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Comparative assessment of the energy effects of biomass combustion and co-firing in selected technologies

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ABSTRACT

The rational use of renewable energy sources depends largely on the processing technology applied and is a key element of sustainable development. The most widespread method of producing electricity from renewable sources in power plants involves the co-firing of biomass with fossil fuels, utilizing the existing infrastructure. In recent years, many existing units have been modernized to enable co-firing, including dedicated systems for feeding biomass directly to the combustion chamber. Simultaneously, work has also begun on building new units designed for the exclusive combustion of biomass, whereas other units have been retrofitted to replace coal with biomass combustion.

To establish a comparative assessment of the energetic and environmental effectiveness of the conversion of biomass into electricity, indicators are developed based on the unit consumption of energy, chiefly electrical, that is used to prepare the fuel. These indicators reflect the effect the energy consumed by different biomass conversion processes have on CO_2 emissions. The results of the calculations are presented for technologies involving combustion and co-firing in both pulverized fuel and fluidized bed boilers. To determine the energy required from the biomass and coal portion of the mixture fed to the boiler, a consistent methodology is developed analogous to the method of avoided fuel inputs used to determine the indicators during the cogeneration of electricity and heat.

The input data for the simulations originated from industrial tests performed under different technological configurations.

1. Introduction

The generation of CO_2 free energy can be achieved by either implementing CCS (carbon capture and storage) technologies or partially (or completely) substituting fossil fuels with biomass (commonly considered a CO_2-neutral fuel). Apart from having a positive environmental effect in terms of CO_2 direct emission reductions, biomass combustion reduces the depletion of non-renewable fuel resources.

The world CO_2 emissions statistics (2008) illustrate that 41% of total CO_2 emissions originate from electricity and heat generation industries. The share of the energy industry in total anthropogenic GHG (greenhouse-gas) emissions volume reaches 83%, of which 94% is CO_2 [1] thus, reducing these emissions in the energy supply sector remains an important issue.

Currently, the Polish energy sector is facing a number of serious challenges due to obligation to reducing CO_2 emission by 2020, while maintaining a high level of energy security. The TAURON group, second largest energy producer in Poland, joined R&D Strategic Programme “Development of a technology for highly efficient zero-emission coal-fired power units integrated with CO_2 capture” [2] developing post-combustion CO_2 capture [3] and oxy-fuel combustion technology [4,5], as well as biomass co-firing [6] to find economically and technically acceptable way to reduce CO_2 emissions.

This paper presents a newly developed methodology for determining the energy- and environment-related indicators to support the scientific debate concerning the real effectiveness of the technological options available for the conversion of biomass into electricity during combustion and co-firing. The methodology used to determine the indicators for units that are used for the co-firing or combustion of biomass is consistent with analogous to the method of reduced fuel inputs used to determine indicators for the cogeneration of electricity and heat [7].

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Abbreviations

CCS	carbon capture and storage
GHG	greenhouse gas
CC	carbon capture
PF	pulverized fuel boiler
CFB	circulating fluidized bed boiler
C	hard coal
SU	sunflower husks
HO	brewer's spent grain
CE	cereal waste
BM	biomass mixture
ACC	alternative coal configuration
COF	co-firing
REF	reference configuration

The Polish Draft Act on Renewable Sources of Energy [8] lists the available renewable (non-fossil) energy sources, including wind energy, solar energy, aerothermal energy, geothermal energy, hydrothermal energy, hydroenergy, energy from sea currents, tides and waves, and energy obtained from biomass, biogas, agricultural biogas and bioliquids. Each of these sources is subject to different conditions for the exploitation of its full potential, in which a notable factor is the average time over the course of a year during which the source can be used. For example, the available time for the use of solar energy by means of photovoltaic cells is approximately 700 h; for wind power plants, the maximum is approximately 2500 h; a biomass-fired power plant can operate at its rated, nominal output for ca 7000 h; and the annual operational time of biomass co-firing units is close to that of conventional, coal-fired units [9].

To obtain a full picture, renewable sources of energy should also be analysed in terms of their effect on the energy security of a country. Based on the definition of energy security, as established in the Polish Energy Law [10] – "Energy security is a state of the economy which enables the satisfaction of the current and anticipated needs of customers for fuels and energy in a technically and economically justified manner and with adherence to the requirements of environmental protection", it can be concluded that among the analysed types of renewable energy sources, only the use of biomass, as a form of accumulated solar energy that is relatively easy to store and transport, appears to satisfy all of the conditions included in the definition.

