Transport and Reaction Phenomena of Municipal Solid Waste (MSW) on WTE Grates

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Background

The MSW fuel is highly non-homogeneous (composition, moister, particle size, shape, and density).

- Simulate the behavior of solid waste particles with transport and combustion phenomena
- Develop a mathematical model to characterize and quantify flow and mixing MSW on a reverse acting grate

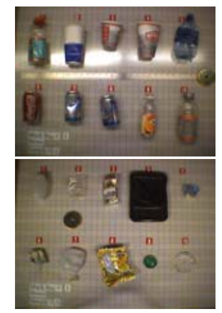
Physical and chemical transformations in bed

- Moisture evaporation in the drying process
- Volatilization in the gasification process
- Combustion of volatile matters
- Combustion of fixed carbon within bed
- Heat generation by combustion of volatile matters
- Heat generation by combustion within bed
- Equation describing dynamic heat balance within bed

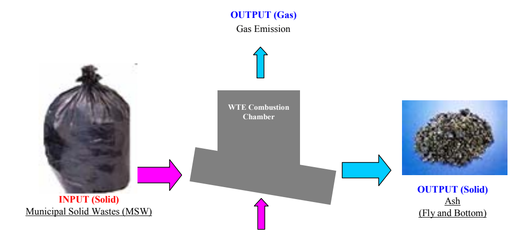
Objectives

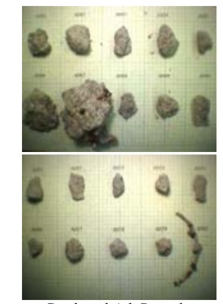
Prediction of transport and chemical phenomena of MSW particles

- Coupling the Particle Size Distributions (PSDs) with the Shrinking Core Model (SCM)
- Comparing the results with the measured data (NYC-MSW)

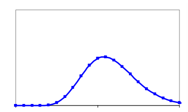


MSW Particles

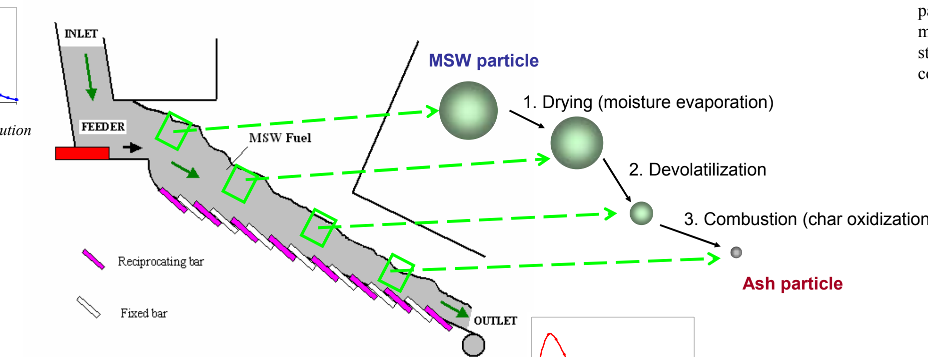


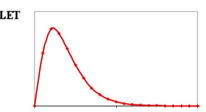


Combined Ash Particles



MSW particle size distribution





Ash particle size distribution

Combustion and transport phenomena of one particle in a MSW bed on the traveling grate

Results and Discussion

Chemical Reaction Control

$$f(D,t)=(1-X_D)=\left(1-\frac{k_{rm}t}{D}\right)^3$$

Film Diffusion Control

$$f(D,t)=(1-X_D)=\left(1-\frac{k_{mn}t}{D}\right)$$

Ash Diffusion Control

$$1-3(1-X_D)^{\frac{2}{3}}+(1-X_D)=\left(\frac{k_{dn}t}{D^2}\right)$$

Overall conversion or fraction reacted

$$OverallConversion=\int_0^{\infty} f(D,t)(f_p(D))dD$$
$$=1-\int_{D_t}^{D_{\max}} f(D,t)\frac{1}{\beta^{\alpha}\Gamma(\alpha)}D^{\alpha-1}e^{-\frac{D}{\beta}}dD$$

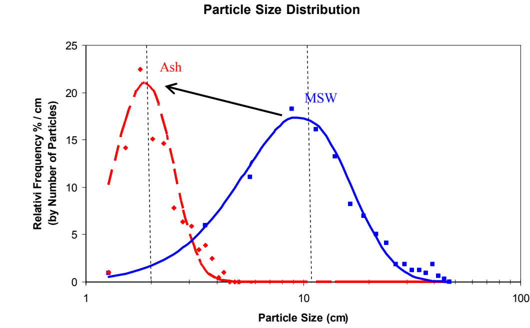
Ash particle size distribution

constant a = 0.3 X 100
parameter $\alpha = 12$
parameter β =0.17
mean $\mu = 2.04$
standard deviation $\sigma = 0.5889$
covariance CV= 3.46

$$f_p(D)=a\cdot\frac{1}{\beta^{\alpha}\Gamma(\alpha)}D^{\alpha-1}e^{-\frac{D}{\beta}}$$

