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Biomass waste co-firing with coal applied to the Sines Thermal Power Plant in Portugal

L.J.R. Nunes [a], J.C.O. Matias [a], J.P.S. Catalão [a,b,c,*]

[a] University of Beira Interior, R. Fonte do Lameiro, 6201-001 Covilha, Portugal
[b] INESC-ID, R. Alves Redol 9, 1000-029 Lisbon, Portugal
[c] IST, University of Lisbon, Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal

HIGHLIGHTS

- The possibility of using waste biomass as fuel in a coal-fired thermal power plant is studied.
- Co-firing biomass waste, from forestry operations, with bituminous coal was simulated.
- The Sines Thermal Power Plant in Portugal was used as a case study.
- Reductions of more than 1,000,000 tons/year of CO_2 were calculated.
- Co-firing is still not economically viable due to the high cost of the residual biomass.

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ABSTRACT

Environmental issues raised by the use of fossil fuels lead to the search for alternatives that promote the reduction of emissions of greenhouse gases. CO_2 has been identified as being the most important and urgent to control. Co-firing is a technique that allows the simultaneous combustion of different types of fuels, for example coal and biomass, combining the advantages of both. This study characterises the advantages of the system and the possibilities of using waste biomass as fuel in a coal-fired thermal power plant. For this, co-firing biomass waste, from forestry operations, with bituminous coal was simulated. Then reductions in CO_2 emissions into the atmosphere from Sines Thermal Power Plant in Portugal were calculated, showing a reduction of more than 1,000,000 tons/year of CO_2. Also it was verified that although environmentally advantageous, co-firing is still not economically viable due to the high cost of the residual biomass, combined with its low-energy density and high transportation costs.

1. Introduction

The environmental advantages of using biomass and other renewable energy forms as alternative energy sources to fossil fuels are the basis that sustains initiatives for the use of these resources, in all their variants, to increase its penetration into energy markets [1].

Unfortunately, these advantages are accompanied, in general, by inherently problematic properties (stationary, low-energy density, scattering, competition with other uses, etc.) that characterise these power sources and, more particularly, biomass waste. These features are closely related to the final costs of its use, delaying its incorporation into the energy markets, and ensuring that its current use remains far below expectations in terms of its expected potential [2].

In any case, to increase the consumption of residual biomass for energy production, as well as to put into practice actions and support tools, cost reduction and improved efficiency of procedures for collecting and processing these energy resources should be promoted [3].

In this study we analyse a technology that could allow an increase in the contribution of biomass energy in the Portuguese energy scenario, especially residual biomass, such as waste from forestry operations, through its co-firing with coal, and an estimation of CO_2 emissions was conducted in order to demonstrate the environmental advantages of using biomass waste in energy production, despite the economic disadvantage that still exists

* Corresponding author at: Department of Electromechanical Engineering, University of Beira Interior, R. Fonte do Lameiro, 6201-001 Covilha, Portugal. Tel.: +351 275 329914; fax: +351 275 329972.
E-mail address: catalao@ubi.pt (J.P.S. Catalão).

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due to low coal prices and to the high collection and transportation costs related to biomass waste.

This brief introduction, where a contextualization is made, is followed by a description of the co-firing technology and the state-of-the-art concerning test realized internationally. After comes the simulation of residual biomass co-firing at Sines Thermal Power Plant in Portugal, divided in description of the plant; the co-firing of biomass; the CO_2 emissions; and the economic feasibility, followed by the conclusions.

2. Co-firing in conventional coal power plants

An interesting and promising alternative for the production of electricity from biomass is through its co-firing in conventional coal power plants already in operation. This is a relatively recent technological development, and consists in replacing part of the coal used in the plant with biomass, with a maximum of 20% in energy potential, but 15% being the most common value achieved in tests performed in many thermal power plants in the EU and USA. Although this percentage is small, due to the large size of the plants, the end result is the production of a very substantial amount of electrical energy with this renewable fuel [4].

In addition, as well as the significant advantages of using biomass instead of fossil fuels, co-firing has other, no less important advantages when compared with the exclusive use of biomass in plants that are only equipped for this purpose.

For example, much lower investment is required per unit of installed capacity, because co-firing biomass can use much of the existing infrastructure in each plant (steam cycle, electrical systems, cooling system, and at least part of the boiler), which is reflected in a drastic reduction in the investment, despite the pre-treatment facilities being usually more complex than in a power plant that is used exclusively for biomass [5].

