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Utilization of oxy-fuel waste nitrogen as a drying agent in a contact-type solid fuel dryer

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HIGHLIGHTS

- Nitrogen-based fuel drying within the oxy-fuel process is analysed.
- The energy and economic assessment factors have been calculated.
- The energy efficiency increases due to nitrogen-based lignite drying by 2.

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ABSTRACT

Methods for drying of hard coal and lignite have a great impact on the economy and the environmental aspects of electricity generation processes. Another contemporary aspect of clean coal electricity production is the process for removing carbon dioxide (CO_2). Oxy-fuel combustion seems to be one of the leading technologies here. The nitrogen, which is co-produced with oxygen in an air separation unit (ASU) – the integral element of the oxy-fuel power unit, is traditionally vented to the atmosphere. The main feature of ASU-waste nitrogen is however a near-zero moisture content at near-ambient temperature. Such a gas has a much higher potential for moisture absorption than ambient air, so the waste nitrogen may be effectively used as a drying medium at relatively low drying temperatures. The research being described here is focused on thermodynamic and economic analyses of the application of the nitrogen-based lignite dryer within large, lignite-fired oxy-fuel power unit. Simulation models for the power unit and dryer were built and solved for selected data describing fuel parameters, plant location and so on. Finally, economic assessment factors applying to a nitrogen-based dryer were calculated. The proposal for use of ASU-waste nitrogen has been positively verified from both a thermodynamic and an economic point of view. The calculated increase in overall oxy-fuel power unit net efficiency is ca 1.5%, and the internal rate of return (IRR) calculated from the viewpoint of all capital suppliers is ca 20%.

1. Introduction

Methods for drying hard coal and lignite have a great impact on the economy and the environmental aspects of electricity generation processes. In most of these methods, high- or medium-temperature air, flue gas or steam are used as the heating medium [1–7]. The use of low-temperature waste heat for solid fuel drying has also been successfully applied in industrial-scale systems for lignite [8].

Another contemporary aspect of clean coal electricity production is the process for removing carbon dioxide. Oxy-fuel combustion seems to be one of the leading technologies here. It is based on a replacement of nitrogen by CO_2 in the combustion chamber, which is achieved by using almost pure oxygen as the oxidiser and partial recirculation of the flue gas leaving the boiler. The nitrogen, which is co-produced with oxygen in an air separation unit (ASU) – the integral element of the oxy-fuel power unit, is traditionally vented to the atmosphere.

The main feature of ASU-waste nitrogen is a near-zero moisture content at near-ambient temperature. Such a gas has a much higher potential for moisture absorption than ambient air, so the waste nitrogen may be effectively used as a drying medium at relatively low drying temperatures. Accordingly, the use of nitrogen as a drying agent in a contact-type coal dryer within an oxy-fuel power generation process has been patented [9]. The crucial aspects of the proposed system are presented in Fig. 1. In general, dry nitrogen leaving the ASU is preheated using waste heat transferred from the flue gas that leaves the oxy-fuel recirculation loop. Preheated nitrogen is then blown into a contact-type fuel dryer where it absorbs part of the fuel's moisture. Wet nitrogen is finally vented to the atmosphere [10].

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Nomenclature

ASU	air separation unit
CCPU	CO_2 compression and purification unit
DPB	discounted pay back
IRR	internal rate of return
k	period in which the expenditures are greater than incomes
M&S	Marshal & Swift index for capital cost updating
MIRR	modified internal rate of return
MNPV	modified net present value
N	time horizon of analysis (the overall duration of the investment and the operation phases)
NCF_t	net cash flow counted at the end of the t-th year
NCF_t^+	net cash flow greater than zero, counted at the end of the t-th year
NCF_t^-	negative net cash flow in the period of investment phase, counted at the end of the t-th year
NPV	net present value
$\dot{Q}_{HE}$	heat transferred in heat exchanger, (kW)
r	discount rate
rei	reinvestment rate of positive cash flows
SPB	simple pay back
t	number of the successive year of analysis
T	dryer inlet gas temperature (°C)
ΔT_{HE}^{log}	logarithmic mean temperature difference in heat exchanger (K)
W	moisture evaporated in dryer (kg/h)

The drying of coal, especially lignite, makes the boiler more efficient, as the water originally contained in the raw coal is removed before the fuel enters the combustion chamber. Application of nitrogen as a drying agent also reduces the danger of fire and explosion within the dryer.

