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Oxygen enriched combustion and co-combustion of lignites and biomass in a 30 kWth circulating fluidized bed

Ufuk Kayahan [a, b, *], Sibel Özdoğan [b, c]

[a] TUBITAK Marmara Research Center Energy Institute, p.o.b. 41470, Gebze, Kocaeli, Turkey
[b] Marmara University, Institute of Pure and Applied Sciences, Göztepe Campus, 34722, Kadıköy, İstanbul, Turkey
[c] Faculty of Engineering, Dept. of Mechanical Engineering, Göztepe Campus, 34722, Kadıköy, İstanbul, Turkey

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ABSTRACT

Oxygen enriched combustion is a promising retrofitting option for existing power plants to improve CO_2 capture. In this study, the effect of oxygen enrichment of air as oxidant was investigated with a 30kWth fluidized bed combustor. Tests were conducted with two different Turkish lignites, one biomass and their blends. Biomass share was increased up to 20%. The oxygen concentration in the oxidant was kept between 21 and 30%.

Oxygen enrichment supports combustion in all cases. Biomass addition to lignites appears to have an increasing synergetic effect on combustion as the oxygen enrichment and biomass portion in the mix increases. It was found that oxygen enrichment increases NO and SO_2 formation in all cases. As the biomass share increases NO emissions increase in all oxygen cases while the opposite is true for SO_2 emissions.

1. Introduction

Global energy demand is estimated to increase by one-third from 2011 to 2035. In spite of the rise of the renewable energy usage the share of fossil fuels is expected to reduce from 82% to 75% only [1]. Moreover global coal consumption increase is expected to be more pronounced than that of petroleum because of China. Increase of fossil fuel consumption in the world, will lead to the increase of CO_2 emissions. According to IEA facts, energy related CO_2 emissions are expected to rise 20% by 2035 resulting in 3.6 °C temperature rise in the atmosphere. Since the fossil fuels will continue to play a dominant role throughout the world it is of utmost importance to develop technologies that reduce CO_2 emissions while using fossil fuels. Biomass co-combustion and carbon capture and storage (CCS) technologies seem popular solutions to reduce CO_2 emissions [2,3].

Biomass co-combustion means partial substitution of biomass for coal in coal power plants. Based on the current worldwide installed coal fired power plant capacity at 800GWe; substitution of each percentage of coal by biomass will reduce annualCO_2 reductions approximately by 60 Mton [4]. Co-combustion approach seems one of the most economic and efficient ways of biomass usage in the existing electricity generation system, because there is no or minor need for extra infrastructure for co-combustion in existing coal power plants [5]. The other major advantages of co-combustion compared to coal firing are related to lower SO_2 and NO_x emissions due to biomass' low sulphur and fuel nitrogen content [6].

CCS is also sought to reduce CO_2 emissions. According to IEA scenario CCS will contribute to 14% of the CO_2 emission reductions required in 2050 [7]. Oxy-combustion technology is considered as an appropriate energy and cost efficient CCS technology among others [8]. In oxy-combustion part of the outgoing flue gases are recycled back to the incoming oxygen stream. Further developments in air separation techniques are expected to make this technology economically feasible. While this technology is being developed, an integration concept, oxygen enriched combustion (OEC), can be applied to the existing power plants [9]. Combustion with increased oxygen concentration in the oxidizer atmosphere is called OEC. Pure oxygen is added to the combustion air, and the oxygen concentration is increased in the oxidant stream. The OEC technique was first used in high temperature metallurgy industry [10]. The benefits of the OEC are increased productivity and energy efficiency along with reduced exhaust gas volume and pollutant

* Corresponding author. Present address: TUBITAK Marmara Research Center Energy Institute, p.o.b. 21 41470, Gebze, Kocaeli, Turkey.
E-mail address: ufuk.kayahan@tubitak.gov.tr (U. Kayahan).

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Table 1
Fuel analysis.

Sample	Ultimate analysis dafbwt%					HV kJ/kg	Proximate analysis dbwt%			
	C	H	N	S	O		FC	V	A	M
Can lignite (CAN)	71.2	6.06	1.53	9.16	12	3890	28.32	31.57	40.11	20.53
Tunçbilek lignite (TNC)	75.6	5.52	1.60	1.35	15.91	6237	46.77	39.41	13.83	14.14
Olive Cake (OC)	54.02	5.98	0.65	0.13	39.19	4922	22.18	74.38	3.44	9.62

FC: Fixed Carbon; V: Volatile matter; A: ash; M: Moisture.

Table 2
Ash melting characteristics of the fuels.

Ash melting temperatures (°C)			
	CAN	TNC	OC
IDT	>1500	1252	1210
ST	>1500	1263	1230
HT	>1500	1305	1265
FT	>1500	1337	1292

emissions [10,11]. Oxygen enriched combustion is considered as one of the promising technologies to improve CO_2 capture among the retrofit options for existing power plants [12].

