Environmental Pollution 242 (2018) 31–41

Contents lists available at ScienceDirect

Environmental Pollution

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

The influence of liquid plant additives on the anthropogenic gas emissions from the combustion of coal-water slurries☆

G.S. Nyashina, P.A. Strizhak*

National Research Tomsk Polytechnic University, Tomsk, 634050, Russia

A R T I C L E I N F O

Article history:
Received 19 January 2018
Received in revised form
21 April 2018
Accepted 21 June 2018
Available online 22 June 2018

Keywords:
Coal-water slurries
Coal and oil processing wastes
Plant additives and dopes
Combustion
Anthropogenic gas emissions
Complex criterion

A B S T R A C T

At present, coal is considered one of the main components for the production of cheap, high-energy and environmentally attractive slurry fuels. The latter can be produced on the basis of low-grade coal dust or coal processing wastes. Thus, coal-water slurries and coal-water slurries containing petrochemicals are produced. The involvement of coal and oil processing wastes expands the scope of raw materials, reduces the fuel costs from traditional energy sources and modifies the main economic characteristics of power plant performance. However, it also increases the impact of coal-fired thermal power stations on the environment. In the last 30–50 years, many efforts have been made to decrease the negative impact of human industrial activity on climate. Involving plant-based components in the process of energy generation to save energy and material resources looks very promising nowadays. This research studies the influence of adding typical bioliquids (bioethanol, turpentine, glycerol) on the concentration of anthropogenic emissions from coal-water slurry combustion. Relative mass concentrations of bioliquids varied in a small range below 20%. We focused on the concentration of the most hazardous sulfur and nitrogen oxides from the combustion of typical filter cakes, as well as plant-containing slurries. It was established that the concentration of sulfur oxides can be decreased (as compared to coal) by 75%, whereas that of nitrogen oxides by almost 30%. Using a generalizing criteria expression, we illustrated the main benefits of adding bioliquids to slurry fuels in comparison with coal. Adding 20% of glycerol was found to provide maximum advantages.

1. Introduction

1.1. The consumption of resources for heat and power generation

In the last 50 years, the rates of global population growth have almost doubled. As a result, the consumption of energy has increased significantly due to the development of new technologies which, albeit convenient and beneficial, are based on rather an unsafe and limited energy structure obtained from fossil fuels (coal, oil and gas) (Farfan and Breyer, 2017; Dai and Finkelman, 2017; Su et al., 2017; Zhao et al., 2017).

The growth of electricity consumption in the world is provided by the increase in demand in the emerging markets (Fig. 1). Starting from the 1990s, the electric energy consumption in *China* and other emerging countries in the *Asia-Pacific region* has been steadily growing. The growth of electricity production in *India* keeps increasing; it outperformed *Russia* in this regard in 2011 (Dai and Finkelman, 2017; Su et al., 2017; Zhao et al., 2017). In general, developing and developed countries generate a stable amount of electricity, whereas the consumption dynamics is similar to the trends in economic ups and downs (Dai and Finkelman, 2017; Su et al., 2017; Zhao et al., 2017).

More than 38% of electricity is produced by coal-fired power plants (Fig. 2) (Dai and Finkelman, 2017; Su et al., 2017; Zhao et al., 2017). The increase in the share of coal was mainly conditioned by the active construction of coal-fired power plants in *India* and *China* (Hu and Cheng, 2016; Su et al., 2017). High coal stocks and low cost of its extraction make it an attractive resource for emerging markets. Meanwhile, developed countries tend to increase the consumption of renewable energy sources in their energy politics since they are the most sustainable and a relatively safe energy source

Abbreviations: CLF, composite liquid fuels; CWS, coal-water slurries; CWSP, coal-water slurries containing petrochemicals.

☆ This paper has been recommended for acceptance by Dr. Jorg Rinklebe.

* Corresponding author.
E-mail address: pavelspa@tpu.ru (P.A. Strizhak).
URL: http://hmtslab.tpu.ru

https://doi.org/10.1016/j.envpol.2018.06.072
0269-7491/

Nomenclature

A^d	ash level of dry sample, %
C^{daf}	fraction of carbon in the sample converted to a dry ash-free state, %
C_i	cost of components, \$/kg
CO	concentration of carbon monoxide, ppm
D_i^{NOx}	relative parameters describing the heat of coal, CWS or CWSP combustion with regard to the cost of components and concentration of NO_x emissions, MJ/\$·ppm
D_i^{SOx}	relative parameters describing the heat of coal, CWS or CWSP combustion with regard to the cost of components and concentration of SO_x emissions, MJ/\$·ppm
$D_i^{NOx\&SOx}$	relative parameters describing the heat of coal, CWS or CWSP combustion with regard to the cost of components and concentration of NO_x and SO_x emissions, MJ/\$·ppm
$D_{relative}$	relative complex parameter
H^{daf}	fraction of hydrogen in the sample converted to a dry ash-free state, %
N^{daf}	fraction of nitrogen in the sample converted to a dry ash-free state, %
NO_x	concentration of nitrogen oxides, ppm
O^{daf}	fraction of oxygen in the sample converted to a dry ash-free state, %
O_2	concentration of oxygen, %
S_t^d	fraction of sulfur in the sample converted to a dry state, %
SO_x	concentration of sulfur oxides, ppm
T_f	flash point of liquid combustible component, K
T_g	air temperature, K
T_{ign}	ignition temperature of liquid combustible component, K
Q^a_s	heat of combustion (J/kg)
V^{daf}	yield of volatiles of coal to a dry ash-free state
W^a	moisture, %
τ	time, s
ρ	density, kg/m^3