2. Selection of dryer type and parameters

To dry solids, evaporation (thermal methods) or mechanical removal of surface and hygroscopic moisture must be used. Thermal methods dominate in contemporary industrial applications. Thus, only thermal methods are considered within the current study.

During thermal drying two general processes occur. First, heat is transported from the heating medium (gas) to the wet surface of the solid and surface moisture is evaporated. Second, moisture is transported from the interior of the solid to its surface and surface evaporation occurs as it does in the first process. The surface evaporation proceeds is mainly determined by the parameters of the heating medium (pressure, temperature, moisture and type of contact with the material). The transport of moisture in the drying material depends mostly on the material's physical properties. Some of the moisture (so-called bound moisture) is usually bound to components of dry matter through chemical bonds or "captivation" in the microstructure. The remaining moisture (so-called free moisture) is located freely in the solid and on its surface; thus it is much easier to remove.

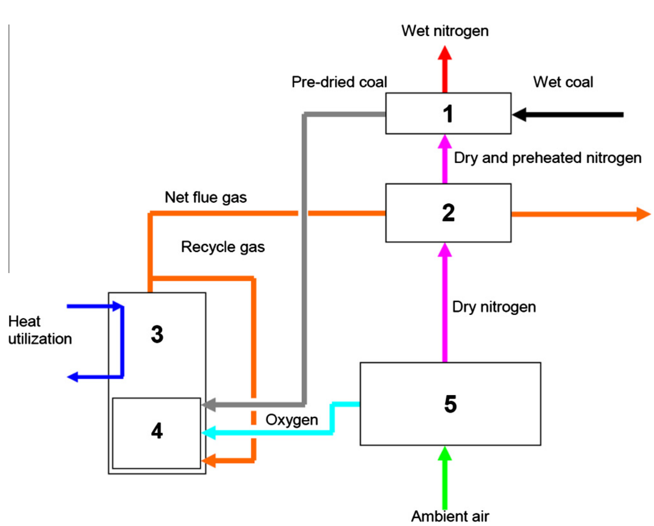

Fig. 1. Idea for drying coal by nitrogen within an oxy-fuel power unit [10].

There are many classifications of drying methods. They are not unique, because many manufacturers have developed their own technologies which sometimes combine elements from different classical drying techniques. However, the main classification for dryers concerns the method of supplying heat to the drying process. If dried material is placed directly in contact with the heating medium (hot air, flue gas or superheated steam), the dryer is called "contact" or "direct". If the heat transfer proceeds through partition (in heat exchanger), with dry material on one side (usually transported using a gas agent) and a flow of heating medium (steam or flue gas) on the other side, the dryer is called "indirect" or "diaphragm". Additionally, there are a number of design solutions for displacing dried material: rotary dryers, steam-tube dryers, fluidised bed dryers, chamber dryers, spray dryers and others.

Taking into account the features of different coal-drying technologies and the main proposal for the current research, which is the use of oxy-fuel waste nitrogen as a drying agent, the following conclusions have been formulated for the selection of the dryer type:

- The most effective methods for drying coal use waste heat instead of high-value steam or specially generated flue gas. The waste heat is available at the coal-fired power unit usually at a relatively low temperature (less than 100 °C).
- On the other hand, the advantage of nitrogen over ambient air for moisture absorption declines with a rise in the drying temperature. The ASU-waste nitrogen should thus be dedicated to low-temperature drying processes.
- It seems that only low-temperature waste heat is available in the thermally integrated oxy-fuel power unit. High-temperature flows are usually used for condensate and boiler feed water preheating within the steam cycle.

Accordingly, the low-temperature fluidised-bed dryer with a water-fed heat exchanger has been selected for further analysis of the use of nitrogen as a drying agent within the oxy-fuel lignite-fired power unit.

3. Thermodynamic simulation

The set of main operating parameters and structural connections of the coal-fired oxy-fuel power unit have been imported mainly from [11,12]. Based on the structure presented in Fig. 2, a