Environmental Research 156 (2017) 761–769

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Mutagenicity of particle emissions from solid fuel cookstoves: A literature review and research perspective

Guofeng Shen[1]

College of Urban and Environmental Sciences, Peking University, Beijing 100871, China

ARTICLE INFO

Keywords:
Mutagenicity
Solid fuel
Cookstove
Emission

ABSTRACT

Household solid fuel use is a major source of many air pollutants causing severe air pollution and adverse health outcomes. In evaluation of health impacts of household air pollution, it is essential to characterize toxic properties like mutagenicity of residential fuel combustion emissions and exposure assessments. Mutagenicity of emissions from solid fuel cookstoves were analyzed through a literature review. T98 and TA100 strains are two most widely used strains in mutagenic Ames test, and results for these two strains are generally positively correlated though they have different endpoints. Direct and indirect mutagenic activities are positively correlated, and statistically insignificantly different though indirect mutagenic emissions are apparently higher. Mutagenicity emission factors on the basis of fuel energy (MJ) or useful energy delivered (MJd) for solid fuel cookstoves vary in nearly 3 orders of magnitude, ranging from 3.0×10^4 rev./MJd to 1.8×10^7 rev./MJd (or 1.1×10^4 rev./MJ to 4.2×10^6 rev./MJ). Low mutagenic emissions are reported for high efficiency stoves such as a forced-draft one. Mutagenicity emission factors are positively correlated with emissions of $PM_{2.5}$. Relationship between mutagenicity and polycyclic aromatic hydrocarbons (PAHs) emissions is inconsistent among studies as PAHs are minor fractions of toxic organics contributing to the total mutagenicity. Generally, studies on mutagenicity of emissions from household cookstoves are very limited, and future studies are encouraged on mutagenic emissions from different fuel types and household stoves, evaluation of mutagenic activities of both gaseous and particulate emissions, and toxicology and exposure assessments of household air pollution.

1. Introduction

Traditional solid fuels such as wood, agricultural waste, dung cake and coals are still used by ~2.8 billion people around the world for daily cooking, with a large population in developing countries like China and India [Bonjour et al., 2013; Duan et al., 2014]. These solid fuels are often burnt in low efficient stoves producing high amounts of products of incomplete combustions (PICs) like fine particulate matter with diameter less than 2.5 µm ($PM_{2.5}$), black carbon, polycyclic aromatic hydrocarbons (PAHs) and their polar derivatives [Jenkins et al., 1996; Shen et al., 2010, 2011, 2012; Vu et al., 2012]. Due to low combustion efficiencies and high consumption amounts, nearly half of primary $PM_{2.5}$ and PAHs were found to be from residential solid fuel combustion [Huang et al., 2015; Shen et al., 2013]. Consequently, severe air pollutions in both indoor and outdoor air, known as "Household Air Pollution, HAP", are frequently reported in rural developing countries. Many PICs are toxic pollutants causing adverse health outcomes via inhalation exposure like lung cancer. Exposure to HAP has been recognized as one leading environmental risk factor causing ~4.0 million premature deaths globally.

Many efforts are making to obtain reliable pollutant emission factors from residential solid fuel combustion, so as to reduce uncertainties in emission inventories and air quality modelling, as well as to evaluate performance of improved high efficiency stoves and clean fuels that may be further adopted in intervention programs. Meanwhile, from the point of health protection and exposure assessment, it is essential to characterize toxicity of emissions and HAP, and consequently health risks. Mutagenicity of emissions and indoor/outdoor ambient particles is one area with growing interests. Mutagenicity is usually evaluated through the *Salmonella* assay (also known as Ames test), which is considered to be a deceptively simple but widely used tool [Claxton et al., 2010]. For example, Bell and Kamens (1990) evaluated mutagenicity of combustion particles from several biomass fuels including dried cow dung, coconut shell, and crop residue. Kim Oanh et al., (2002) tested mutagenicity of emissions from the sawdust briquette, wood and kerosene burning in Thailand. Mukherji et al. (2002) compared mutagenic emissions from wood, dung cake and biofuel briquette combustion in several traditional stoves in India.

E-mail address: gfshen12@gmail.com.
[1] Present address: ORISE postdoctoral fellow at National Risk Management Research Laboratory (NRMRL), U.S. Environmental Protection Agency, RTP, Durham NC 27709.

http://dx.doi.org/10.1016/j.envres.2017.05.001
Received 16 December 2016; Received in revised form 7 March 2017; Accepted 2 May 2017

Recently, Canha et al. (2016) evaluated mutagenicity of aerosols in emissions from domestic combustion processes of a variety of biomass fuels during the devolatilisation and flaming/smouldering phases. Multu et al. (2016) reported mutagenicity and pollutant emissions from wood combustion in three-stone fire, a natural-draft stove and a forced-draft stove, and found that though mutagenicity was significantly reduced in emissions from a forced-draft stove in comparison with a natural-draft stove and three-stone fire, the mutagenic activity on the basis of fuel energy was still comparable to that for diesel exhausts.

With interests on research status and data gaps of mutagenic emissions from household cookstoves, the present study conducted a literature review on mutagenicity of emissions from cookstoves, with main focuses on 1) which strains are used in mutagenicity assessment, 2) is there any difference between direct and indirect mutagenicity, 3) comparison of solid fuel cookstove emissions with other sources, and 4) contributions of polycyclic aromatic compounds.

