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Review article

Numerical simulation of Opposed Multi-Burner gasifier under different coal loading ratio

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HIGHLIGHTS

- A comprehensive three-dimensional numerical model is developed for simulation of Opposed Multi-Burner (OMB) gasifier.
- Influence of the burners atomization performance on OMB gasifier performance has been studied.
- The temperature distribution in the impinging jet stream can be expressed as decaying exponential function.

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ABSTRACT

The Opposed Multi-Burner (OMB) gasifier has been widely used in commercial plants throughout China. A comprehensive three-dimensional numerical model is developed for the simulation of an OMB gasifier. In this model, the realizable k–ε turbulence model is applied to close the Reynolds-averaged Navier–Stokes equation and the eddy-dissipation-concept model is used to simulate the homogeneous reactions. The coal water slurry (CWS) droplets or particles are described by Lagrangian equation of motion and the evaporation, devolatilization, and heterogeneous reactions processes are modeled. The effect of the coal water slurry atomization on droplets size is also considered. Lastly, the influences of the gasifier coal loading ratio (*CLR*) on the OMB gasifier performance, particle concentration distribution and temperature distribution have been investigated. The results show that by increasing the gasifier coal loading ratio, the carbon conversion and effective gas yield increase. The temperature distribution in the impinging jet stream can be expressed as a decaying exponential function and the decaying rate corresponds to the particle ratio distribution. Due to the increase of the coal loading ratio, the temperature decaying rate of the impinging up jet stream increases and gas temperature at the top of the gasifier decreases. The numerical results for the OMB gasifier are in good agreement with the industry operation data and observed phenomenon.

Contents

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Nomenclature

a, b	temperature decay parameter
C	the heat capacity of gas
CLR	coal loading ratio
CWS	coal water slurry
C_{jr}	molar concentration of species j in reaction r
D_j	diffusion coefficient
dq_m	heat source of the heterogeneous reactions
d_p	particle size
dH	length of the control volume
E_r	activation energy of the reaction
H	dimensionless axis distance
h_{air}, h_t	air and total heat transfer coefficient
K_r	equilibrium constant of the reaction
$k_{f,r}$, $k_{b,r}$	forward and backward reaction rate constant
k_0, k_1	model constant
k_m, k_r	thermal conductivity of refractory and metal
L	length scale
M_p	the particle number flow rate in the jet stream
$M_{w,i}$, MC	molecular weight of species i and carbon
m_{O_2}, m_{CWS}	O_2 and CWS mass flow rate
N	Rosin–Rammler distribution parameter
N_p, $N_{p,up}$, $N_{p,down}$	number of particle, flow up and down
N_r	number of the reactions
n_j	j size group particle number
p_j, p_{atm}	a partial pressure of species j and reference pressure
R	molar gas constant, 8314 J/kmol K
q_m	particle mass flow rate in jet stream
R_i	species i Arrhenius reaction sources
R_j	char depletion rate of j heterogeneous reaction
$R_{kin,j}$, $R_{diff,j}$	intrinsic and diffusion rate for reaction j
SMD	Sauter-mean diameter
St	Stokes Number
T, T_P	gas and particle temperature
T_{max}	maximum temperature at gasifier axis
u_1, u_3	O_2 velocity of the inner and outer channel
ΔS_r^0, ΔH_r^0	change of the standard-state entropy and standard-state enthalpy in reaction r
Δx_r, Δx_m	refractory and metal thickness
β	particle ratio in jet stream
β_r	temperature exponent of the reaction
λ_1, λ_3	the ratio of the O_2 in the inner and outer channel
μ	CWS viscosity
$v''_{i,r}$, $v'_{i,r}$	stoichiometric coefficient of reactant i in reaction r, product i in reaction r
$\eta\Delta Q_r$	gas heat absorbed in the reactions
ρ_g, v_g, μ_g	gas density, velocity and viscosity
ϕ	mechanism factor

1. Introduction

The Opposed Multi-Burner (OMB) coal water slurry gasification technology [1–3], which has developed by East China University of Science and Technology (ECUST), is an advanced entrained-flow coal gasification technology and has been widely used throughout China.

The flow field and multiphase reaction process in the OMB gasifier have been thoroughly studied in the past [4–6]. According to previous studies, the flow field of opposite multi-burner gasifier is composed of jet (I), impingement (II), impinging jet (III), reflux (IV) and plug flow (V) regions, As shown in Fig. 1(a). The coal water slurry (CWS) and oxidant are introduced into the gasifier from the 4 burners which are located in the top portion of the gasifier. At the outlet of the burners, the CWS is transformed from the bulk liquid into fragments or small droplets.

In the OMB gasifier commercial operation, it is found that not only does the O_2/CWS ratio have a significant impact on the gasifier operation performance, but also that the coal loading ratio (*CLR*) at fixed operation pressure and CWS/O_2 mass ratio dramatically affects the performance of the gasifier. In general, the gas and coal particles residence time will decrease with the increase of the gasifier coal loading ratio. However, the commercial unit operation shows that by increasing the gasifier coal loading ratio, the gasifier performance, such as the effective gas (CO and H_2) flow rate and carbon conversion, are enhanced. Another phenomenon observed from commercial operation is that the temperature at the top of the gasifier is higher than the temperature at bottom of the gasifier, and the difference between them reduces as the gasifier coal loading ratio increases. These phenomena provide key information that the high coal loading ratio has the potential for enhancing gasifier performance and extending the refractory brick life at the top of the gasifier.

According to the atomization theory, the burner atomization plays a very important role on CWS combustion and thus, gasification efficiency. The CWS atomization involves interaction between the slurry liquid and carrier gas. There are many reports on CWS atomization characteristics [7–10]. According to this study, both the interfacial [7] and rheological [8] properties of the slurry, the suspended coal particles size [9], gas liquid ratio and two phase jet velocity [10] play important roles on burners atomization performance and mean droplet diameter after atomization. From an operational point of view, the atomization agent velocity increases with gasifier increasing coal loading ratio which subsequently enhances the burners atomization performance.

The modeling and simulation method have been widely used for studying the complex two phases reactions and flow processes in the gasifier. Despite there are many numerical simulation study reports on the entrained-flow coal gasifier, literature about the