Fuel 195 (2017) 243–252

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Estimation of the structure-related share of radiation heat transfer in a carbonised packed coal bed

Sylwia Polesek-Karczewska

Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, PL 80-231 Gdansk, Poland

HIGHLIGHTS

- A model of fissuring was developed to analyse radiation heat transfer in a coke layer.
- A significant thermal anisotropy of fissured coke layer was pointed out.
- Thermal conductivity of coke bed is a function of temperature and the process stage.
- Fissure development strongly increases effective thermal conductivity of coke.

ARTICLE INFO

Article history:
Received 12 July 2016
Received in revised form 13 January 2017
Accepted 18 January 2017
Available online 28 January 2017

Keywords:
Coal
Coke
Fissuring
Optical path length
Thermal anisotropy

ABSTRACT

The contribution of radiation to heat transfer in a packed bed of coal during its thermal decomposition in a coke oven chamber has been investigated. The phenomenon was analysed while considering the structure change that the coal experiences. The study focused on the increased role of radiation in the processing stage following coal re-solidification. This is when the macrocracks begin to propagate. A simple fissure development model was proposed to describe the influence of varying textures of coke oven charge on the heat transfer process. The results show that the length of fissures penetrating the coke layer perpendicularly to an oven wall is the main factor affecting heat transport due to radiation. This leads to a significant increase in effective thermal conductivity of the coke layer. The work underlines an anisotropic character of thermal radiation in carbonisation beds.

1. Introduction

Mass and heat transport processes are important in many industrial applications associated with reactive porous beds including coke production, which is based on the carbonisation of bituminous coals. Although this technology of thermochemical conversion of coal has been known for decades, its mathematical modelling is still an active area of research in the coke and steel industries. This is because the process is strongly affected by many parameters that eventually influence coke quality. The basic one, apart from coal type, is the temperature regime of the process. This determines both the dynamics of the coal charge heating and the final process temperature. Real scale coal carbonisation is performed in a coke oven battery that is a set of single coke ovens separated by heating channels. Here, gas evolved in the coke oven is combusted to provide heat for the thermochemical conversion. Most of the coking installations are based on a charge-compacting system. The compacted coal charge is mechanically inserted into the hot coke oven. When heated, this undergoes decomposition and structure change. First, moisture from the raw coal is released followed by devolatilisation. The charge softens and becomes a thick fluid with dispersed gas bubbles at 623–773 K (depending on the coal type). At about 773 K, the coal re-solidifies and turns into the porous material – first into a semi-coke (<973 K) and then a coke. Both of these have pores, cracks and fissures.

Coal is going through the variety of structures during thermal processing. This fact impacts the heat transfer patterns. Since the heating dynamics of the coal charge is of crucial importance for practical reasons, an appropriate estimation of the thermal conductivity of coal charge becomes important in the context of predicting temperature evolution. As discussed previously [1], thermal conductivity is a key parameter in the numerical modelling of fixed coal bed. It affects the expected total time of the coking. The effective thermal conductivity of such a medium results from various heat transfer mechanisms, which include: (i) conduction in solids and gas, (ii) convection and (iii) radiation through different voids. The latter, in particular, strongly accelerates the

E-mail address: sylwia.polesek-karczewska@imp.gda.pl

http://dx.doi.org/10.1016/j.fuel.2017.01.069

Nomenclature

N	number of fissures
q	heat flux, W m^{-2}
t	time, s
A	area, m^2
d	diameter, m
H	height of representative coke volume, m
h	mean fissure spacing, m
l	radiation path length, m
T	temperature, K
T_r	temperature of re-solidification, K
T_s	temperature of softening, K
$\mathbf{n}$	unit vector
Greek symbols	
α	area ratio
β	angle, radians
γ	extinction enhancement factor
λ	thermal conductivity, W m^{-1} K^{-1}
$\langle\sigma_{ex}\rangle$	extinction coefficient, m^{-1}
$\boldsymbol{\lambda}$	thermal conductivity tensor, W m^{-1} K^{-1}
σ	Stefan-Boltzmann constant, 5.67 × 10^{-8} W m^{-2} K^{-4}
ε	volume fraction, porosity
ε'	total porosity
Subscripts/superscripts	
c	contact, coke
eff	effective
f	fissures
g	gas
gap	intra-particle void
p	internal pores
r, rad	radiation
s	solid
sv	solid–void system
t	tar
w	water
x, y, z	coordinate, direction
1	primary fissures
2	secondary fissures

