Applied Thermal Engineering 142 (2018) 371–379

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Experimental study of coal dust ignition characteristics at oil-free start-up of coal-fired boilers

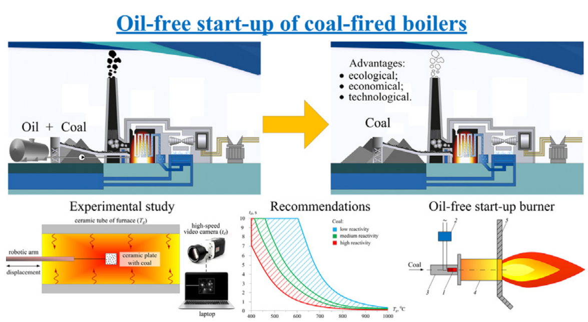
Dmitrii O. Glushkov[a,*], Geniy V. Kuznetsov[a], Diana A. Chebochakova[a], Olga E. Lyakhovskaya[a], Nikita E. Shlegel[a], Igor S. Anufriev[b], Evgeniy Yu. Shadrin[b]

[a] National Research Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk 634050, Russia[1]
[b] Institute of Thermophysics SB RAS, 1, Akademik Lavrentiev Avenue, Novosibirsk 630090, Russia

HIGHLIGHTS

- Oil-free start-up of coal-fired boilers can be implemented in practice.
- The ignition characteristics of bituminous and brown coal dust were determined.
- Ambient temperature 500 °C is minimal for coal dust ignition (sizes about 100 μm)
- Low-temperature ignition of high reactivity (V^{daf} ≥ 50%) coals is guaranteed during 1–4 s.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Coal dust
Ignition
Coal-fired boiler
Oil-free boiler start-up

ABSTRACT

The conditions and characteristics of ignition of bituminous and brown coal widely used in thermal power engineering as the main fuel have been studied experimentally. The studies were carried out under the heating of fine coal particles in the muffle furnace. Such conditions are similar to those of coal dust ignition in muffle burners used in the implementation of advanced technology of oil-free start-up of coal-fired boilers. This technology is characterized by positive economic and environmental indicators in comparison with the widespread technology of coal-fired boilers start-up by liquid fuel combustion. Processes of ignition were studied in a wide range of temperature variation (400–1000 °C) for several grades of coal with various combustion heats and volatile matter content and different particle sizes: 40, 140, 250 μm. Minimum air temperatures necessary for ignition of fine particles of coal, as well as dependences of the main characteristic of the process, i.e. ignition delay time, on ambient temperature have been determined. The ambient temperature required to ignite coal particles with the sizes of about 100 μm is 500 °C for coals with relatively high volatile content (more than 30%) and 600 °C for coals with low volatile content (less than 30%). Approximation expressions are given for the obtained dependences. The results of the experiments serve as a basis for predicting the conditions and characteristics of coal dust ignition instead of liquid fuel and for justifying the size of the muffle burners for the development works and for optimization of their operation modes in the conditions of coal-fired boiler start-up.

* Corresponding author.
E-mail addresses: dmitriyog@tpu.ru (D.O. Glushkov), kuznetsovgv@tpu.ru (G.V. Kuznetsov), dianagax@list.ru (D.A. Chebochakova), o.l.g.a21@mail.ru (O.E. Lyakhovskaya), anufriev@itp.nsc.ru (I.S. Anufriev), evgen_zavita@mail.ru (E. Yu. Shadrin).
[1] Heat Mass Transfer Simulation Laboratory, URL: http://hmtslab.tpu.ru/.

https://doi.org/10.1016/j.applthermaleng.2018.07.010
Received 3 March 2018; Received in revised form 15 June 2018; Accepted 3 July 2018
Available online 11 July 2018
1359-4311/

Nomenclature

A^d	ash (%)
C^{daf}, H^{daf}, N^{daf}, O^{daf}, S^{daf}	fraction of carbon, hydrogen, nitrogen, oxygen and sulfur in the coal converted to a dry ash-free state (%)
CO	carbon oxide
CO_2	carbon dioxide
d50	abbreviation of the grain diameter at which 50% of the coal dust sample is finer (%)
NO_x	nitrogen oxide
$Q^a_{s,V}$	higher heating value (J/kg)
SO_x	sulfur oxide
T_g	temperature in the furnace (°C)
t_d	ignition delay time (s)
V^{daf}	volatile content (%)
V_g	air flow velocity (m/s)
W^a	humidity (%)

1. Introduction

According to statistical data [1,2], the world level of consumption of thermal and electric energy continuously grows. Coal-fired thermal power plants make a significant contribution of 40–45% to energy production [3,4]. The combustion of solid fossil fuel in thermal power plants (TPP) annually produces energy in the amount of about $46{\cdot}10^{12}$ MJ [1–4]. Quite a significant share of coal thermal power in the total volume of power generation is due to the prevalence and availability of coal as a solid fossil fuel in many countries. Leaders in coal production (over 100 million tons per year) and at the same time in its combustion for energy production are [5]: China, the USA, India, Australia, Indonesia, Russia, Germany, Poland, and Kazakhstan.