The generation of electricity with higher performance is not feasible, because the use of low-density biomass resources implies that, to achieve significant electrical potential, the collection should encompass too large an area, which would entail high transportation costs. Therefore, and by a simple matter of economy of scale, the promoters of a biomass thermal plant find themselves forced to decide between getting a high performance and a high cost per installed kW, or reducing this investment by reducing performance. This last option is the most frequently chosen to ensure the economic viability of the project. Thus, in a biomass thermal plant (usually less than 20 MW_e), performance hardly reaches 30%, whilst in coal thermal power plants of large dimensions (500 MW_e or more), where co-firing takes place, performance can reach 36% [6]. This possibility also allows much greater flexibility in operation, because a co-firing plant allows great flexibility and easy adaptation to the availability of biomass at a precise moment. A biomass plant would have to face the possibility of stopping or reducing production in certain periods due to either a shortage of resources or an increase in situational prices. However, a co-firing plant, even with these situations, could continue in full operation using the fuel which has been projected, in a greater proportion or even exclusively [7]. And, a very important environmental advantage would be the reduction in NO_x emissions due to the lower nitrogen content of biomass and synergistic effects between biomass and coal. This is an advantage that should be proven and quantified at each plant where co-firing may be conducted, because there may be significant differences among them [8].

Thus, co-firing becomes an easy and economical way to increase the short-term consumption of biomass in place of fossil fuels. However, this technology also has certain drawbacks and uncertainties, such as operating costs, because the pre-treatment of biomass co-firing is more costly (in facilities already in operation), especially in the case of co-firing in a pulverized coal thermal power plant. However, this increase in cost can be compensated, at least partially, by the fact that these power plants already have specialized personnel, which reduces both the cost of manpower [9] and uncertainty regarding the behaviour of the boiler due to a mix of fuels for which it was not designed [10].

Furthermore, although the concept of co-firing is relatively simple and has already been tested successfully in many power plants around the world, particularly in the USA and EU, there are many aspects (such as ideal pre-treatment and place of introduction of biomass) that should be studied in detail for each case: type of boiler, type of coal and type of biomass [11–20].

Although co-firing can be applied to all types of thermal power plants, the possibilities are greater in those that have installed pulverized fuel boilers, not for technical reasons, but because this technology is more widespread. In these boilers, finely pulverized coal with reduced moisture content is introduced, achieving high performance with very low residence times. These aspects require that biomass should present similar capabilities, and therefore before combustion it must undergo pre-treatment that, although varying from case to case, consists primarily of drying (natural or forced) to reduce the moisture content to values generally under 20% [21], and on grinding to reduce the particle size usually to less than 3 mm [22].

Regarding the type of coal used in the case of Portugal, mainly bituminous coal from Colombia, but also from other sources, such as South Africa and the USA, Table 1 shows the characteristics of this type of coal, as well as biomass waste [23].

The majority of the co-firing experiments were carried out with coal with an energy density higher (anthracite type) than that of biomass. However, the heating value of bituminous coal used in Portugal, although higher, is not much higher, as anthracite is, than that of biomass waste, as can be seen in Table 1. This may imply a considerable reduction in the investment necessary because there is the possibility of using biomass in the same systems as those designed for feeding coal to the boiler, especially burners. Additionally, it is possible to introduce the biomass in a simple way, at the centre of the flame generated by the coal, and it is technically feasible to use a particle size bigger than that of coal. This involves a reduced pre-treatment cost compared to other types of co-firing [24].

3. Residual biomass co-firing at Sines Thermal Power Plant

3.1. Sines Thermal Power Plant

The thermal power plant is located in the municipality of Sines (SW Portugal), near the harbour of Sines, where the coal that feeds the plant is unloaded. The plant consists of four groups of identical generators which have an independent autonomy able to contribute an electrical capacity of 314 MW each. The construction of the plant began in early 1979 and its first generator went into operation in 1985, with the rest following in 1986, 1987 and 1989 [25].

Each group of generators which makes up the plant system includes a steam natural circulation group (GGV), a turbo alternator (GTA) and one main transformer. The supply of coal that fuels

Table 1
Characteristics of bituminous coal of Colombian origin, used in Portugal and residual biomass (adapted from [23]).

	Bituminous coal[a]	Biomass waste	Units
LHV	7.85	2.80	kW h
Ashes	<11	<3	%
Moisture	<5	<30[b]	%

[a] Data obtained from EDP – Gestão da Produção de Energia, S.A.
[b] After 2 months of cutting and stored in a sheltered location.