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Oxyfuel Power Plant Design: Retrofit Options for Different Fuels

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1. Introduction

In order to reduce the anthropogenic CO_2-emissions to limit the global warming the oxyfuel process is a promising concept for fossil fired power plants. In oxyfuel combustion oxygen (O_2) is used instead of air to produce a flue gas with high concentrations of carbon dioxide (CO_2). After further conditioning and compressing CO_2 can be captured and stored in geological formations. The oxyfuel concept is not only applicable for new builds but also for existing plants. In this work oxyfuel retrofits of existing power stations are investigated for different fuels with the focus on the overall process design.

2. Oxyfuel Retrofits

The Oxyfuel technology can be retrofitted to existing bituminous coal and lignite fired power plants, if certain pre-conditions are met. Most important are

- overall efficiency
- amount of false air entering the steam generator
- space for the air separation unit in the vicinity of the power plant
- space for a flue gas recirculation system
- space for other additional auxiliaries like flue gas cooling and CO_2 compression.

The flue gas recirculation is required to control the combustion temperature on a level which assures a reliable operation of the modified plant with specified fuels. Various extraction points in the flue gas path can be used e.g. up- or downstream $DeNO_x$, the electrostatic-precipitator (ESP), the flue gas desulphurization (FGD) plant or the flue gas cooler (FGC), see Figure 1. Since no preheating of the recycled flue gas takes place in the recirculation up- or downstream $DeNO_x$ (a, b) the gas preheater is no longer required. In the other recirculation variants a preheater still can be used. A recirculation upstream of the ESP (a, b, c) leads to an accumulation of dust, sulphur-oxides and water in the flue gas. The accumulation of dust can be avoided by recirculation downstream of the ESP (d), the accumulation of sulphur-oxides by the recirculation downstream FGD (e) and the accumulation of water by the

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recirculation after FGC (f). The selection of the extraction point is a result of a straight optimization process. Issues like overall efficiency, erosion and corrosion in flues and ducts are taken into consideration, but minimum life cycle cost is achieved with minimum modification work on the existing plant.

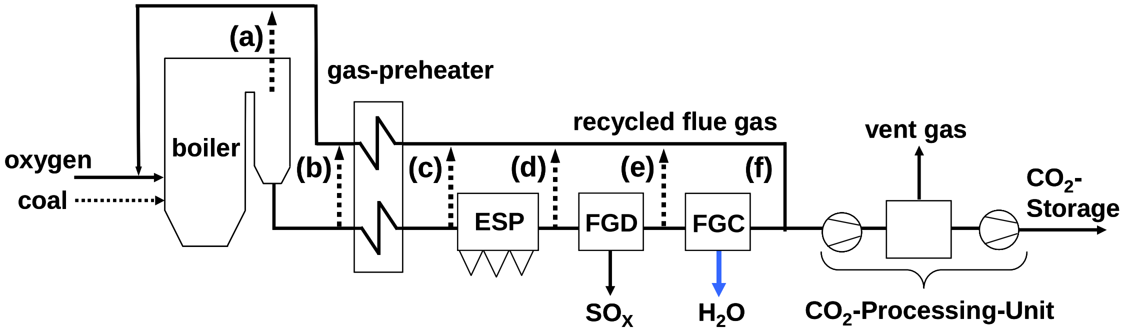

Figure 1: Different extraction points for the flue gas recirculation in an oxyfuel-process

2.1. Bituminous Coal

Typical retrofit measures for a bituminous coal fired power station can be explained on a state-of-the-art 600 °C plant with a gross output of 820 MW_{el}. The design parameters are listed in table 1.

Table 1: Design parameters of the state-of-the-art bituminous power station

design parameters	temperature [°C]	pressure [bar]
superheated steam	600	276
reheated steam	620	51

The retrofit design is shown in Figure 2. All components of the existing power plant are marked in green whereas the components which are necessary for the oxyfuel-retrofit are shown in red.

