International Journal of Heat and Mass Transfer 127 (2018) 183–187

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Regularities of filtration combustion of bidisperse fuel mixtures in an inclined rotary reactor

D.N. Podlesniy [a,*], A.Yu. Zaichenko [a], E.A. Salgansky [a], M.V. Salganskaya [a,b]

[a] Institute of Problems of Chemical Physics, Russian Academy of Sciences, 1 Academician Semenov Ave., Chernogolovka 142432, Russia
[b] Lomonosov Moscow State University, 119991 Moscow, Russia

ARTICLE INFO

Article history:
Received 2 July 2018
Received in revised form 6 August 2018
Accepted 7 August 2018

Keywords:
Filtration combustion
Bidisperse fuel mixtures
Inclined rotary reactor
Nonuniformity of combustion front

ABSTRACT

Present study reports the application of inclined rotary reactor for gasification of bidisperse fuel mixtures. A variety of mixtures of different particle sizes are tested and corresponding values of coefficient of combustion front nonuniformity depending on the reactor inclination angle also have been shown. In addition, the influence of the total flow rate and gas composition on combustion temperatures has been investigated. Obtained results indicated that using of inclined rotary reactor showed more sustainable performance than the vertical packed bed reactor.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Filtration combustion (FC) arranged with a heating wave propagating in the same direction with the direction of gas flow (in case of countercurrent flows of gas and the porous medium in the reference frame associated with the reaction zone) is very interesting from both scientific and practical viewpoints [1–3]. The heat exchange between the flows of solid and gaseous phases, which move toward each other, results in that heat from combustion products is recuperated into the reaction zone. As a consequence, the phenomenon of "superadiabatic heating" can be observed, with the temperature in the combustion zone exceeding the adiabatic value [4]. The superadiabatic combustion of solid fuels provides, compared to known technologies, a higher energy efficiency. It provides a possibility to process low grade fuels with about 5% combustibles [5,6], low content of pollutants in gaseous combustion products, a possibility to efficiently process various wastes [7].

It is known that the FC of porous monodisperse fuel for a sufficiently narrow parametric field may be stable (the permeability of the starting mixture nearly coincides with that of combustion products) [8,9]. However, the fuel mixture contains in real conditions, even if such fuel preparation technological methods as pelletizing or sieving are used, a fine fraction. It appears due to the grinding of the material in its transportation or charging into the reactor, or to burning-out of particles. One of important drawback of this method when the process is performed in a vertical shaft kiln reactor is the gas-dynamic instability of the combustion front at a low gas permeability of the layer [10–12]. However, if particles are forced to move in the combustion zone in the front plane with a sufficiently high speed, this may avoid the occurrence of burnout, or at least its development, because the burnout channel will be filled with unburned particles. This may be done by using a reactor that is inclined at a certain angle to the horizon and rotating about its axis [13–15]. The inclined position of the reactor leads to formation of single burnout in the upper part of reactor and the rotational motion of one can fill the burnout by unburned material. In this case, mixing under the action of gravity force will provide both filling of voids and channels and the uniform distribution of overheated solid particles across the reactor in combustion zone. To characterize the instability of the filtration combustion front, we introduced a dimensionless coefficient (k), which characterizes the spatial distortions of the combustion front and is equal to the ratio between the maximum and minimum front widths [16]. Using the example of bidisperse coal fuel mixtures, it has been shown that the use of an inclined rotary reactor allows to stabilize the gasification process in comparison with a vertical one.

The aim of this work was to study regularities of FC bidisperse fuel mixtures of coal in an inclined rotary reactor with following control parameters: reactor inclination angle, composition and flow rate of the gaseous oxidant.

* Corresponding author.
E-mail address: dim1990@mail.ru (D.N. Podlesniy).

https://doi.org/10.1016/j.ijheatmasstransfer.2018.08.020
0017-9310/© 2018 Elsevier Ltd. All rights reserved.

2. Experimental procedure

To study regularities of FC of bidisperse fuel mixtures in an inclined rotary reactor we used mixtures of brown coal of various particle sizes with an inert solid. Analysis of dry coal samples on CHNS/O using element analyzer "Vario MICRO cube" showed the following average elemental composition (wt.%): C – 64.1; O – 9.7; H – 3.4; N – 1.4; S – 0.4; ash – 21%. The coal humidity is found to be 15%; the yield of volatiles during coal pyrolysis comprised 25–30%; the lower heating value of coal is found to be 20.2 MJ/kg. Preliminary, coal ash was analyzed on a scanning field emission electron microscope "Zeiss LEO SUPRA 25" and on an atomic absorption spectrophotometer "AAS-3" (for sodium and potassium). The chemical composition is found to be in terms of oxides (wt.%): SiO_2 — 65.8, Al_2O_3 — 18.8, Fe_2O_3 – 12.1, MgO – 1.0, TiO_2 – 0.88, CaO – 0.7, Sc_2O_3 – 0.012. According to formulas of [17,18], the melting temperature of ash (spreading) was calculated for tested sample of ash, which was 1334 °C.

Crumbs of crushed shamotte brick "NM-ShA/I-8" type was used as an inert solid (heat resistance is 1690 °C, density is 2100 kg/m3). The fuel was constituted by two fractions: coarse fuel fraction with size of 5–7 mm and a fine fuel fraction of size 1–2 mm. The particle size of the inert solid was 5–7 mm. Size of fine fraction was chosen in such a way that even for the ideal case of spherical particles in the simplest cases of packing, fine particles overlapped the channels between coarse particles. Specific diameter of these channels in our cases was ~0.8 to 2.5 mm. Consequently, we obviously deteriorated the gas-dynamic characteristics of fuel mixtures.