The efficiency of energy production at coal-fired TPP depends on a large number of interrelated stages of the technological process [6]. One of the fundamental stages is the boiler start-up. The parameters of this process depend on the design of the furnace. The purpose of any boiler start-up is to heat the furnace and to achieve the temperature necessary to initiate combustion of pulverized coal. The furnace heating is realized by combustion of reserve or auxiliary fuel, usually liquid, which is well lit and steadily burns at relatively low ambient temperatures. Quite often, this fuel is oil. On average, the start-up of a coal-fired boiler with a water steam capacity of 75 t/h lasts for quite a long time period (3–5 h). In such conditions, at least 20 tons of oil are burnt in 3–6 boiler start-up during the year. This value of fuel oil consumption is about 15% of fuel oil consumption during the year spent on the maintenance of stable combustion in the boiler furnace. Although the heat of oil combustion (about 44 MJ/kg) is 2 times higher than that for coal that is typical for thermal power (about 22 MJ/kg), the specific energy cost at oil combustion is 2.8 times higher than at coal combustion. This is due to the high cost of oil [6]. Therefore, from the economic point of view, the technology of boiler start-up by coal dust combustion is more effective. In addition, the technology of oil-free start-up of the boiler can be adapted to illuminate the torch in stationary and dynamic modes of the boiler operation instead of the technology of joint combustion of solid and liquid fuels. The latter technology is characterized by technical, economic and environmental disadvantages. Joint combustion of solid and liquid fuels leads to intensified contamination of heat exchange surfaces by solid combustion products. This reduces the overall efficiency of the boiler. Besides, the co-combustion of coal and fuel oil leads to a significant increase in the concentration of greenhouse gases (CO, CO_2, NO_x, SO_x) in flue gases [6] due to the peculiarities of the chemical interaction of solid and liquid fuel components in a high-temperature environment of the oxidizer.

The joint influence of the following factors leads to positive economic effect of perspective technology of oil-free start-up:

(1) reduction of costs for the purchase of fuel;
(2) no costs for maintenance of storage systems and distribution of liquid fuel (along with the increase in electricity consumption for the grinding of coal);
(3) lower costs for servicing the fire alarm systems and fire extinguishing systems;
(4) reduced tax rates on low quantity of harmful emissions into the environment (ashes of micron fractions, CO, CO_2, NO_x, SO_x).

Table 1
The main operating costs of start-up (about 5 times a year) of a typical coal-fired boiler with steam capacity of 75 t/h.

Characteristics	Fuel oil	Coal	Economic effect
Purchase of fuel	4855 EUR	2250 EUR	2605 EUR
Storage and preparation of fuel to combustion	850 EUR	150 EUR	700 EUR
Tax on harmful emissions	3340 EUR	1360 EUR	1980 EUR
Total	9045 EUR	3760 EUR	5285 EUR

Table 1 shows the main operating costs of start-up (about 5 times a year) of a typical boiler (steam capacity of 75 t/h) by high-reaction coal and by fuel oil, and also an approximate economic effect of means at a transition from a traditional start-up technology of coal-fired boiler by liquid fuel to the technology of oil-free start-up.

The operating costs for boiler start-up are only 5–10% of all operating costs. Application of perspective technology of oil-free start-up and illumination of the boiler torch will save more than 70,000 EUR/year annually (for a coal-fired boiler with steam capacity of 75 t/h in 2017 prices). Besides abandonment of the use of flammable liquid as an auxiliary fuel for coal-fired boiler will increase the fire safety in TPP.

Thus, the replacement of fuel oil by the amount of solid fuel with the equivalent heat generation is an urgent task of thermal power engineering. Also in recent years, there have been research and development of new devices and technologies of combustion initiation for possible replacement of liquid fuel with solid fossil fuel and other composite fuels [7–9] in transient modes of boiler operation. The instability of prices in the world market of liquid energy sources confirms the high relevance of the problem of oil-free boiler start-up.

To date, several different concepts of straight-flow coal-dust burners have been developed [10]. Energy sources in such burners are: the plasma torch (Fig. 1), electric heater (Fig. 2), small scale gas or liquid fuel burner (Fig. 3).

Burners (Figs. 1–3) quite significantly differ in design and size due to different methods of dust-air flow preheating and, as a result, due to

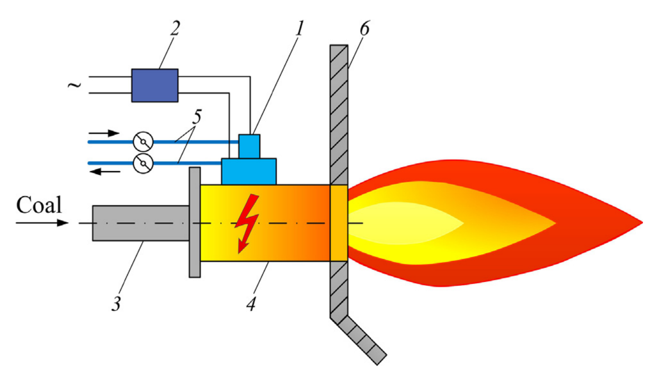


Fig. 1. Scheme of the fire burner with plasmatron: *1* – plasmatron, *2* – power supply, *3* – coal dust flue, *4* – muffle, *5* – cooling system, *6* – furnace.