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Co-combustion of sewage sludge from different treatment processes and a lignite coal in a laboratory scale combustor

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ABSTRACT

One sustainable use of sewage sludge (SS) is to use it as fuel in existing coal-fired plants. Towards this end, this study evaluated thermal characteristics and co-combustion efficiency of dried SS samples from six wastewater treatment plants with different sludge treatment units. Fuel quality of SS based on proximate and ultimate analyses and calorific value, and ash composition by XRF analysis were investigated. Then the SS samples were co-combusted in a laboratory batch reactor in mixtures with coal (3%, 5%, 10%, 20% and 30%). Results showed that samples had good calorific values (between 1931 and 3852 cal/g). Furthermore, the type of sludge stabilization processes had an important effect on thermal characteristics of samples and the point where the sludge addition started to intrude the combustion efficiency. Among all stabilization methods, lime stabilization was observed to affect the thermal characteristics the most. Sludge treated with anaerobic stabilization had lower calorific values than the ones stabilized aerobically. The results from co-combustion experiments showed that as the percentage of SS in the mixture increased from 5% to 30%, the combustion efficiency decreased gradually from 99.5% to 97.5%. Furthermore, according to XRF analysis result, fouling and slagging indices of samples were higher than the limit values.

1. Introduction

Sewage sludge is a by-product of municipal wastewater treatment processes. Sludge production will continue to increase as new wastewater treatment plants are built and environmental quality standards become more stringent [1]. According to the recent data in Ref. [2], the total amount of municipal sludge produced in the European Union countries is about 10.9 million tons of dry matter (DM) per year. In Turkey, more than 1000 tons DM of sewage sludge is produced daily [3]. With the increasing amount of sludge produced worldwide, developing urgent and effective approaches for sewage sludge management becomes crucial. Currently the common sludge disposal methods are agricultural use, landfilling, compost production, and incineration [4]. Recent data show that, in Europe 45% of sewage sludge produced is applied for agricultural purposes, 23% is used in incineration, 12% is landfilled, 11% is composted, 1% is discharged into sea, and 8% is managed by other methods [2]. As seen, currently, the agricultural application is the most widely used method for sewage sludge disposal in Europe; however, it has the potential for accumulation of organic pollutants and heavy metals in soils, plants, and animal pastures [5–7] and causing serious human health problems [8]. In many countries including Turkey and Greece, landfilling is the most common method to dispose sewage sludge [2]. However, due to lack of available land, increasing quantities of sewage sludge production, and the regulations aiming to valorize sludge, the amounts of biodegradable waste sent to landfill will soon be minimized. These limitations of landfilling and agricultural use make sludge incineration an attractive solution since it reduces sludge volume, and simultaneously destroys the toxic organic constituents and recovers energy [9]. The main drawback of incineration is that the sludge has a complicated composition and low heating value; therefore, the sludge mono-combustion is difficult. To overcome this problem, sewage sludge can be used as auxiliary fuel in coal-fired power plants and cement kilns [10]. This is both a safe and economical way of sludge disposal since it decreases the fuel costs of these plants [11]. In addition to decreasing the use of fossil fuels,

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co-combustion of sludge also recovers the available energy in sludge and overall CO_2 emission is reduced [10].

The elemental composition of sewage sludge is different from that of coal; thus, the co-combustion of sewage sludge with coal mixtures may have different combustion characteristics than coal combustion alone [12]. If the combustion process is properly designed by considering the unique properties of sewage sludge, high combustion efficiencies can be achieved [13].

Many studies have been conducted to gain a better understanding of the characteristics of the co-combustion of sewage sludge with coal. The research in this area is focused on determining the change in combustion efficiency and air emissions, ash characteristics, heavy metal partitioning and some other aspects of combustion when sewage sludge is co-combusted with coal.

Lu [14], and Nadziakiewicz and Kozioł [15] studied the changes in CO, NO_x and SO_2 emissions during co-combustion of sewage sludge with coal. They showed that the emissions of these air pollutants increase with the increasing sludge ratio in the fuel mixture. Lu [14] stated that the share of sludge ratio in a fuel mixture should not exceed 25%. Another study conducted by Otero et al. [16] showed that the activation energy needed for co-combustion of sewage sludge and coal fuel mixtures that include %3, 5% and 10% by wt. sludge ratios were similar to that of the combustion of coal alone. Also, Park et al. [12] and Kim and Lee [17] stated that sewage sludge-coal mixture samples and pure coal samples had similar thermogravimetric analysis (TGA) curves and their combustion activation energies were close to each other. Thus, it was found that the co-combustion of sewage sludge and coal mixture containing up to 20% by wt. sewage sludge had a similar combustion behavior with coal combustion alone [12]. In the study [17], it was shown that the efficiency of sewage sludge combustion was very sensitive to change in temperature and residence time. Kijo-Kleczkowska et al. [13] revealed that coal combustion was enhanced by the addition of sewage sludge to hard coal because coal ignition time and ignition temperature decreased due to the high volatile content of sewage sludge.

