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Review article

Occurrence and sources of zinc in fuels

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ABSTRACT

Several studies have shown that the presence of high amounts of Zn, in addition to other elements, in fuels can be a cause of operational difficulties during combustion due to corrosion and slagging and can also cause environmental and health problems due to emissions. In nature, Zn is an essential micronutrient for humans, animals and plants, but in excessive amounts it becomes toxic. This paper presents a review on the content of Zn in different fuels used in energy conversion systems. Altogether, over 20 different fuels divided among waste, biomass and fossil fuels were studied. The highest amounts of Zn are present in waste-derived fuels, particularly in Tire-Derived Fuel (TDF). In tires, Zn is used as a vulcanizing agent and can reach concentration values of 9600–16,800 mg $kg^{-1}{}_{DS}$. Waste Electrical and Electronic Equipment (WEEE) is the second Zn-richest fuel; while on average Zn content is around 4000 mg $kg^{-1}{}_{DS.}$, values of over 19,000 mg $kg^{-1}{}_{DS.}$ were also reported. High amounts of Zn, 3000–4000 mg $kg^{-1}{}_{DS.}$, are also found in municipal solid waste (MSW), sludge with over 2000 mg $kg^{-1}{}_{DS.}$ on average (some exceptions up to 49,000 mg $kg^{-1}{}_{DS.}$), and other waste-derived fuels (over 1000 mg $kg^{-1}{}_{DS.}$). Zn can also be found in fossil fuels. In coal, the level of Zn is quite low, on average 100 mg $kg^{-1}{}_{DS.}$, while higher amounts of Zn were reported for oil shale, with values between 20 and 2680 mg $kg^{-1}{}_{DS}$. The content of Zn in biomass is basically determined by its natural occurrence, typically 10–100 mg $kg^{-1}{}_{DS}$.

Contents

Abbreviations: ACZA, Ammoniacal Copper Zinc Arsenate; CCA, Chromated Copper Arsenate preservative-treated wood; EU, The European Union; IEA, International Energy Agency; IPCC, Intergovernmental Panel on Climate Change; MSW, Municipal Solid Waste; PCB, Printed Circuit Board; PVC, Polyvinyl Chloride (here a type of plastic); RDF, Refuse-Derived Fuel; RWW, Recovered Waste Wood; SRF, Solid Refuse Fuel; TDF, Tire-Derived Fuel; UNESCO, United Nations Educational, Scientific and Cultural Organization; WEEE, Waste Electrical and Electronic Equipment; WWF, a conservation organization (previously "World Wildlife Fund").

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1. Introduction

Environmental issues, diminishing fossil fuel sources and increasing fossil fuel prices have considerably increased interest in the utilization of waste and biomass in energy converting systems. Waste fuels are very inhomogeneous and contain high levels of unwanted elements, while biomass fuels are rich in alkali metals. Previous research has shown that the presence of Zn in addition to other elements, e.g., Cl, can lead to operational difficulties in the boilers such as slagging, fouling, and corrosion, and can also contribute to environmental problems and health issues due to pollution [1–7]. Total worldwide emissions of Zn resulting from major anthropogenic sources such as metal production, fossil fuel combustion, and waste disposal were estimated at 57,000 tons/year in the mid-1990s [8].

Worldwide production of Zn is over 11 million tons/year. Galvanizing (steel's protection against corrosion) is Zn's largest use, accounting for over 50% of annual production. Approximately 17% of Zn finds use in die casting and another 17% is used to produce brass (Cu–Zn alloy). The remainder is consumed in compounds such as zinc oxide and zinc sulfate [9]. Around 1.2 million tons/year of zinc oxide are produced globally. Automotive tire production makes up about 20% of the total consumption of zinc oxide, where it is used as the vulcanizing agent of the tire rubber. A large part of the rubber that is not consumed in the tire segment goes into other automotive applications. The other large application area for Zn chemicals is in the production of tiles, ceramics and glass [10].

