SUMMARY

Contemporary challenges related to the growing global demand for energy and the necessity to reduce emissions of harmful substances encourage the search for alternative, renewable fuel sources. Biomass, particularly that derived from agro-food industry waste, such as apple pomace, walnut shells, and sunflower husks, presents a promising energy potential. The use of woody biomass, as well as biomass from the agro-food sector, is part of broader efforts aimed at more sustainable waste management and the creation of a cleaner environment. In Poland, according to the National Energy and Climate Plan for 2021–2030, a significant share of solid biomass is foreseen in the national energy balance.

The combustion of biomass, although considered an environmentally friendly solution compared to fossil fuels, generates by-products, primarily ash. Its chemical composition is crucial for assessing environmental impacts through landfilling (burden on the environment, e.g., due to contaminant leaching), agricultural application, and pollutant emissions during the combustion process. The ash composition is highly variable and may contain potentially toxic elements (PTEs) such as Pb, Cd, As, Cr, Cu, Ni, Se, and Zn.

This doctoral dissertation presents innovative research focused on a comprehensive analysis of ashes resulting from the combustion and co-combustion of agro-food biomass (apple pomace, walnut shells, sunflower husks, and cherry biomass pellets composed of branches and pits in a 1:1 ratio) with hard coal at temperatures of 400±15°C and 850±15°C. The study analyzed ashes from the combustion/co-combustion of agro-food biomass with hard coal in terms of the content of PTEs, rare earth elements (REEs), uranium (U), thorium (Th), and mineral composition. In the context of the globally increasing importance of critical raw materials, including REEs, for the development of modern technologies, the search for new, sustainable sources for their recovery is gaining priority, in accordance with the European Union's strategy emphasizing the recycling and processing of waste.

Raw woody biomass (alder and birch) and ashes from its combustion were also studied to determine the concentration of PTEs and the impact of environmental factors on wood quality (samples were collected from the Małopolskie Voivodeship and the Bory Tucholskie National Park). Thermogravimetric analysis of alder and birch enabled the evaluation of mass changes as a function of time under a set temperature program, providing insights into their potential for energy use. Water extracts from these ashes indicated that the concentrations of leached sulfate and potassium ions exceeded the permissible limits for pollutants discharged into water and soil.

Chemical, mineralogical, and thermal analyses were conducted using advanced analytical techniques such as ICP-OES/MS (Inductively Coupled Plasma Optical Emission Spectrometry/Mass Spectrometry), AAS (Atomic Absorption Spectrometry), XRD (X-ray Diffraction), SEM-EDS (Scanning Electron Microscopy with Energy-Dispersive Spectroscopy), IC (Ion Chromatography), and TG-DSC-FTIR (Thermal Analysis). These methods allowed for the determination of PTE, REE, U, and Th concentrations in raw biomass and combustion ashes, identification of mineral phases and particle morphology in ash samples, evaluation of components leached into aqueous eluates from ashes, and provided insights into the thermal processes occurring in wood.

The conducted research provides valuable data on the feasibility of burning agro-food biomass (e.g., in pellet form) in individual household heating systems, enables the environmental impact assessment of agro-food and woody biomass combustion, and opens new perspectives for the potential recovery of REEs from ashes.