It is obvious that the thermal characteristic of sludge is a function of origin of the sludge and the treatment process that the sludge has gone through. Therefore, the thermal characteristics of sewage sludge may differ considerably from plant to plant; however, the factors that affect thermal characteristics of sewage sludge are not fully investigated in literature. Therefore, more information is needed especially in linking the wastewater and sludge treatment processes that the sludge has been subjected to with the combustion characteristics of the sludge. The first aim of this study is to investigate sludge characteristics from different wastewater treatment plants. This include measuring the thermal properties of sludges originating from different wastewater treatment plants, evaluating their potential as fuels and trying to relate these properties to the wastewater treatment and sludge treatment processes. The other aim of this study is to determine how the combustion efficiency is affected by the addition of sewage sludge to coal. In order to satisfy this aim, the coal and sewage sludge mixture was co-combusted in a laboratory scale drop tube furnace with various mixing ratios. Combustion efficiency was determined by making a carbon mass balance.

2. Materials and methods

2.1. Wastewater treatment plants investigated

Six wastewater treatment plants (WWTP), having different wastewater and sludge treatment processes are included in this study. Treatment processes of these WWTPs are listed in Table 1. The flowcharts showing the units of wastewater and sludge treatment for these treatment plants are given in the Supplementary Material.

From these WWTPs, sewage sludge samples were taken at the outlet end, i.e. either from the dewatering or the drying process. The only exception is WWTP-E. In this treatment plant, lime stabilization is applied after dewatering process. Therefore, there are two kinds of sewage sludge which is produced in this plant, one is dewatered (E2) and the other one is dewatered and lime stabilized sewage sludge (E1). Sewage sludge samples were collected 3 times, in Fall, Winter and Spring, at each treatment plant. Due to logistic reasons, samples were collected from WWTPs A, D and F only twice. Also, lime stabilized sludge sample was collected once in fall (E1). List of sewage sludge samples collected from WWTPs are given in Table 2.

2.2. Sample preparation for combustion

As a first stage of sample preparation, all sewage sludge samples were air dried at 40 °C in an oven for 3–4 days in order to achieve similar moisture content. This pretreatment provided more than 90% dry matter for the samples. After drying, all sewage sludge samples were sieved to 60 mesh sieve size in order to minimize the effect of different particle sizes. The coal sample used in the study is typical Turkish lignite and it was also subject to same pretreatment procedures as sludge samples to obtain homogenous coal-sludge mixtures. The lower heating value of coal sample is 6128.43 cal/g on dry basis which is similar to those of coal used in the other studies [11,18–20]. Then, sewage sludge-coal mixture pellets were prepared by mixing sewage sludge with coal at ratios of 0%, 3%, 5%, 10%, 20% and 30% (on total energy basis of the sludge-coal mixture) in order to observe the effects of sewage sludge addition to coal.

The pellets had 15 mm diameter and about 2 mm height. Each sample (pellet) combusted was formulated to keep the calorific value constant as 1000 cal. Therefore, in this work, the sewage sludge mixing ratio denotes the share of the energy input from the sewage sludge in the total energy input from the coal-sludge mixture. Coal sample alone was also combusted without any

Table 1
Treatment processes of WWTPs sampled.

Treatment Plants	Treatment Processes			
	Primary Clarifier	Wastewater Treatment Process	Sludge Treatment Process	Sludge Dewatering/Drying
A	Yes	A2O	Anaerobic Stabilization	Dewatering + Drying
B	Yes	UCT	Anaerobic Stabilization	Dewatering
C	No	A2O	Cannibal Treatment	Dewatering + Drying
D	No	A2O	Aerobic Stabilization	Dewatering + Drying
E	No	A2O	Lime Stabilization	Dewatering
F	Yes	A2O	Anaerobic Stabilization	Dewatering + Drying

A2O: Anaerobic-Anoxic-Oxic Biological Wastewater Treatment Process with Nutrient Removal.
UCT: University of Cape Town Biological Wastewater Treatment Process with Nutrient Removal.