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Computational modeling of the combustion of coal water slurries containing petrochemicals

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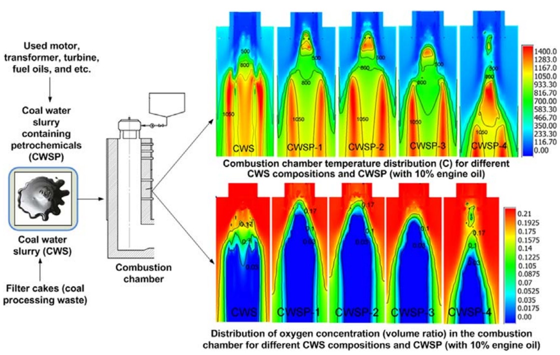
GRAPHICAL ABSTRACT



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ABSTRACT

The combustion predictive model was developed based on the results of experiments with coal water slurry and coal water slurry containing petrochemicals. Unlike other known models, it takes into account the effect of liquid flammable component (in particular, engine oil waste) on the main mass and heat transfer as well as other physical and chemical processes in the combustion chamber. The main differences, conditions and characteristics of the combustion of coal water slurries containing petrochemicals and without additives have been studied theoretically with different defining parameters: fuel composition, component properties, and furnace chamber temperature. Temperature fields and volumetric concentration distribution of combustion products in the furnace chamber are established for fuel compositions based on water, coal, and industrial oil waste. Temperatures and concentrations for both the initial fuel components and their combustion products are established at different points of the furnace chamber for various component concentrations, properties, and furnace air temperatures. The main research findings are the quantitative differences between the characteristics of ignition and combustion of slurries with and without a liquid fuel component. These differences are critical to illustrate the benefits of using coal water slurries containing petrochemicals in heat and power plants. Adding as little as 10% (relative mass fraction) of waste industrial oils was shown to significantly reduce the ignition delay times and improve the combustion efficiency of fuel compositions. Possible ranges, in which the ignition delay of slurry fuels can be reduced, and the displacement of their ignition zones in the combustion chamber were

Abbreviations: CLF, composite liquid fuel; CWS, coal water slurry; CWSP, coal water slurry containing petrochemicals; SIMPLE, Semi-Implicit Method for Pressure Linked Equations; PSI-CELL, Particle-Source-In-Cell

