Science of the Total Environment 613–614 (2018) 1117–1129

Contents lists available at ScienceDirect

Science of the Total Environment

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

Coal-water slurries containing petrochemicals to solve problems of air pollution by coal thermal power stations and boiler plants: An introductory review

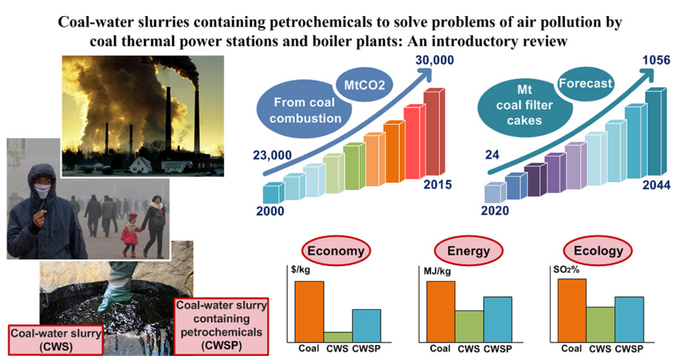
Margarita A. Dmitrienko, Pavel A. Strizhak *

National Research Tomsk Polytechnic University, Tomsk 634050, Russia

HIGHLIGHTS

- Research enables the assessment of the prospects of power plants switching to CWSP.
- CWSPs are more economically and environmentally efficient than coals or fuel oil.
- Charges at TPSs required for switching to CWSP pay off within several years.
- The greater the fuel consumption and energy output, the shorter the payback period.
- By varying the type of waste in CWSP, one can change the power plant performance.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 August 2017
Received in revised form 16 September 2017
Accepted 18 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Air pollution
Anthropogenic emissions
Sulfur and nitrogen oxides
Thermal power stations and boiler plants
Coal combustion
Coal water slurries containing petrochemicals

ABSTRACT

This introductory study presents the analysis of the environmental, economic and energy performance indicators of burning high-potential coal water slurries containing petrochemicals (CWSP) instead of coal, fuel oil, and natural gas at typical thermal power stations (TPS) and a boiler plant. We focus on the most hazardous anthropogenic emissions of coal power industry: sulfur and nitrogen oxides. The research findings show that these emissions may be several times lower if coal and oil processing wastes are mixed with water as compared to the combustion of traditional pulverized coal, even of high grades. The study focuses on wastes, such as filter cakes, oil sludge, waste industrial oils, heavy coal-tar products, resins, etc., that are produced and stored in abundance. Their deep conversion is very rare due to low economic benefit. Effective ways are necessary to recover such industrial wastes. We present the cost assessment of the changes to the heat and power generation technologies that are required from typical power plants for switching from coal, fuel oil and natural gas to CWSPs based on coal and oil processing wastes. The corresponding technological changes pay off after a short time, ranging from several months to several years. The most promising components for CWSP production have been identified, which provide payback within a year. Among these are filter cakes (coal processing wastes), which are produced as a ready-made coal-water slurry fuel (a mixture of flocculants, water, and fine coal dust). These fuels have the least impact on the environment in terms of the emissions of sulfur and nitrogen oxides as well as fly ash. An important conclusion of the study is that using CWSPs based on filter cakes is worthwhile both as the main fuel for thermal power stations and boiler plants and as starting fuel.

Abbreviations: ASW, ash and slag waste; CWS, coal water slurry; CWSP, coal water slurry containing petrochemicals; SLCF, synthetic liquid composite fuel; TPS, thermal power station.

* Corresponding author.
E-mail addresses: mad2@tpu.ru (M.A. Dmitrienko), pavelspa@tpu.ru (P.A. Strizhak).

https://doi.org/10.1016/j.scitotenv.2017.09.189
0048-9697/

Nomenclature

A^d	ash level of dry sample, %
C^{daf}	fraction of carbon in the sample converted to a dry ash-free state, %
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, %
O^{daf}	fraction of oxygen in the sample converted to a dry ash-free state, %
S_t^d	fraction of sulfur in the sample converted to a dry ash-free state, %
T_g	air temperature, K
T_f	flash temperature, K
T_{ign}	ignition temperature, K
V^{daf}	yield of volatiles of coal to a dry ash-free state, %
W^a	humidity, %
$Q^a_{s,V}$	heat of combustion, MJ/kg
ρ	density, kg/m^3
t_d	ignition delay time, s
τ_b	duration of combustion, s

1. Introduction

Energy providers bear the primary responsibility for the accelerating environmental degradation in the world. Despite the extensive use of gas, oil, and uranium, the share of coal in the global electricity generation is an impressive 35–45% (Lior, 2008; Kontorovich et al., 2014; Coal Facts, 2014; International Energy Agency, 2016; BP Statistical Review of World Energy, 2016). The annual growth of coal consumption by energy providers results from the increased demand for inexpensive heat and electricity. BP Statistical Review of World Energy (2016) states that the coal consumption in 2015 was as follows: China 1920.4 million tons, India 283.9 million tons, the USA 455.2 million tons, Australia 275 million tons, and Russia 184.5 million tons. According to forecasts (International Energy Outlook, 2016; Liu et al., 2017; Kucukvar et al., 2017), these numbers are most likely to increase. In particular, the average coal production in China will reach 5.5 billion tons by 2020 (Liu et al., 2017). With its 210 GW, India is the fifth largest electricity producer in the world. Coal-fired power stations account for 66% of the power-generating sector in this country (Kucukvar et al., 2017; Guttikunda and Jawahar, 2014).