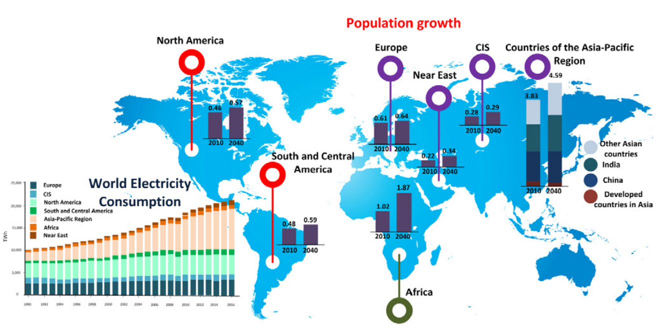

Fig. 1. Global electricity consumption and population growth (based on the data from (Dai and Finkelman, 2017; Su et al., 2017; Zhao et al., 2017)).

(Zhao et al., 2017; BP Statistical Review, 2016; Mallick et al., 2017).

In the modern market conditions, programs for the development of energy-saving and environmentally friendly technologies of using fuel tend to involve biological types of fuel in energy production. Using biomass in its pure form or through the production of biofuel (bioethanol and biodiesel) can satisfy energy needs with no damage to biodiversity or ecological balance (Mallick et al., 2017; Liu et al., 2016). Although biomass is a renewable and carbon-neutral energy resource as compared to fossil fuels, its direct application is limited by high transportation costs and lower energy density (Liu et al., 2016).

Therefore, a lot of research has been done on the topic of mixing plant and coal fuels (Naik et al., 2010; Gil et al., 2010; Bae et al., 2015; Liu et al., 2017) to study the preparation, ignition and combustion of such kinds of fuels. Special attention was paid to gas emissions and ash deposition from the co-firing of coal and biomass. In fuels (Naik et al., 2010; Gil et al., 2010; Bae et al., 2015; Liu et al., 2017), the authors argue that involving plant additives significantly decreases the amount of emissions.

One of the most promising ways of using biomass and coal is the production of composite liquid fuels, coal-water slurries and coal-water slurries containing petrochemicals on their basis. Their implementation is likely to save energy and material resources, as well as the environment fuels (Bae et al., 2015; Liu et al., 2017; Lee

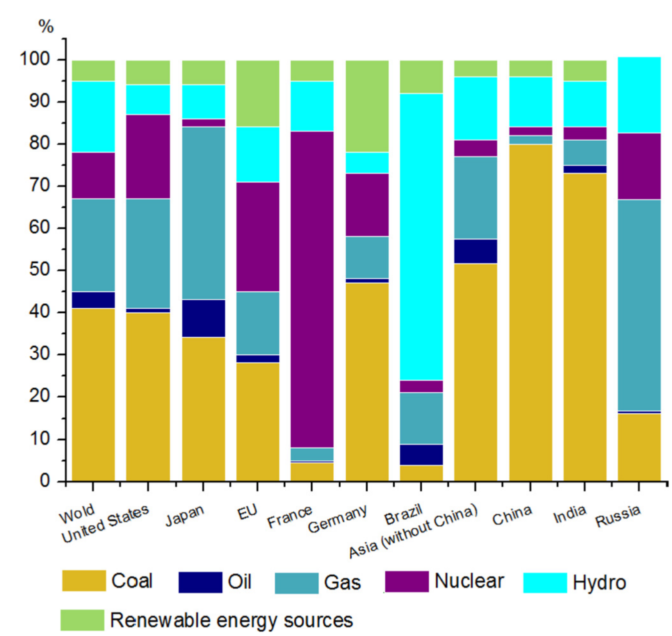

Fig. 2. Electricity production by type of fuels in countries and regions of the world (based on the data from (BP Statistical Review, 2016; Mallick et al., 2017)).

et al., 2016; Zhu et al., 2017b; Armesto et al., 2003). Using low-grade coal, coal sludge, rock fines and coal washing plant wastes (filter cakes) as coal fuel components is a very effective and environmentally friendly way of utilizing fine coal sludge from coal mining and coal processing enterprises.

To increase the calorific value, we suggested adding to CLF such components as petroleum wastes, wastes from oil refineries and chemical industries (used industrial oils, oil sediments, heavy coal-tar products, resins, and fuel oil) (Strizhak and Vershinina, 2017; Glushkov and Strizhak, 2017; Dmitrienko and Strizhak, 2017). We have discovered (Dmitrienko et al., 2017; Dmitrienko and Strizhak, 2017) that these components improve the energy performance of slurry fuels, though with some consequences for the environment.