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A technique to quantify incinerability of municipal solid waste

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ABSTRACT

A technique to quantify the incinerability of municipal solid waste (MSW) called incinerability index or *i*- Index is formulated. Incorporating the 3-E concept (potential environmental impact, energy recovery and economic sustainability), the incinerability can be quantified into a unique number on a scale of 0–100. This helps to assess the feasibility of incineration of MSW and ascertain the sustainability of the waste management scheme. A detailed account of the formulation of *i*- Index is presented in this article. Being a complex multi-criteria decision-making problem (MCDM), the opinions of more than 200 experts were collected through the different stages of its formulation. The relative weighting of the parameters was determined through the analytic hierarchy process (AHP) and normalisation was done using rating curves. Incinerability of the MSW generated in countries belonging to three economic groups, namely, the United States of America (USA), China and India and the *i*-Index values were subsequently determined, which amounted to 72.38, 62.68 and 41.94 respectively. Being an increasing scale index, a high *i*-Index value indicates higher incinerability. This also substantiates how the variation in the composition of MSW across different economies affect the incinerability of the MSW.

1. Introduction

Waste destruction by incineration has become an attractive treatment route in recent times. Incessant increase in waste generation, unavailability of land for disposal and environmental and public health impacts of landfilling have triggered this change. Although incineration is deemed to be a pathway to sustainable waste management, it may not always be a viable disposal technique though, as it largely depends on the waste characteristics, which in turn, is influenced by the local demography, the social status and cultural differences, seasonal fluctuations and topography (Rajaeifar et al., 2017). With the daily municipal solid waste (MSW) generation in countries like China anticipated to be 1.3 million tonnes by 2025 (Hoornweg and Bhada-Tata, 2012), biological treatment may not be an ideal choice for primary treatment. Furthermore, source-segregation, which is an integral element for sustainable solid waste management is seldom practised in developing countries. The treatment and disposal of the resultant heterogeneous MSW is a challenging task, especially with high generation rates. Land-dumping of this heterogeneous MSW can cause severe environmental degradation. Kan et al. (2008) state that land dumps are responsible for nearly 67% of the GHG emissions from the waste sector in Korea, in contrast to about 28% from incineration. Composting of poorly segregated waste results in low-grade compost with low nutrient and high heavy metal content (Annepu, 2012). Nixon et al. (2017) affirmed that poor segregation is the biggest constraint for waste to energy (WtE) in India.

Environmental impact is a crucial criterion, besides the monetary aspect, while determining optimal MSW management strategy (Panepinto et al., 2015). Waste incineration is reported to be an environmentally superior choice in comparison to landfilling through the life cycle assessment studies by Assamoi and Lawryshyn (2012). Besides reducing the GHG emissions, the heat energy generated from waste incineration may also be used for power generation thus marginally reducing the reliance on non-renewable fossil fuels (Ouda et al., 2013). The primary objective of incineration is to dispose of the waste volumes with minimal environmental impact while recovering energy from it (Tabasová et al., 2012) The potential obnoxious pollutant emissions emanating from incineration can be minimised with advanced incineration and air pollution control technology and segregation of waste streams. For instance, WtE plants recently developed in China based on circulating fluidised bed (CFB) technology is reported to have dioxin emissions much less than EU limits (World Energy Council, 2016). Nevertheless, high installation and maintenance costs and labour costs make the technology highly capital-intensive. Hence the

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technology is strongly preferred when the MSW to be fed as input is fit for incineration. The first WtE plant in India at Timarpur was not a success due to erroneously assumed MSW characteristics during its design (Gupta et al., 2015). Similar was the case with incinerators in the resort islands of Malaysia (Abd Kadir et al., 2013).

The choice of the treatment technique may rightly be called a multi-criteria and multi-stakeholder problem (Antonopoulos et al., 2014; Wang et al., 2018). The two primary factors to be considered while choosing the treatment technique is (a) Potential to reduce waste volumes (b) Potential to efficiently manage the waste, with minimal health and environmental impacts (Liu et al., 2017). The decision-makers need to consider the economic viability and the social acceptability of the systems as well, besides considering the improvement of energy and material recovery (Ohnishi et al., 2018). Incineration being a cost-intensive process needs extensive feasibility assessment prior to its implementation. The knowledge of the variability in the waste feed quantity and characteristics is instrumental in ascertaining the environmental and economic feasibility of the technique (Milbrandt et al., 2018). The feasibility of incineration of MSW or the *'incinerability'* of MSW may be defined as the amenability of MSW to be burned to sterile ash with minimal environmental impact, optimum energy recovery and economic sustainability (Sebastian et al., 2018a). Stehlík (2009) asserts that maximum energy output with minimal energy input is the ideal scenario for thermal treatment with energy recovery. The question now though, is, how to determine the incinerability of MSW.

Conventionally Tanner diagram or certain thumb rules were followed to approximately decide on the incinerability of MSW. The first one relies on the proximate analysis of the MSW feed to define a zone of combustibility (Tanner, 1965). The proximity to the point of maximum combustibility defined by 100% volatile fraction, 0% inert content and 0% moisture content was taken as the measure of incinerability (Fig. 1(a)). Another traditionally followed rule uses the calorific value of MSW to decide on the feasibility of MSW incineration, as shown in Fig. 1(b) (Rand et al., 2000). The major drawback of these conventional methods is the negligence of the environmental impact posed by the process.