2. Method

Literature search was done via Web of Science, Thomson Reuters from both Web of Science Core Collections databases of Citation Indexes and Chemical Indexes. The search was conducted by finding the following words: "Mutagenicity & combustion", or "Mutagenicity & cookstove", or "Mutagenicity & emission", or "Mutagenicity & particle", or "Mutagenic emission" in the Topic, instead of Keywords or Title so as to cover as many as possible studies included from the first round search. After removing duplicated records, remaining articles were reviewed based on title and abstract. Articles on mutagenicity of emissions from household cookstoves were download and read in full text. A total of 852 articles were found from the database. While a large number of studies are for mutagenicity of particles in ambient air, emissions from vehicle emission (diesel, biodiesel or gasoline), and some past studies evaluated mutagenicity of emissions from industrial boilers and/or residential heating finances (Alfheim et al., 1983; Lewis et al., 1988; Löfroth et al., 1986; Löfroth, 1978; Moller et al., 1983; Nielsen et al., 1992; Nielsen and Jensen, 1991; Yao and Xu, 1991), a limited number of studies (16 studies, and two were on mutagenicity of gas stove emissions (Monarca et al., 1998; Hannigen et al., 1994) focused on mutagenicity of emissions from household cookstoves. Studies by Kim Oanh et al. (2002), Mukherji et al. (2002) and Multu et al., (2016) reported mutagenic emission factors on the basis of fuel mass (kg), fuel energy (MJ) and/or per unit useful energy delivered (MJd), whereas other studies on mutagenicity of cookstove emissions reported mutagenic activities per unit particle mass or per mass of extracted organic matter (EOM). The studies by Vu et al. (2012) and Canha et al. (2016) tested mutagenicity of PAH extracts only, while other studies measured mutagenic activity of the whole extract.

3. Results and discussion

3.1. Strains used in Ames tests for mutagenicity assays

TA98, TA100, TA104 and YG1041 are typical strains used in Ames tests to evaluate mutagenicity, and others like TA1538, TA1535 and TM677 are sometimes used in past studies. Addition of a metabolic activation (e.g. S9 mix) or not is often conducted to detect indirect and direct mutagenicity, respectively. It is believed that TA98 and YG1041 detect mutagens that cause frameshift mutations while TA100 and TA104 detect mutagens that induce base-substitution mutations. While Mutlu et al. (2016) tested mutagenicity using all these four strains, most studies used one or two strains in the mutagenicity study. Of these strains, TA98 and TA100 are two most widely used strains.

Fig. 1 compares detected mutagenicity of particles in solid fuel cookstove emissions between the TA98 and TA100 strains. For both direct and indirect mutagenicity, detected results using TA98 strains were positively correlated with that from TA100 assay results ($p < 0.001$). The mutagenicity activities from the TA100 assay were higher than those from the TA98 assay, in 10 of 15 cases of indirect mutagenicity (with S9), and 11 of 15 direct mutagenicity assay cases (without S9). In the study by Asita et al. (1991), mutagenic potency (in the unit of revertants per microgram condensate) of 5 wood smokes showed more mutagenic in TA100 + S9 than in TA98 + S9, but another wood type, mahogany, only had mutagenicity activity in TA98 + S9 test. But when they examined the ratios of colonies numbers on test plates to the control plates, higher ratios were in TA98 compared to TA100, seemly suggesting more mutagenic potentials in TA98 than in TA100. Note that a comparison might be difficult since the spontaneous reversion frequency was higher in TA100 compared to TA98 (Asita et al., 1991), and the end points were different (Mutlu et al., 2016). Therefore, it can be expected that a generally positive correlation exists between the TA98 and TA100 mutagenicity assay, at least in solid fuel cookstove emissions, but it is difficult to conclude that which one show a high mutagenic potency.

3.2. Mutagenicity of particles from solid fuel cookstoves

Fig. 2 compares measured direct and indirect mutagenicity of particles emitted from solid fuel cookstoves. As seen, statistically positive correlations exist between direct and indirect mutagenicity, for both TA98 and TA100 strains. It appears that particle mutagenicity

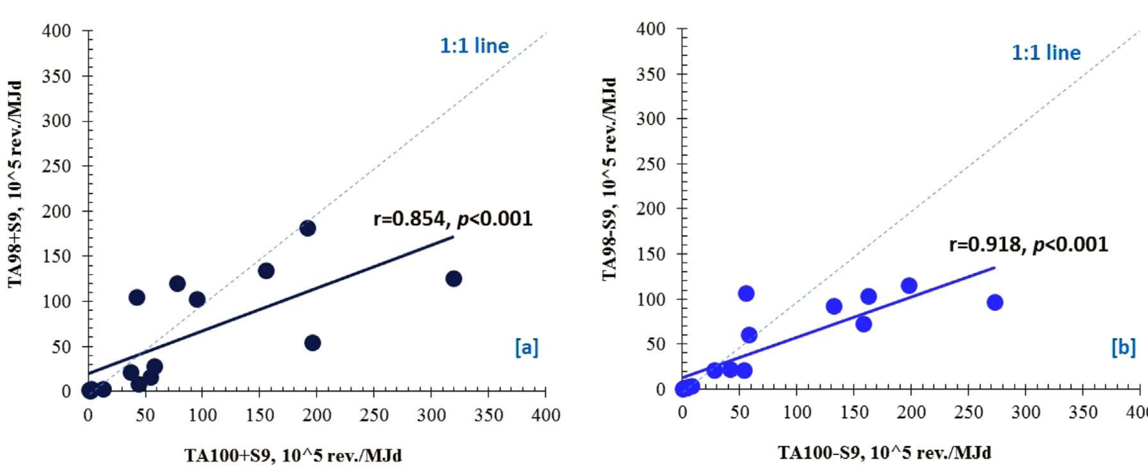

Fig. 1. Comparison of TA98- and TA100-based mutagenicity activities of particles emitted from household solid fuel combustions. [a] indirect mutagenicity with S9, [b] direct mutagenicity without S9.