Content of fuel in the mixture with inert was from 30 to 70% by weight. To examine the influence of fine fraction in fuel on structural changes in the FC front, its content was varied from 0 to 50%. The volume weight of examined mixtures was 770 ± 20 kg/m^3 and bed length was 220–250 mm. Presence of fine coal particles in fuel provided that fuel mixtures with sharply different filtration characteristics were formed. Laboratory research was carried out in an inclined rotary quartz 66-mm inner diameter 450-mm long reactor (Fig. 1). Thickness of the reactor tube wall was 3 mm. Reactor inclination angle to the horizon in experiments was varied from 30° to 90°. The thermal insulation of the reactor was not used to visually observe the structure of the combustion front during the experiment. The presence of thermal insulation leads to an increase of the temperature on the reactor wall and the extent of the high-temperature zone, but does not affect the structural characteristics of the combustion front. Examined mixture was charged from the upper end of the reactor (1). Gaseous oxidant (air) was supplied to reactor via inlet of the bin's cover.

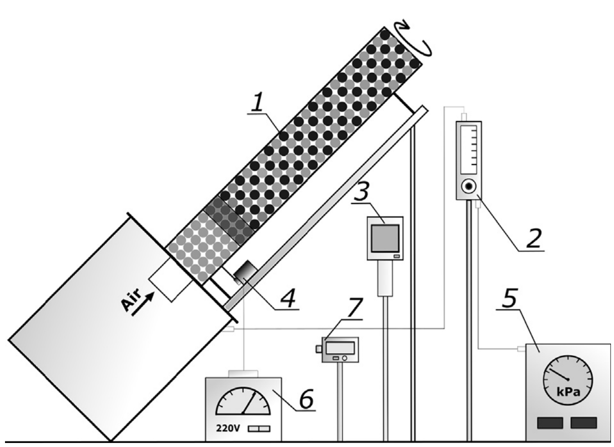

Fig. 1. Schematic of the laboratory setup: (1) Reactor, (2) electronic flow rate meter, (3) thermal camera, (4) reactor drive, (5) compressor, (6) laboratory transformer, (7) video camera.

The air flow rate was controlled with an electronic "Mass-view MV-306" flow meter (2). The product gas was carried outside from the upper end of reactor. Reactor was being rotated with electric drive (4) at a speed of 6 s^{-1}. In work [15] it was shown that the rotational speed of inclined reactor does not affect the stabilization process.

Preliminarily, 80-mm-high bed of inert solid was charged into reactor to avoid the overheating of the rotation drive. Further, reactor was charged with an initiating mixture of 50 g charcoal with inert solid, heated to 700 °C in the muffle furnace. Then a gaseous oxidant (air) was supplied into reactor. The flow rate of gas was varied from 600 to 1200 $m^3/(m^2\,h)$. The examined mixture was loaded batch wise in 100 g, its weight was constant (600 g) for all experiment. Once done, the propagation of the FC front along the length of reactor began in the direction of oxidant filtration. The bed length was decreasing during experiment due to burning-out of coal particles. In experiments, gaseous products were periodically sampled into a glass flask. The composition of gaseous products was analyzed using a chromatograph "GC-CRYSTAL-5000". During the whole experiment, a video (7) and/or thermal (3) scope recording was performed from a fixed distance, in such a way that combustion front was continuously in the field of camera lens view. The thermal camera "FLUKE Ti400" was used to measure the temperature in an inclined rotary reactor; in case of a vertical packed bed reactor the temperature was measured with K-type thermocouples.

3. Results and discussion

In previous experiments on gasification of mixtures with a fine component content of 3–5 mm fraction in fuel from 0 to 100%, a stable combustion front was observed in the entire range of fine component content [16]. Despite the higher permeability (compared to a mixture containing a fine fraction of 1–2 mm), the coefficient of nonuniformity in this case is greater. This is explained by the less dense packing of particles. But at the same time, the composition of gaseous products remained practically constant both during whole series of experiments and during individual experiments. The maximum combustion temperature in all experiments was constant, and in individual experiments a uniform temperature distribution over the cross section of combustion front was also observed.

In the continuation of work [16], experiments on gasification of mixtures with fine component fraction 1–2 mm were carried out. Such particle size of fine component provided local overlapping of the inter-porous space, thereby reducing the coefficient of mixture permeability 3–4 times, in comparison with previously used mixtures (fine fraction was 3–5 mm). The total content of the combustible part was 50% by weight. Fig. 2 presents the results of experiments at different reactor inclination angles – from 30° to 90°, with different contents of fine fraction in mixture.

As can be seen from the graph, for inclination angles of 30° and 45° the process proceeded stably and values of k were not exceed 1.2 (which indicates a practically flat front of combustion) up to 30% of fine component in fuel. Apparently, the rotation of reactor at these inclination angles creates radial oscillations of large particles, which facilitates the axial flow of fine fraction through them. In this case, fine particles also move rather intensely, evenly distributing over the bed in the radial direction. Also, for these experiments, the maximum combustion temperature (970 ± 50 °C) and the composition of gaseous products were constant: CO – 14–16%, H_2 – 4–7%, CH_4 – ~1%. However, with an increase of fine fraction in the mixture above 30%, there significant distortions in the structure of combustion front were occurred, which are characterized by sharp differences in value of the coefficient of nonuniformity in different experiments. This is due to the fact that

Download English Version:

https://daneshyari.com/en/article/8941960

Download Persian Version:

https://daneshyari.com/article/8941960

Daneshyari.com