In fuels used for power generation, the highest Zn content, over 1 wt.% (9600–16,800 mg $kg^{-1}{}_{DS.}$), can be found in waste-derived fuels, primarily in Tire-Derived Fuels (TDFs) [11], Municipal Solid Waste (MSW) (3000–4000 mg $kg^{-1}{}_{DS.}$), and sludge, in which average Zn content is over 2000 mg $kg^{-1}{}_{DS}$. However, the maximum permitted values of Zn in sludge in the EU are set to 2500–4000 mg $kg^{-1}{}_{DS.}$ [12]. Zn can also be present in high amounts in recovered wood waste (RWW) and other waste-derived fuels (~1000 mg $kg^{-1}{}_{DS.}$). The biomass fuels, e.g., forest residues, energy crops and agricultural residues, usually contain 10–100 mg $kg^{-1}{}_{DS.}$ of naturally-occurring Zn. As cited in Chukwuma et al. [13], Zn is an essential micronutrient for plants, animals, and humans. Its deficiency may cause many dysfunctions, but on the other hand, when some specified concentrations are exceeded, it becomes toxic [14].

In this paper, detailed data regarding Zn content in various fuels are presented. Altogether 18 different fuel types used for power and heat production were studied in this work. The fuels to be discussed are presented in Fig. 1.

2. Zn sources and concentrations in selected fuels

2.1. Waste

2.1.1. TDF (Tire-Derived Fuel)

A tire-derived fuel, generally known as TDF, consists of refined scraps of shredded automotive tires. Processing of the TDF includes shredding tires into rubber chips of a certain size [15]. The tire chips are rich in synthetic rubber and contain bead and radial wires, which are removed in certain cases [11,15]. Tires contain high amounts of Zn, which is a vulcanizing agent added to the rubber mainly as ZnO, but sometimes together with small amounts of different organo-zinc compounds [6,16]. High quantities of Zn can be found in both the tread and the wall of tires. Smolders et al. [16] reported that the average amount of ZnO present in car tire tread was 1.2 wt.% and in truck tire tread, it was 2.1 wt.%. This corresponds to 9600–16,800 mg $kg^{-1}{}_{DS.}$ of the element Zn. With regard to flue gas emissions, Zn is of special interest due to its relatively high volatility [11]. It was reported that combustion of tires may increase Zn emissions by a factor of up to 20, which seems

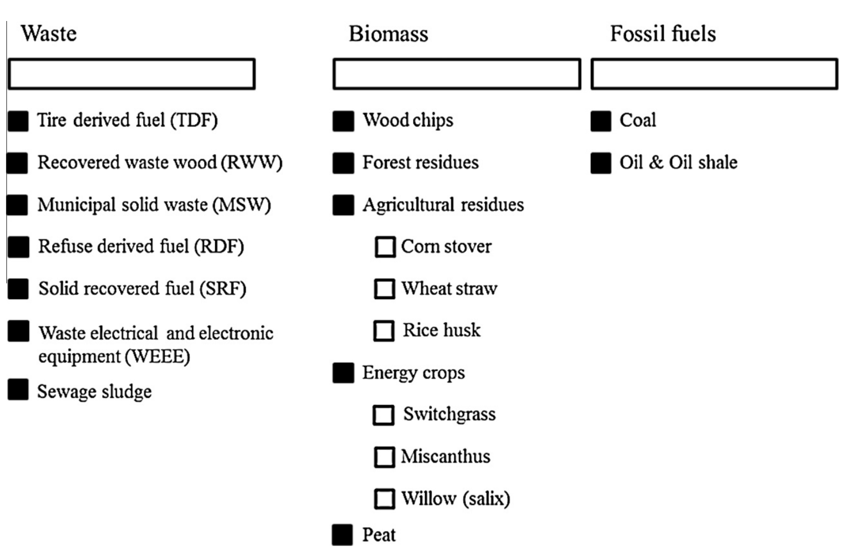

Fig. 1. Fuels studied in this work.