charge heating when cracks appear and propagate inward due to semi-coke and coke deformations [2]. The majority of fissures expand perpendicularly to an oven wall. This leads to a substantial increase in the heat transfer along the oven width versus other directions. The development of an exact relationship for effective thermal conductivity is impossible due to the complex geometry of coal/coke inner structures; this remains a challenge. An additional challenge is that the fissuring mechanism is dependent on the parent coal type [3] as well as heating rate or coke shrinkage [4]. Witos [5] prepared a compilation of empirical correlations for the effective thermal conductivity of a coal/coke charge. The comparisons include the functions of Kasperczyk and Simonis [6], Rhode et al. [7] or Butorin and Matveeva [8]. There are large discrepancies in the thermal conductivity values for temperatures above 1100 K. Buczynski et al. [9] recently highlighted the substantial divergence between the literature data on thermal conductivity for temperatures over 823 K when the effect of radiation becomes significant. Many studies have analysed the thermal and flow processes in a coke oven. Most approaches to numerical modelling of heat transfer during coal carbonisation involve parallel or series thermal resistances of heat conduction inside the coal/coke bed or a combination of both. Atkinson and Merrick [10] have analysed the effective thermal conductivity of a charge distinguishing between a granular and porous semi-coke/coke. They described the radiative heat exchange inside a coke oven via characteristic lengths for both structure types. Their correlations were partly adopted by others [11,12]. An effect of radiative heat transfer on temperature distribution in a lump coke was mentioned for instance in [2]. However, there are only a few detailed studies on the effect of radiation aiming at an improve method for thermal conductivity estimate.

The paper considers heat transfer changes as a function of radiation in a coal packed bed during carbonisation. For the purpose of these studies, since the gas flow through the charge is relatively low, the gas is assumed to be non-moving and the convective heat transfer is neglected. The analysis accounts for all types of bed structure characteristics at different stages of coal decomposition including the plastic stage. However, special attention is given to the increase in radiative heat transfer due to progress in fissuring, which starts after coal charge re-solidification. The analysis uses numerical and experimental literature data on fissure network development.

2. Coal charge structures and their thermal conductivity

As the heat front moves through the coal bed, from the wall towards the centre of a coke oven chamber, the charge undergoes a strong structure change from the granular type medium at the beginning of the process to a semi-liquid type material and ends in a highly porous non-particulate material [13]. This changes

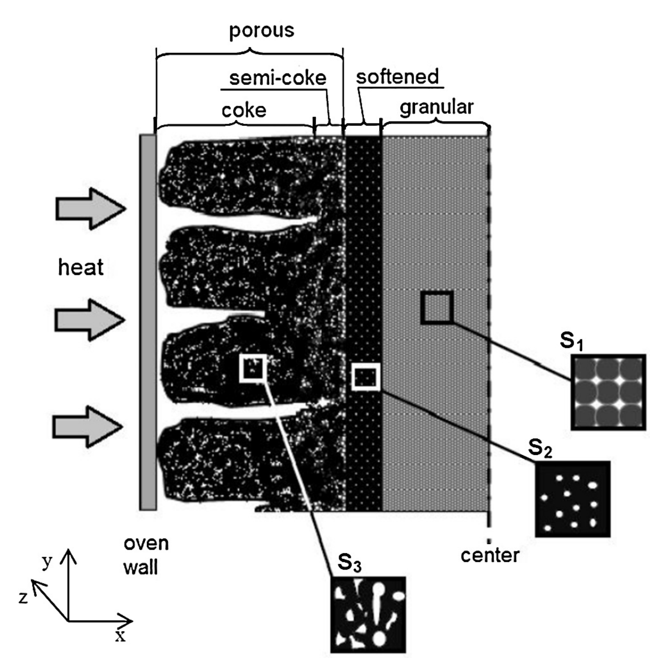

Fig. 1. Schematic illustration of structure change of a coke oven coal charge; enlarged details show: particles with interstices (S_1), semi-liquid layer with gas inclusions (S_2) and porous coke (S_3); (dark and white colours refer to solid/liquified solid and gas, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)