As previously mentioned, biomass plays a fundamental role in reducing effective carbon dioxide emissions in conventional electricity production by replacing coal – fossil fuel; the combustion of fossil fuels is a main source of anthropogenic CO_2 emissions. The need to reduce global emissions of carbon dioxide, in the absence of any other substitute fuels with a zero CO_2 emission index, establishes biomass as the only direct substitute for coal that can provide the possibility of zero-emission combustion. These considerations have driven the development of technologies for the co-firing and combustion of biomass. In the present work, these technologies are assessed in terms of their energy, economic and environmental effectiveness.

Aspects of the assessment of biomass combustion and co-firing on energy and ecological effects have already been subject to analyses e.g., [11,12,13]. The economic aspects of biomass co-firing have been studied with regard to incentive systems [14]. The process simulation package, ECLIPSE has been used here to analyse three different biomass co-firing configurations and to perform techno-economic assessment studies of each technology. The SI (specific investment) and BESP (Break-Even Electricity Selling Price) for each system were calculated and compared with the coal-fired plants. The sensitivity of the economics of these large power plants to such factors as fuel cost, load factor and insurance, operational and maintenance costs for two discount cash flow rates was investigated. The effect of applying the ROC (Renewable Obligations Certificate) subvention to the economics of the power plants was also assessed for a wide range of wood fuel costs. When retrofitting coal-fired condensing power plants to co-fire with biomass, two methods were used to determine whether co-firing is an environmentally friendly solution [15] to cover all significant aspects of the electricity production process that may influence the environment: carbon footprint and energy evaluation. These environmental accounting approaches were selected to determine the maximum supply distance of biomass that allows the co-firing of coal and biomass to be more environmentally efficient than pure coal combustion. Furthermore, the geological origin of the coal combusted was considered because the environmental inputs for feedstock varied. The results of the study showed that the addition of approximately 20% biomass to the mass of the combustion mixture decreases carbon-dioxide emissions by nearly 11–25% and total energy flow by 8–15%.

A previous study [16] evaluated the technical and economic aspects of biomass co-firing electricity production with and without CC (CO_2 capture) using different mixtures of coal and sawdust. The effect of biomass co-firing on the performance of power plants was evaluated in terms of energy efficiency, auxiliary power consumption, capital costs, operational & maintenance costs, specific CO_2 emissions, electricity cost and CO_2 avoidance costs. Depending on the feedstock composition, the biomass co-firing power plant generated 750–800 MW electricity in the case of carbon capture and 980–1027 MW electricity without capture. This indicated a continuous decrease in both technical and economical performances with increasing biomass content in the feedstock.

A techno-economic model for the estimation of economics of co-firing was previously presented [17] using pilot plant test results for biomass co-firing and general heat and mass balances. Additionally, a sensitivity analysis was performed with this developed model to investigate the effects of different operating and logical parameters on the economics of the biomass coal co-firing process.

In the process of co-firing of coal and biomass, directly determining the quantity of energy consumed by the auxiliary needs of devices (e.g., blowers, ventilators, mills) that are associated directly with the biomass is not technically possible. Therefore, an indirect method must be used to determine the components related to the efficiency of the conversion of biomass and the actual reduction in carbon dioxide emissions. In the present work, a detailed analysis of this problem is undertaken using an example of a co-firing process performed in a PF (pulverized fuel boiler) with the co-firing of sunflower husks and spent hops at three characteristic loads(electric power output): 200 MW, 180 MW and 140 MW. The identical procedure was applied for the co-firing of biomass in a fluidized bed boiler (CFB) at characteristic electric power output: 66 MW, 56 MW and 42 MW. In the case of biomass combustion in a dedicated fluidized bed boiler, the process energy requirement could be calculated directly from measurements taken for the system as a whole.

In consequence, a definitive comparison of the following indicators is possible: unit consumption of energy on driving process devices, boiler net energy efficiency, efficiency of electricity production from biomass, and reduction in carbon dioxide emissions.

In this paper, the results of the calculations are reported for technologies related to the combustion and co-firing of pulverized fuel and in fluidized bed boilers. The results are based on data that were obtained in trial tests performed under different