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# Co-combustion of paper sludge in a 750 t/d waste incinerator and effect of sludge moisture content: A simulation study

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ABSTRACT

Co-incineration with municipal solid waste (MSW) is an efficient method in disposal of paper sludge (PS). CFD technology was adopted to verify the possibility of different blending ratio of sludge to combust with MSW in a 750 t/d waste incinerator, and to predict the impact of different moisture content of sludge on co-combustion. In this paper, the reliability of the numerical model is verified by comparing predicted results with operating data; the sludge which contain 30%, 40%, 50%, 60% and 67% moisture content were blended with MSW by the mass proportion of 5% (wet basis, the same below), 10%, 15%, 20% and 25%. The simulation shows that mass residual on bed increases from 19.8% to 27.6% with the mass percentage of sludge rising from 5% to 25%; as the moisture content in sludge increased, the volatiles release and fixed carbon burning are both delayed. The solid gasification efficiency has a negative correlation with blending ratio of sludge and moisture content of sludge. The NO emission is observed to be positively correlated to the percentage of sludge and the highest is not higher than 162 mg/Nm$^3$. Raw paper sludge with high content of water will aggravate coking and corrosion on rear flue wall because of local high temperature. The result indicates that co-combustion of 25 wt% sludge (up to 67% moisture) with MSW is feasible which maintains the furnace temperature, mass residual and several pollutants in allowable range. However, partially dried paper sludge is more proper for incinerator in the consideration of mitigating corrosion. The current work greatly help to understand the effect of paper sludge and its moisture content in large-scale waste incinerator.

## 1. Introduction

Sludge is a by-product of waste water treatment [1]. With the development of industrialization and urbanization process, sludge production increased year by year to form a serious environmental threat [2], which needs to be solved urgently. In 2007–2013, the average annual growth rate of total sludge produced in China reached 13%[3] and 7.12 million tons of dried sludge was produced in 2014 [4]. There are three main methods of sludge disposal: landfill, composting, incineration or thermal conversion [5]. Landfill is limited to application in Europe for some environmental problem, for example, occupying large land area, leachate difficult to deal with and may affect the groundwater quality and even caused secondary pollution. The sludge usage of composting is also restricted for harmful ingredients in sludge such as heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenyls [6]. In contrast, incineration is more acceptable due to its ability to achieve fast handling, reducing volume by 70% and completely eliminating pathogens and harmful organic substances [7].

The heating value of wet sludge is not high enough to support stable incineration so that auxiliary fuel is usually involved [8] which raises the operation cost of incineration. The organic contents of sludge is very low in southern China therefore self-combustion without fuel input cannot be achieved if the moisture content of sludge higher than 50% [9]. Moisture content is the key factor influencing the performance of sludge in incineration, including combustion completeness, energy recovery and pollutant emission [10]. Besides, a large flue gas treatment system is needed for sludge incineration plant to prevent secondary pollution, which further push up the cost of investment and operation. Therefore, co-incineration of sludge and municipal solid waste (MSW) is proposed, considering the problem associated with combustion of wet fuel can be avoided and the cost of sludge disposing can be cut down. Moreover, the waste incineration plant already has complete system for flue gas treatment, helping avoid the secondary pollution to atmosphere and water. However, the mass ratio of sludge in mixed fuel which make co-incineration feasible has no uniform standard. Instead, it varies on incinerator type and scale, heating values, moisture content and other factors.

Many studies focusing on the co-incineration of sludge have been

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**Nomenclature**

| | |
|---|---|
| b | power index for NO formation reaction |
| D | mass diffusion coefficients, $m^2 s^{-1}$ |
| H | enthalpy, $J kg^{-1}$ |
| $\Delta h_k$ | heat effect for *k*th process or reaction, $W m^{-3}$ |
| p | pressure, Pa |
| $S_a$ | particle surface area, $m^2 m^{-3}$ |
| $S_{gj}$ | mass source term of gaseous species $Y_{gi}$, $kg m^{-3} s^{-1}$ |
| S | mass source term, $kg m^{-3} s^{-1}$ |
| $S_s$ | mass loss rate from solid ($S_s = R_{evp} + R_V + R_C$), $kg m^{-3} s^{-1}$ |
| t | time, s |
| T | temperature, K |
| V | vertical velocity, $m s^{-1}$ |
| x | co-ordinate in the direction of grate length, m |
| X | solid mass loss fraction, mass fraction of pollutants |
| y | co-ordinate in the direction of bed height, m |
| Y | mass fraction of species |
| ε | emissivity |
| ϕ | void fraction in the bed |
| ρ | density, $kg m^{-3}$ |
| λ | thermal conductivity, $W m^{-1} K^{-1}$ |