The states with developed coal power industry (China, India, Japan, Russia, the USA, and Australia) register a high air pollution level on their territories every year. Coal combustion does not only provide energy but also produces hazardous substances and their mixtures (Deng et al., 2014; Chen et al., 2015; Noli and Tsamos, 2016): anthropogenic emissions (CO_x, NO_x, SO_x); ash and slag waste; fly ash with high content of heavy metals (As, Cr, Ba, Sr, Zn, Pb, Mo, etc.); and toxic radionuclide-contaminated water. The world academic community is well aware of the massive detrimental effects of these wastes on the environment (Chen et al., 2013; Yuan et al., 2014; Adiansyah et al., 2017; Pan et al., 2017). In particular, sulfur and nitrogen oxides combine with the moisture in the atmosphere and oxidize to form weak solutions of sulfuric and nitrous acids, which cause acid rains (Ge et al., 2016). Increased concentrations of nitrogen oxides catalyze the depletion of the ozone layer, which protects the earth from ultraviolet radiation. Moreover, combustion products contain fluorine, chlorine and their derivatives, toxic and carcinogenic compounds, as well as carcinogenic hydrocarbons (Chen and Xu, 2010). Energy providers do not only affect the global environment by emissions of the above oxides but also of carbon dioxide and water vapors. These enhance the greenhouse effect and cause climate change (Chen et al., 2013; Yuan et al., 2014; Adiansyah et al., 2017; Pan et al., 2017).

The world's major economies place special emphasis on developing technologies to reduce air pollutant emissions by energy providers and to advance the living standards (Meylan et al., 2015; Fan et al., 2015; Ma et al., 2016). Industrial nations are often enforced to reduce the emissions or stabilize their increment rate (Kyoto protocol, 1998; International Energy Outlook, 2016; Facing Climate Change, 2016). Nevertheless, coal combustion accounts for no less than about 45% of the world CO_2 emissions (International Energy Agency, 2016; Trends in Global CO_2 Emissions: Report, 2016). The USA, China, India, the European Union, and Russia are the leaders in this aspect (Abas and Khan, 2014). In China, 70% of all ash particle emissions come from coal power plants (Chen and Xu, 2010). The situation is similar with other hazardous substances: coal-burning power plants are to blame for 90% of all sulfur dioxide (SO_2) emissions, 67% of nitrogen oxides (NO_x), and 70% of carbon dioxide (CO_2) (Chen and Xu, 2010). Many states, including the Brazil, China, India, USA, South Africa, and Russia, cannot restrict the coal power generation for a number of reasons (Rodriguez-Iruretagoiena et al., 2016; Civeira et al., 2016a, b; Agudelo-Castañeda et al., 2016; Schneider et al., 2016; Saikia et al., 2016; Sehn et al., 2016; Dalmora et al., 2016; Ramos et al., 2017; Fdez-Ortiz de Vallejuelo et al., 2017; Agudelo-Castañeda et al., 2017). Therefore, the ecological impact can only be reduced by improving the coal-burning technologies.

Vast amounts of hazardous anthropogenic emissions do not only lead to serious environmental consequences but also have adverse effects on human health (Oliveira et al., 2014a). For example, Indian coal-fired power plants annually emit over 110 thousand tons of ash particles, 43 million tons of SO_2, and 1.2 million tons of NO_x (Oliveira et al., 2014a). Study (Guttikunda and Jawahar, 2014) shows that exposure to solid ash particles and coal dust caused 115 thousand premature deaths and about 21 million of asthma cases in this country between 2010 and 2011.

A significant share of mined coal is washed when prepared for export. Wet high-ash wastes (filter cakes), which are formed as a result, are annually accumulated in the amount of tens of millions of tons (Glushkov et al., 2016a). Currently, Russia, China, and India are thinking of involving coal filter cakes in the power industry (Glushkov et al., 2016a). The coal concentration in CWSs and filter cakes usually ranges from 40% to 60%, so wet filter cakes per se are ready-made coal-water slurries (Glushkov et al., 2016a).

Using CWSs as the main fuel (for example, instead of coal or fuel oil) will help energy providers to reach a number of goals: reduce anthropogenic emissions into the environment, recover coal processing wastes, free vast territories of the corresponding disposal areas, and lower the rate of coal mining and development of new deposits (Saikia et al., 2015; Sanchís et al., 2015; Tezza et al., 2015; Wilcox et al., 2015; Sindelar et al., 2015). Moreover, there are other issues related to the lamination of the slurry (settling of solid particles or sedimentation). This complicates the pipeline transportation of CWSs as well as their long-term storage and subsequent combustion (Glushkov et al., 2016a). To prevent lamination, one can add liquid flammable plasticizers to slurries and thus obtain the so-called coal water slurries containing petrochemicals (Glushkov et al., 2016a). These are also known as synthetic liquid composite fuels.

Using CWSPs will not only reduce the emissions and smooth the way for effective waste recovery, but also expand the scope of raw materials for fuel production from the corresponding wastes and improve the combustion efficiency of low-rank coals. Boilers have already been operationally tested for burning CWSPs based on coal cakes at Barzas station in Kemerovo region, Russia (Glushkov et al., 2016a). The power industry will benefit greatly from a comprehensive analysis of the prospects of CWSP usage in terms of environmental, economic and energy performance.

The purpose of this introductory study is to analyze the sustainability and energy performance prospects of thermal power stations and