MSW particle size distribution

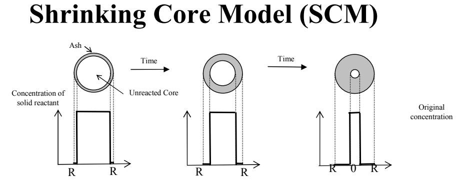
constant a = 2.5 X 100
parameter $\alpha = 4$
parameter β =3.2
mean $\mu = 12.8$
standard deviation $\sigma = 6.4$
covariance CV= 2



Particle size distributions (PSDs) by particle numbers of residential MSW and combined ashes in NYC: (lines: estimated gamma distributions, dots: experimental data)

Calculation Methods

Shrinking Core Model (SCM)



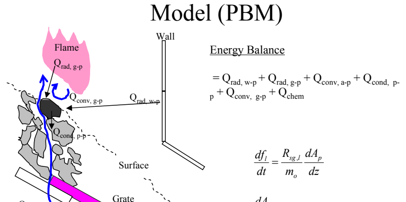
Energy Balance

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T_p}{\partial r}\right)=\frac{\rho_c C_{pc}\partial T}{\lambda_c \partial t}$$

Mass Balance

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial \rho_{O_2}}{\partial r}\right)=\frac{R_{O_2}}{r_N D_{O_2}}$$

Shrink core model is combined with Packed Bed Model (PBM)



Energy Balance

$= Q_{rad,\,w\text{-}p} + Q_{rad,\,g\text{-}p} + Q_{conv,\,a\text{-}p} + Q_{cond,\,p\text{-}p} + Q_{conv,\,g\text{-}p} + Q_{chem}$

$$\frac{df_l}{dt}=\frac{R_{sg,l}}{m_o}\frac{dA_p}{dz}$$

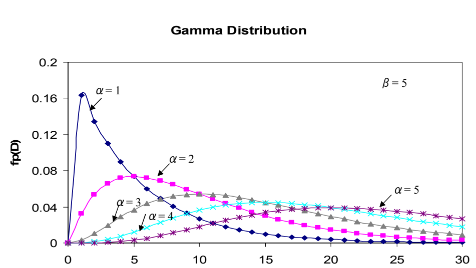
$$\frac{dA_p}{dz}=afA(1-\varepsilon)$$

Particle Size Distribution (PSD)

The Gamma distribution is one of the common particle size distributions

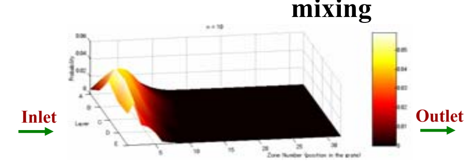
$$f_p(D)=a\cdot\frac{1}{\beta^{\alpha}\Gamma(\alpha)}D^{\alpha-1}e^{-\frac{D}{\beta}}$$

$f_p(D)$: the Gamma distribution
a : constant
D : particle size
α , β : positive parameters

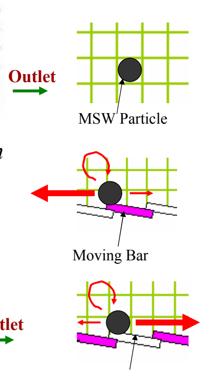


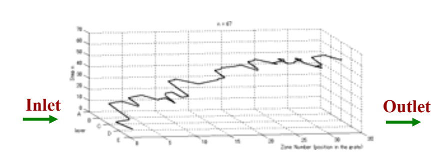
Future Work

Integration with the stochastic model for MSW mixing



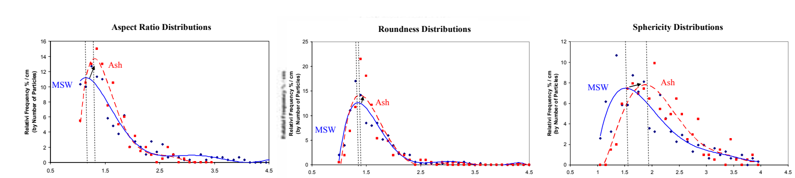
Particle distribution by positions on the bed

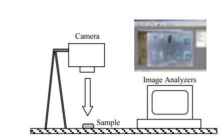




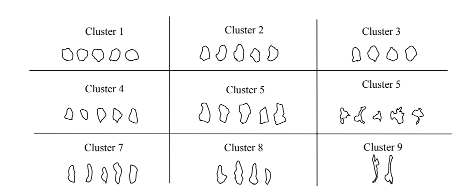
Tracing a behavior of one particle on the bed

Integration with Shape Factor Distributions (SFDs)





The image analyzer system, outlining the shapes of particles regarding length, width, perimeter, area



Particle Outlines Representing 9 Clusters (Ash Particles)