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An initial study on feasible treatment of Serbian lignite through utilization of low-rank coal upgrading technologies

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ABSTRACT

Despite benefiting from vast fuel reserves, combustion of low-rank coals is commonly characterized by low thermal efficiency and high pollutant emissions, partly due to high moisture content of the coals in question. Thus, removal of moisture from low-rank coals is deemed an important quality upgrading method. The paper provides an overview of the current status of low-rank coal upgrading technologies, particularly with respect to utilization of drying and dewatering procedures. In order to examine the influence of relevant parameters on the moisture removal process, a model of convective coal drying in a packed, as well as in a fluid bed combustion arrangement, is developed and presented. Product-specific data (intraparticle mass transfer, gas–solid moisture equilibrium) related to the coal variety addressed herein (lignite) are obtained through preliminary investigations. Effective thermal conductivity of the packed bed as defined by Zehner/Bauer/Schlünder is used to define heat transfer mechanisms occurring in the packed bed. Similar two-phase fluidization model has been validated for different types of biomaterials.

Keywords: Coal drying; Thermal treatment; Moisture transfer; Fluid bed; Modeling

1. Introduction

It is generally expected that low-rank coals, i.e. lignite, will continue to be the main energy source used in Serbian power plants, mainly due to the fact that they represent the most abundant and cheapest fossil fuel available. Lignite in particular, with its deposits found and extensively exploited in Serbia (as well as in many other European countries) is relatively inexpensive and is characterized by relatively low sulfur content, but with moisture content of 25–70% and low energy output (Fig. 1). The presence of moisture in coal reduces coal friability, negatively affecting the quality of grinding, as well as pneumatic transport of pulverized coal.

Reduced moisture level in coal result in increased power plant efficiency, reduced ash disposal requirements and reduced pollutant emissions. On the other hand, upgrading processes used to reduce the moisture content in coal cause an increase in combustion temperatures, due to the higher calorific value achieved at the expense of reduced moisture, thereby leading to operational problems in steam generator.

Nowadays there are several ways to reduce moisture content of low-rank coals. The methods used may be divided into two main groups: conventional evaporative drying (direct or indirect dryers, packed or fluid bed dryers, rotary kiln, etc.) and non-evaporative dewatering processes (mechanical thermal expression, hydro-thermal dewatering, etc.).

The superheated steam drying process patented by Fleissner (Fleissner, 1926; Monazam et al., 1998) has been used for many years in Thermal Power Plant “Kolubara” (located in the vicinity of Belgrade) to produce dried coal for commercial use. In the first stage of this two-stage batch process, coal (lignite) is exposed to an ambient of high-pressure superheated steam

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Symbol used

a, b	exponents of Eq. (27)
a_b	bed specific surface area ($m^2\,m^{-3}$)
A_K	coefficient with dimensions as defined by Eq. (29)
A_1	axial heat transfer as defined by Eq. (36)
A_2	fluid-to-solids heat transfer as defined by Eq. (40)
A_3	heat transfer inside the solids as defined by Eq. (44)
B_0	coefficient with dimensions as defined by Eq. (27)
c	specific heat capacity ($J\,kg^{-1}\,K^{-1}$)
d	diameter (m)
D	dispersion coefficient of solids ($m^2\,s^{-1}$)
f	volume fraction
g	acceleration of gravity (=9.81 $m\,s^{-2}$)
h	bed height (m)
$(H_{BC})_B$	volumetric heat transfer coefficient between bubble and cloud-wake region ($W\,m^{-3}\,K^{-1}$)
$(H_{BE})_B$	overall volumetric heat transfer coefficient between bubble and suspension based on volume of bubbles ($W\,m^{-3}\,K^{-1}$)
$(H_{CE})_B$	volumetric heat transfer coefficient between cloud-wake region and suspension phase ($Wm^{-3}\,K^{-1}$)
k_b	relative thermal conductivity defined by Eq. (30)
k_i	internal mass drying coefficient (s^{-1})
$(K_{BC})_B$	coefficient of gas interchange between bubble and cloud-wake region (s^{-1})
$(K_{BE})_B$	overall coefficient of gas interchange between bubble and suspension based on volume of bubbles (s^{-1})
$(k_{CE})_B$	coefficient of gas interchange between cloud-wake region and suspension phase (s^{-1})
M	mass (kg)
$\dot{M}$	mass flow-rate ($kg\,s^{-1}$)
$\tilde{M}$	molecular mass ($kg\,k\,mol^{-1}$)
n_D, n_T	exponents in Eq. (29)
p	pressure (Pa)
r	heat of evaporation ($J\,kg^{-1}$)
A	cross section of the bed (m^2)
S_Φ	general source term as defined by Eq. (1)
T	temperature (°C, K)
u	velocity ($m\,s^{-1}$)
$\vec{u}$	velocity vector
V	volume (m^3)
$\dot{V}$	volume flow-rate ($m^3\,s^{-1}$)
X	material moisture content (dry basis)
Y	gas moisture content (dry basis)
z	axial coordinate (m)

Greek letters

α	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
β	mass transfer coefficient ($m\,s^{-1}$)
Γ_Φ	general diffusion coefficient as defined by Eq. (1)
δ	diffusion coefficient ($m^2\,s^{-1}$)
η	dynamic viscosity (P as)
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
ρ	density ($kg\,m^{-3}$)
φ	relative air humidity
ϕ	sphericity of particulate solids
Φ	general dependent variable
ψ	bed void fraction
τ	time (s)

Dimensionless criteria

Ar_S	Archimedes criterion, $d_S^3\rho_S(\rho_S-\rho_G)g\eta_G^{-2}$
Nu_S	Nusselt criterion, $\alpha_{S,G}d_S\lambda_G^{-1}$
Pr	Prandtl criterion, $c_G\eta_G\lambda_G^{-1}$
Re_S	Reynolds criterion, $d_S u_G\rho_G\eta_G^{-1}$

Subscripts

at	atmosphere
ax	axial
b	bed
B	bubble, bubble phase
d	dry
E	suspension phase
F	fluid
eff	effective
eq	equilibrium
G	gas
i	internal
lam	laminar
L	liquid
in	inlet
m	moisture
mf	minimum fluidization
turb	turbulent
S	solids
sf	surface
sat	saturated
V	vapor
0	initial, superficial

(SHS) so as to heat the coal to an approximately uniform temperature, while simultaneously cooling down and condensing steam. As the temperature rises and the pressure increases, a portion of the colloidal water is removed from the coal in a liquid state. As a result of removed moisture the coal reduces in volume and its structure collapses. In the next stage of the process, pressure reduction enables additional water to be removed through evaporation facilitated by sensible heat stored in the coal. After being subjected to the described high-pressure steam treatment, solids (coal pieces) are reloaded into a cylindrical container and exposed to a stream of drying agent that flows in an upward direction (from the bed bottom to the top). The drying agent is ambient air whose temperature and moisture content strongly depend on weather conditions at the time of drying. Hydro-thermal dewatering process, as one of the newest dewatering procedures, is evaluated in reference to the Fleissner process.

The main objective of the work presented herein is to provide a brief overview of the current status of low-rank coal upgrading technologies, whereby particularly addressing utilization of drying technologies, as well as to propose appropriate calculation method for evaluating parameters of the coal pre-drying process. A previously developed packed bed drying model was validated for biological materials (Stakić and Stefanović, 1995; Stakić, 1997, 2000; Stakić and Tsotsas,

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