-exploded or torrefied softwood, or controlled headspace gas exchange (intermittent ventilation) during storage of steam-exploded bark.

In conclusion, rates of off-gassing of CO and CO₂ from thermally treated biomass, and associated O₂ depletion, are comparable to or lower than corresponding rates for untreated biomass. Thermal treatment induces shifts in both concentrations and profiles of VOCs. It is believed that the knowledge and insights gained provide refined foundations for future research and safe implementation of thermally treated fuels as energy carriers in renewable energy process chains.

Keywords

Torrefaction, steam explosion, enclosed storage, CO, CO₂, O₂ depletion, VOCs, Tenax-TA, SPME, process settings, storage temperature, storage time

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