Replacing N_2 with O_2 in oxidizing atmosphere will reduce the dilution effect of N_2 and lead to increased combustor temperatures, thus resulting in higher efficiency and capacity for the same system. Adding new equipment to the existing power plant to increase efficiency and capacity is much more expensive than retrofitting the system to OEC. This is one of the most popular reasons for using OEC [11].

Extensive research has been conducted and presented in the area of oxy-combustion [13–18]. However, there is limited experimental data on OEC [12]. Bench scale experiments have shown that volatile release rate increases and burnout temperature decreases under oxygen enriched atmosphere compared to air combustion at the same excess air [19]. Horbaniuc et al.has proposed a model to analyze the effect of oxygen enrichment on heat transfer in an existing boiler [9]. The study has shown that OEC has advantages of improved combustion, higher flue gas temperature and higher thermal conductivity of flue gas compared to air firing. They have concluded that the OEC can increase the boiler efficiency by 2–5% [9]. Pawlak-Kruczek et al. have conducted experiments with coal and coal biomass blends at different oxygen concentrations between 20% and 30% in an isothermal reactor. Tests have been carried out with biomass fractions of 20% and 40% in hard coal. The main conclusion is that the co-firing in oxygen enriched atmosphere improves the burnout degree significantly [20]. Zhu et al. have studied the effect of oxygen enrichment and steam addition on NOx emissions in a fluidized bed combustor. The conclusion of the study is that adding steam (steam/fuel mass ratio 0.8) at below 35% oxygen concentration will reduce the NOx emissions. They also observed an improvement in combustion with a steam/fuel mass ratio at 0.5 [19].

In this study, one high heating value and low sulphur lignite, namely Tuncbilek(TNC), is selected along with a lower heating value, high sulphur lignite, namely Can (CAN) for co-combustion with olive cake (OC) in oxygen enriched atmospheres in a circulating fluidized bed combustor (CFBC).

2. Experimental

2.1. Fuel and bed materials

Experiments were performed with two different kinds of Turkish lignites (TNC and CAN) and one biomass (OC). The received materials were below 50 mm particle size. They were crushed to

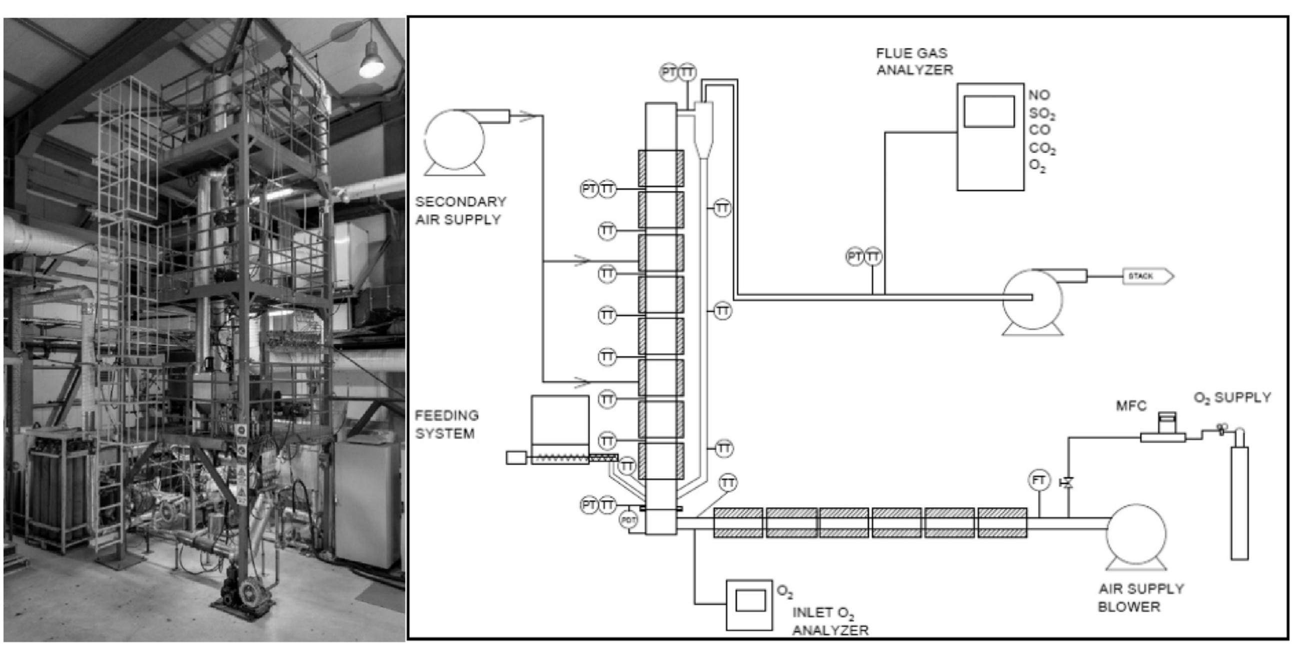

Fig. 1. 30kWth CFB Combustion System (a photo of the system on the left, flow diagram on the right).