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Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review

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Abstract

The present review discusses the current views on methods to minimise dioxins, namely polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs), formation in MSW incineration systems. The structure of this group of compounds is discussed initially and then the toxic equivalence scale is presented for the most common isomers and congeners in the dioxin family. The current status on dioxin limits imposed in various countries and by various organisations is presented. A detailed analysis of the theories leading to dioxin formation in MSW incineration is given, since, this has been one of the most controversial areas of dioxin chemistry for the past 20 years.

Three dioxin formation theories were considered possible for a long time; (i) from PCDD/PCDFs originally present in the furnace feedstock; (ii) from precursor compounds (foundation formatting molecules which could react rapidly with other groups in the system to form dioxins) in the MSW feed; (iii) from de novo synthesis of smaller, relatively innocuous chemical molecules combining together to form the dioxins. Methods (ii) and (iii) are based on heterogeneously catalysed reactions. Some researchers are considering possible homogeneous thermal reaction formation of dioxin.

This review demonstrates that with the advanced modern MSW combustion systems, option (i) is a most unlikely route and also methods (ii) and (iii) are quite feasible. Based on thermodynamic and kinetic data in the literature, the rate and extent of the formation of dioxins and their precursors by certain mechanisms can definitely be contributing to routes (ii) and (iii). Since even the most advanced MSW combustion systems do not produce complete combustion, predominantly because of inadequate feed preparation and turbulence, some de novo synthesis of precursors can also take place.

These 'de novo precursors' could be carried through the combustion unit adsorbed or absorbed on particulate material such as soot and dust, but also these precursors could be formed during the cooling process by heterogeneous catalytic reactions and go on to form dioxins. The maximum rate of formation of PCDD/PCDFs from both sources lies in the temperature range 300–400 °C. This knowledge of formation rates and mechanisms provides the basis of designing combustion systems. A two stage approach is adopted; firstly, system design to achieve complete combustion and minimise formation; secondly, end-of-pipe treatment systems to remove dioxins.

In the first case, combustion temperature should be above 1000 °C, combustion residence time should be greater than 1 s, combustion chamber turbulence should be represented by a Reynolds number greater than 50,000, good MSW feed preparation and controlled feed rate are also critical. In the second category, very rapid gas cooling from 400 to 250 °C should be achieved, semi-dry lime scrubbing and

Abbreviations: AC, activated carbon; ACSS, activated carbon scrubbing solution; APCD, air pollution control device; APME, Association of Plastics Manufacturers in Europe; ASME, American Society of Mechanical Engineers; BF, bag filter; BPM, best practical means; COT, UK Committee on Toxicology of Chemicals in Food, Consumer Products and Environment; CTZ, critical temperature zone; DOE, Department of the Environment, UK; DIAC, direct injection of activated carbon; DS, dry scrubber; DSI, dry sorbent injection; EADON, toxic equivalence factors proposed by Eadon method; EEC, European Economic Community; EGB, electro granular bed; ESP, electrostatic precipitator; FF, fabric filter; FRG, Federal Republic of Germany; GCP, good combustion practice; HMIP, Her Majesty's Inspectorate on Pollution, UK; HOC, hearth-oven coke; HRGC, high resolution gas chromatography; HRMS, high resolution mass spectrometry; IARC, International Agency for Research on Cancer; K_{ow}, octanol-water partition coefficient; MSW, municipal solid waste; MSWI, municipal solid waste incinerator; NATO, Northern Atlantic Treaty Organisation; NOAEL, no observed adverse effect level; OCDD, octachlorinated dibenzodioxin; OCDF, octachlorinated dibenzofuran; PCB, polychlorinated biphenyls; PCCS, programmable computer control system; PCDD, polychlorinated dibenzodioxin; PCDF, polychlorinated dibenzofuran; PCP, pentachlorophenol; RDF, refuse derived fuel; SCR, selective catalytic reduction/reactor; SDA, spray dry absorber; TALuft, Technische Airbildung Luft; TCDD, tetrachlorinated dibenzodioxin; TCDF, tetrachlorinated dibenzofuran; TDI, tolerable daily intake; TEF, toxic equivalence factor; TEQ, toxic equivalence; USEPA, United States Environmental Protection Agency; WHO, World Health Organisation; WQ, water quench; WS, wet scrubber

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