



## Full Length Article

# Computational modeling of the combustion of coal water slurries containing petrochemicals

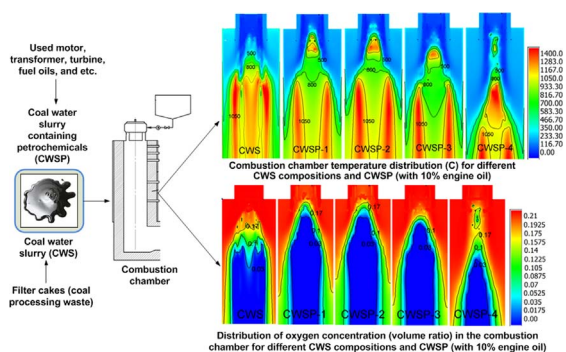


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## GRAPHICAL ABSTRACT



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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; CWS-P, 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	$Q$	calorific value [J/kg]
$A$	prefactor in Arrhenius equations	$Q^r$	lower fuel heating value [MJ/kg]
$A^d$	ash content (dry basis) [%]	$Q_{s,v}^a$	higher fuel heating value [MJ/kg]
$A^r$	ash content (as received) [%]	$R$	gas constant [kJ/(kg·°C)]
$A_p$	particle effective surface area [m <sup>2</sup> ]	$r_{char}$	radius of char [m]
$A_{char}$	prefactor of char [s <sup>-1</sup> ]	$R_{EBU}$	eddy breakup model reaction rate
$B^{CO}C_{O_2}$	stoichiometric coefficient indicating the ratio of mass of unreacted char to the mass of consumed oxygen	$R_{KIN}$	kinetic model reaction rate
$B_m$	Spalding mass number	$R_{vol}$	reagent combustion rate (including volatiles)
$B_T$	Spalding heat transfer number	$Re$	Reynolds number
$C_D$	particle drag coefficient	$S$	source terms
$C_{O_2}$	the concentration of oxygen [kg/m <sup>3</sup> ]	$Sc$	Schmidt number
$c_p$	specific heat [J/(kg·K)]	$Sh$	Sherwood number
$C^r$	fraction of carbon (as received) [%]	$S_{pm}$	the rate of mass change due to the interphase interaction
$D$	mass diffusion coefficient [m <sup>2</sup> /s]	$S_{pv}$	the rate of momentum change due to the interphase interaction
$D^b$	binary gas diffusion coefficient [m <sup>2</sup> /s]	$S^r$	fraction of sulfur (as received) [%]
$D_{O_2}$	the oxygen diffusion coefficient [m <sup>2</sup> /s]	$T$	temperature [°C]
$D_0$	binary steam diffusion coefficient under reference conditions [m <sup>2</sup> /s]	$T_b$	liquid boiling temperature [°C]
$d_p$	particle diameter [m]	$T_g$	gas temperature [°C]
$E$	activation energy [J/mol]	$T_p$	particle temperature [°C]
$E_{char}$	activation energy of char [J/mol]	$v$	velocity [m/s]
$E_{kin}$	gas combustion activation energy [J/mol]	$v^{daf}$	volatiles (dry ash-free state) [%]
$E_r$	radiation flux density [J/mol]	$w$	release rate of reaction products [m/s]
$f_i$	mass fraction of <i>i</i> th component	$W^a$	moisture content of analytical sample of coal in an air-dry state [%]
$f_V$	vapor mass fraction	$W^r$	moisture content (as received) [%]
$f_{VS}$	vapor mass fraction at the surface	$Z_a$	number of particles release points
$h$	enthalpy [J/kg]	$Z_b$	mass fraction of particles size-class <i>b</i>
$h_j$	enthalpy of the <i>j</i> th component (H <sub>2</sub> O, O <sub>2</sub> , C <sub>x</sub> H <sub>y</sub> , C) [J/kg]	$x_{r,i}$	mass concentration of <i>i</i> th reactant
$H^r$	fraction of hydrogen (as received) [%]	$x,y,z$	longitudinal, wall-normal and tangential coordinates