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Nomenclature

a	absorption coefficient
A	prefactor in Arrhenius equations
A^d	ash content (dry basis) [%]
A^r	ash content (as received) [%]
A_p	particle effective surface area [m^2]
A_{char}	prefactor of char [s^{-1}]
$B^{CO}C_{O2}$	stoichiometric coefficient indicating the ratio of mass of unreacted char to the mass of consumed oxygen
B_m	Spalding mass number
B_T	Spalding heat transfer number
C_D	particle drag coefficient
C_{O2}	the concentration of oxygen [kg/m^3]
c_p	specific heat [J/(kg·K)]
C^r	fraction of carbon (as received) [%]
D	mass diffusion coefficient [m^2/s]
D^b	binary gas diffusion coefficient [m^2/s]
D_{O2}	the oxygen diffusion coefficient [m^2/s]
D_0	binary steam diffusion coefficient under reference conditions [m^2/s]
d_p	particle diameter [m]
E	activation energy [J/mol]
E_{char}	activation energy of char [J/mol]
E_{kin}	gas combustion activation energy [J/mol]
E_r	radiation flux density [J/mol]
f_i	mass fraction of ith component
f_V	vapor mass fraction
f_{VS}	vapor mass fraction at the surface
h	enthalpy [J/kg]
h_j	enthalpy of the jth component (H_2O, O_2, C_xH_y, C) [J/kg]
H^r	fraction of hydrogen (as received) [%]
k	turbulent kinetic energy [m^2/s^2]
k_{char}	reaction rate constant [m/s]
K_{comb}	empirical coefficient
k_{EBU}	eddy breakup model constant
k_{kin}	pre-exponential factor of gas combustion reaction
k_p^c	combustion rate of char [kg/(m^2 s)]
k_{char}^{kin}	rate constant of the chemical reaction [m/s]
k_{vol}^{dif}	rate of devolatilization in the diffusion regime [s^{-1}]
k_{char}^{dif}	rate constant of the diffusion mass transfer [m/s]
k_{vol}^{kin}	rate of devolatilization in the kinetic regime [s^{-1}]
k_{vol}	the rate of devolatilization [s^{-1}]
L_{eva}	latent heat [J/kg]
M	molecular mass [kg/kmol]
$\dot{m}_{char}$	char oxidation rate [kg/s]
$\dot{m}_p$	mass flow rate of particles [kg/s]
m_{vol}	the mass of volatiles released from particle [kg]
$m_{0,vol}$	is the total mass of volatiles in the initial coal particle [kg]
M_{dry}	molar mass of environment matter (vapor excluded) [kmol]
$\Delta\dot{m}_j$	mass rate of change of the jth component (H_2O, O_2, C_xH_y, C)
m_p	mass of a single particle [kg]
$\dot{m}_p$	mass flow rate of particles [kg/s]
$M_{r,i}$	molecular mass of ith component [kg/kmol]
M_{vapor}	vapor molar mass [kmol]
N^r	fraction of nitrogen (per fuel operating condition) [%]
N_r	the number of reagents
Nu_d	diffusion Nusselt number
p	pressure [N/m^2]
$p_{sat}(T_p)$	saturated vapor pressure at the droplet temperature [N/m^2]
p_r	operating pressure [Pa]
Pe	Peclet number
Q	calorific value [J/kg]
Q^r	lower fuel heating value [MJ/kg]
$Q_{s,V}^a$	higher fuel heating value [MJ/kg]
R	gas constant [kJ/(kg·°C)]
r_{char}	radius of char [m]
R_{EBU}	eddy breakup model reaction rate
R_{KIN}	kinetic model reaction rate
R_{vol}	reagent combustion rate (including volatiles)
Re	Reynolds number
S	source terms
Sc	Schmidt number
Sh	Sherwood number
S_{pm}	the rate of mass change due to the interphase interaction
S_{pv}	the rate of momentum change due to the interphase interaction
S^r	fraction of sulfur (as received) [%]
T	temperature [°C]
T_b	liquid boiling temperature [°C]
T_g	gas temperature [°C]
T_p	particle temperature [°C]
v	velocity [m/s]
V^{daf}	volatiles (dry ash-free state) [%]
w	release rate of reaction products [m/s]
W^a	moisture content of analytical sample of coal in an air-dry state [%]
W^r	moisture content (as received) [%]
Z_a	number of particles release points
Z_b	mass fraction of particles size-class b
$x_{r,i}$	mass concentration of ith reactant
x,y,z	longitudinal, wall-normal and tangential coordinates

Greek symbols

α	convective heat transfer coefficient [W/(m^2 °C)]
α_g	absorption coefficients of gas
α_p	absorption coefficients of particles
β	temperature exponent in Arrhenius equation
γ_p	particle dispersion coefficient
Δ	difference
δ	particle size before volatile emission [mm]
δ_{char}	char dimensions [mm]
ε	rate of dissipation of turbulence kinetic energy [m^2/s^3]
ε_p	particle radiation emissivity
μ	dynamic viscosity [Pa·s]
ν_i	stoichiometric coefficient of $x_{r,i}$ species
ξ	coefficient of scattering anisotropy
ρ	density [kg/m^3]
σ	Stefan-Boltzmann constant [J/K]
τ	stress tensor
τ_t	tensor of turbulent stress
τ_μ	tensor of viscous stress
φ	dimensionless parameter
χ	fraction of char heat absorbed by gas (relative to particles) fraction of heat release from char burning goes into the gaseous phase

Suffices and superscripts

char	char
conv	convection
devol	devolatilization
diff	diffusion (regime)
eb	eddy breakup
i	ith component in the mixture
in	conditions at the inlet