Most of the feasibility studies over the years fail to offer reasonable weightage to factors like environmental impact, energy recovery and economy of operation in decision-making. With the rise of incineration as an inevitable treatment technique, there is an increased emphasis on the need for an all-encompassing tool for assessing the incinerability of MSW. Since extensive characterisation studies may prove to be tedious, a quick assessment technique/tool for incinerability shall be highly beneficial, especially in the present scenario. Incinerability index or *i*-Index has been developed by the authors with a view to quantifying the incinerability of MSW which may be used for such feasibility studies. The paper elaborates on the concept of *i*-Index for MSW and its potential applications. A detailed step-by-step account of the formulation of i^{-} Index for MSW shall be presented in the subsequent sections. The application of the index shall be demonstrated by deriving an incinerability based ranking of MSW generated from countries belonging to different economic groups, USA, China and India. A detailed demonstration of the calculation of *i*- Index and its various applications shall, however, be presented as a different research paper.

1.1. A new approach to incinerability of MSW: concept of i-Index

Incinerability is a complex, multi-faceted concept with trade-offs among multiple dimensions. While composite indicators can quantify the incinerability of MSW, the method of the formulation can radically affect the measured outcome (Gan et al., 2017). Numerous environmental indices have been reported in the literature to quantify variables which are otherwise immeasurable, viz. air pollution indices (Babcock, 1970; Green, 1966), life cycle index (Khan et al., 2004) etc. The feasibility of incineration of MSW is governed primarily by the properties of MSW, which in turn is determined by its composition. One of the most crucial criteria while making sustainable waste management choices is the threat posed to the environment (Al-Salem et al., 2014). Although energy recovery is not the prime objective of MSW incineration, it is an anticipated added benefit which helps in sustaining the fiscal viability of the operation to a great extent.

i- Index for MSW was formulated such that it not only encompasses the prospect of energy recovery from incineration of MSW but also incorporates the potential of the process to impact the environment while being fiscally feasible. In certain cases, the process may be economical with appreciable energy recovery, but unacceptable due to obnoxious pollutant emissions. Apart from primary pollutants like SO_2, some amount of dioxins and furans may also be released. Further, GHG emissions mentioned earlier also result in environmental distress. While CO_2 is the GHG gas released in large quantities, methane emission is usually not accounted for as it is released in negligible quantities. N_2O emissions, on the other hand, can be regulated if the furnace

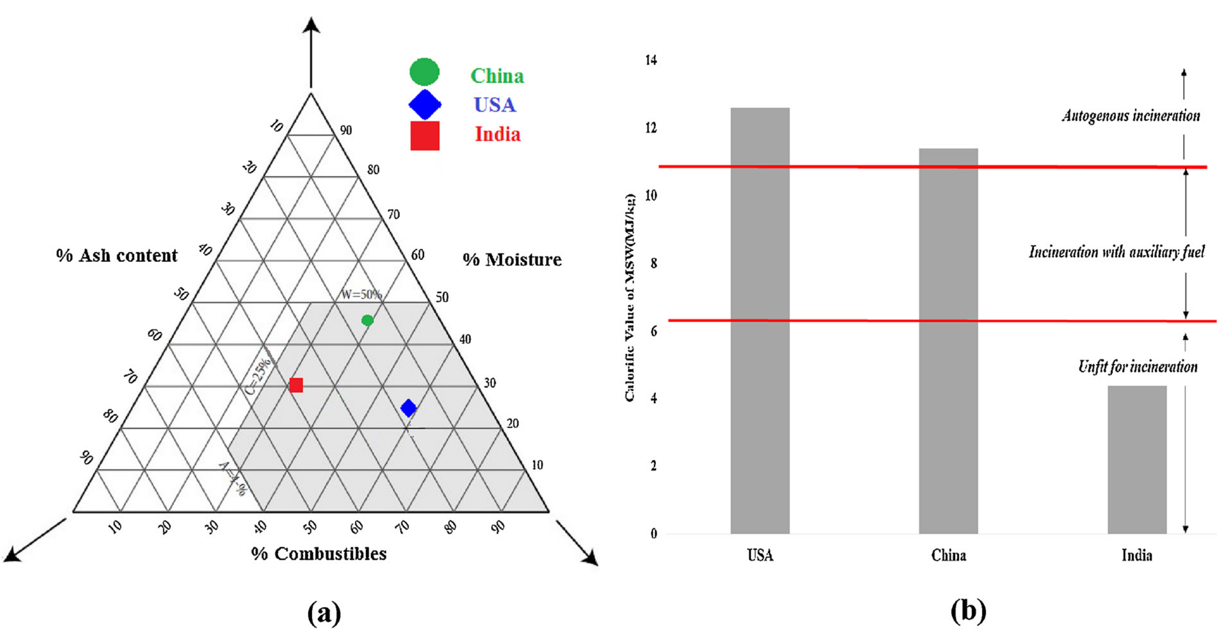

Fig. 1. (a) Position of study areas in Tanner diagram (b) Thumb rule using heat content (Rand et al., 2000; Tanner, 1965).