$k$	turbulent kinetic energy [m <sup>2</sup> /s <sup>2</sup> ]	<b>Greek symbols</b>	
$k_{char}$	reaction rate constant [m/s]	$\alpha$	convective heat transfer coefficient [W/(m <sup>2</sup> ·°C)]
$K_{comb}$	empirical coefficient	$\alpha_g$	absorption coefficients of gas
$k_{EBU}$	eddy breakup model constant	$\alpha_p$	absorption coefficients of particles
$k_{kin}$	pre-exponential factor of gas combustion reaction	$\beta$	temperature exponent in Arrhenius equation
$k_p^c$	combustion rate of char [kg/(m <sup>2</sup> ·s)]	$\gamma_p$	particle dispersion coefficient
$k_{char}^{kin}$	rate constant of the chemical reaction [m/s]	$\Delta$	difference
$k_{vol}^{dif}$	rate of devolatilization in the diffusion regime [s <sup>-1</sup> ]	$\delta$	particle size before volatile emission [mm]
$k_{char}^{dif}$	rate constant of the diffusion mass transfer [m/s]	$\delta_{char}$	char dimensions [mm]
$k_{vol}^{kin}$	rate of devolatilization in the kinetic regime [s <sup>-1</sup> ]	$\varepsilon$	rate of dissipation of turbulence kinetic energy [m <sup>2</sup> /s <sup>3</sup> ]
$k_{vol}$	the rate of devolatilization [s <sup>-1</sup> ]	$\varepsilon_p$	particle radiation emissivity
$L_{eva}$	latent heat [J/kg]	$\mu$	dynamic viscosity [Pa·s]
$M$	molecular mass [kg/kmol]	$\nu_i$	stoichiometric coefficient of $x_{r,i}$ species
$\dot{m}_{char}$	char oxidation rate [kg/s]	$\xi$	coefficient of scattering anisotropy
$\dot{m}_p$	mass flow rate of particles [kg/s]	$\rho$	density [kg/m <sup>3</sup> ]
$m_{vol}$	the mass of volatiles released from particle [kg]	$\sigma$	Stefan-Boltzmann constant [J/K]
$m_{0,vol}$	is the total mass of volatiles in the initial coal particle [kg]	$\tau$	stress tensor
$M_{dry}$	molar mass of environment matter (vapor excluded) [kmol]	$\tau_t$	tensor of turbulent stress
$\Delta \dot{m}_j$	mass rate of change of the <i>j</i> th component (H <sub>2</sub> O, O <sub>2</sub> , C <sub>x</sub> H <sub>y</sub> , C)	$\tau_\mu$	tensor of viscous stress
$m_p$	mass of a single particle [kg]	$\varphi$	dimensionless parameter
$\dot{m}_p$	mass flow rate of particles [kg/s]	$\chi$	fraction of char heat absorbed by gas (relative to particles)
$M_{r,i}$	molecular mass of <i>i</i> th component [kg/kmol]		fraction of heat release from char burning goes into the gaseous phase
$M_{vapor}$	vapor molar mass [kmol]	<b>Suffices and superscripts</b>	
$N^r$	fraction of nitrogen (per fuel operating condition) [%]	<i>char</i>	char
$N_r$	the number of reagents	<i>conv</i>	convection
$Nu_d$	diffusion Nusselt number	<i>devol</i>	devolatilization
$p$	pressure [N/m <sup>2</sup> ]	<i>diff</i>	diffusion (regime)
$p_{sat}(T_p)$	saturated vapor pressure at the droplet temperature [N/m <sup>2</sup> ]	<i>eb</i>	eddy breakup
$p_r$	operating pressure [Pa]	<i>i</i>	<i>i</i> th component in the mixture
$Pe$	Peclet number	<i>in</i>	conditions at the inlet

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