*Subscripts*

| | |
|---|---|
| b | bed |
| g | gas |
| i | species in solid, i.e., moisture, volatile matter, fixed carbon and ash |
| j | species in gas, i.e., $O_2$, $CO_2$, CO, $NH_3$, NO, $N_2$, $H_2$, $CH_4$ and $H_2O$ |
| s | solid |
| sb | bulk density |

carried out. The release and combustion of volatiles during sludge combustion in fluidized bed combustors were analysed by Werther et al. [11]. They also paid attention to how the high content of nitrogen of sludge influenced the NOx emissions. Lee et al. [12] carried out experiments on co-combustion of paper sludge and high-calorific industrial wastes in a pilot-scale industrial incinerator. They pointed out that the high CO emission that mainly came from the rapid vaporization of volatiles of industrial waste and could be reduced by blending sludge into industrial waste. And if the total heating value of the fed fuel was lower than 750,000 kcal/h, for 25–30% of sludge co-firing, the temperature of gases exiting the secondary combustion chamber might be lower than that required by regulations. Vamvuka et al. [13] investigated the possibility of co-processing paper sludge and coal in power plant by thermo gravimetric analysis. They indicated that the inorganic ingredients of sludge hinder the combustion process. The combustion reactivity showed no remarkable improve after sludge and coal were mixed. But when the minerals in ash of sludge were removed by acid washing, the releasing of volatiles and mass loss rate were promoted remarkably. It probably proved the minerals in paper sludge as inert substances, inhibiting thermal decomposition process. Hu et al. [14] gave a combustion character and kinetics analysis to paper mill sludge, municipal solid waste and their blends. Significant synergistic effect was observed in co-combustion. When the blending ratio of paper mill sludge was less than 30%, the mixed fuel showed a good combustibility. Lin [15] researched the effect of co-incineration of sewage sludge and MSW in a 450 t/d incinerator, using computational fluid dynamics analysis. Wet sludge (83.2% moisture) and semi-dried sludge (55% moisture) were blended into MSW by different mass percentage. Results showed temperature, ignition character and other indicators, drawing the conclusion that 10% of wet sludge or 20% of semi-dried sludge can maintain incineration to meet the requirements of environmental regulations.

However, the lower heating value (LHV) of MSW in Lin's study is 6703.4 kJ/kg, lower than the current average value of MSW in Guangzhou which is around 7980 kJ/kg. The cause is that composition of MSW changed very fast during the last decades. In Guangzhou, for example, food residue and plastics accounted for 76.1% and 9.6% respectively in MSW in1994, and they accounted for 37.8% and 25.5% respectively in 2011 [16]. More plastic and less water contribute a lot to the increase of heating value of MSW. As a result, due to the

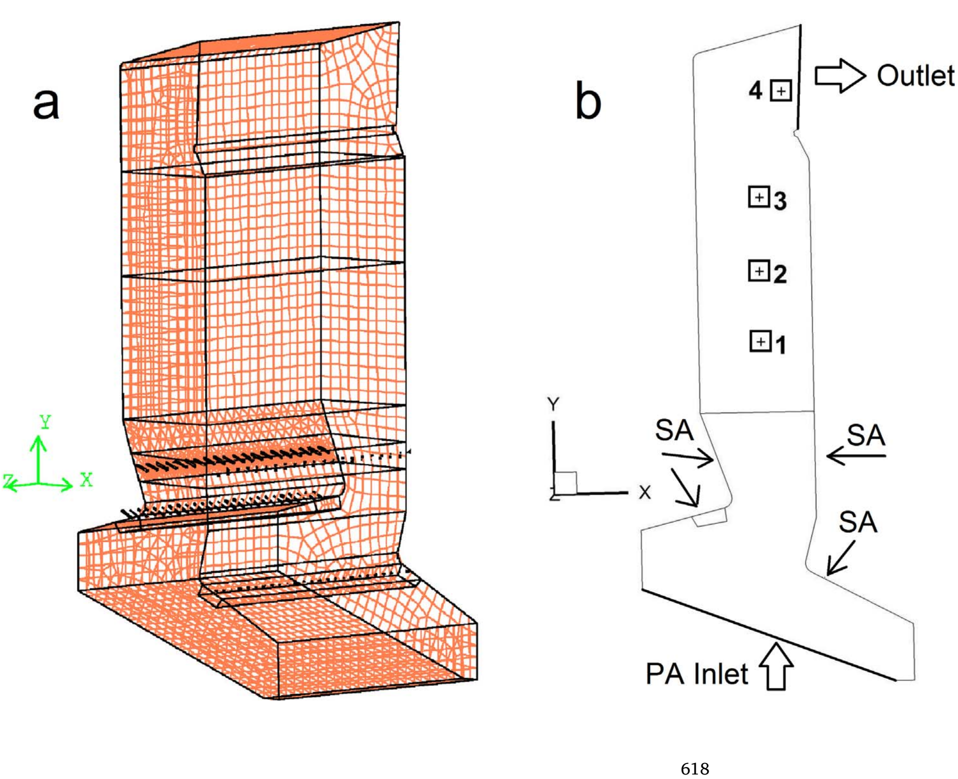


**Fig. 1.** (a) Mesh scheme applied to incinerator. Total volume meshes 675,088 (fewer and sparser meshes are shown for pure clarity); (b) Schematic of the incinerator furnace. PA – primary air, SA – secondary air.