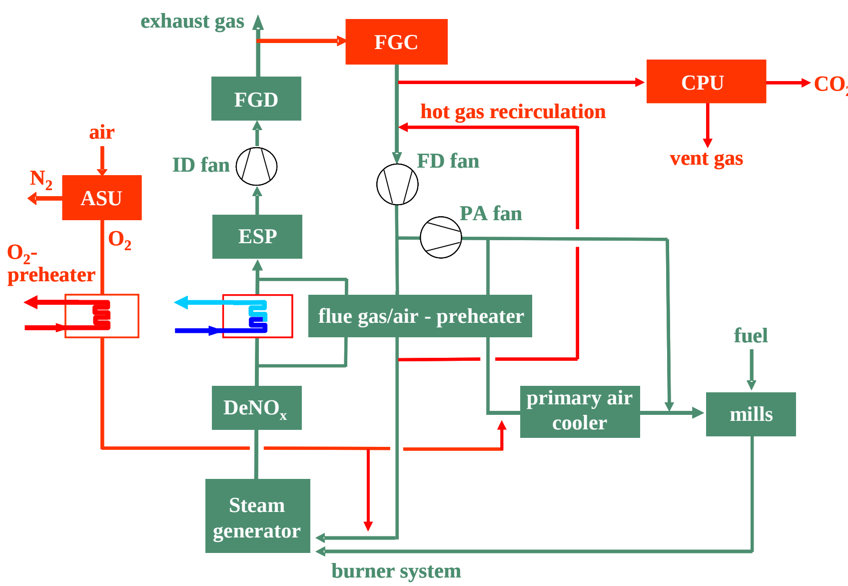

Figure 2: Overall process design and modifications for an oxyfuel retrofit for bituminous coal

Biggest cost benefits can be achieved if the retrofit can be done without any changes on pressure part, burners, combustion air ducts and fans. In this respect, the flue gas recirculation plays a major role. Most important are following parameters:

- The heat transfer in the convective path and the furnace exit temperature has to be similar.
- The flame shape and length have to be similar compared to the combustion with air.
- The adiabatic flame temperature and furnace radiative heat transfer must be similar.
- The momentum of the gas flows at the burner should be similar.
- The volumetric gas flow to the mills must be similar to ensure the transport of fine particles.
- The drying effect in a mill has to be maintained also in case of changes for the gas humidity when retrofitting.

Detailed calculations of the overall process have revealed that a cleaned and partially dried recirculated flue gas and a recirculation rate of about 75 % ensure the similarity of the mentioned parameters and therefore no changes on all existing components in the boilerhouse as well as ducts and blowers are required. Furthermore the steam parameters shown in table 1 are kept constant.

The required high purity oxygen can be produced in a cryogenic air separation unit (ASU). For an 820 MW power plant four ASU-lines with a space of 26000 m² are needed. The ASU does not have to be placed near to the steam generator. It is also possible to install this system in some distance from the power plant. The oxygen is transported to the boilerhouse by pipeline. It is reasonable to preheat the oxygen for the same reasons as in air firing. This can be done by extracted steam from the turbine. The oxygen temperature should not be higher than 200 °C in order to limit safety risks and cost of controls and instruments in the O_2 path. Due to the leakage of the regenerative air preheater the oxygen is added to the recycled flue gas after preheating. The original air preheater is used to preheat the recycled flue gas. This gas cannot take all the heat due to the absence of the oxygen mass flow. Because of the high flue gas temperature upstream of the air preheater of about 380 °C, a part of the heat is used in a by-pass for the high pressure feed water preheating (see Figure 2, shown in blue). Hereby extracted steam of the turbine is saved and the overall efficiency is increased. This is the only major change in the flue gas path of the existing system. After preheating, the oxygen is mixed with the preheated primary gas to a concentration of 21 vol.-% (wet), which is the same concentration as in air mode. The remaining oxygen needed to ensure complete combustion is distributed to the secondary, tertiary and over fire gas. The overall stoichiometry can be limited from 1.17 to approximately 1.15 to minimize the use of excess oxygen and therefore to decrease the energy demand of the air separation unit.

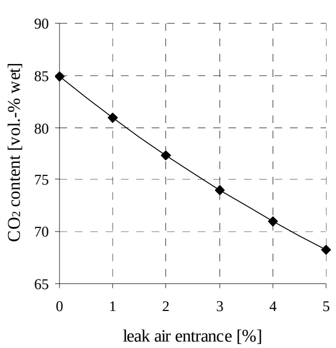

Figure 3: CO_2 content after FGC as a function of the leak air entrance with

A minor part of the preheated flue gas is internally recirculated to increase the flue gas temperature after the FGC (see hot gas recirculation in figure 2) to above the saturation point and thus avoid condensation. In the FGC, which is installed downstream the FGD, the flue gas is cooled below the water dew point to condensate most of the moisture. The moisture content and flue gas temperature after FGC depend on the cooling water temperature. At a cooling temperature of 20 °C the flue gas can be cooled down to 30 °C which leads to a moisture content of roughly 4.2 vol.-% wet in the recycled flue gas. The achievable CO_2 content in the exit gas depends on the total amount of leak air entrance as shown in Figure 3 and the oxygen purity. Thus all components have to be sealed, otherwise the CO_2 content in the flue gas would decrease, thus, increasing the energy demand for the compression. For an air ingress of two percent (related to the flue gas mass flow downstream of the ESP) and an oxygen purity of 95 vol.-% the CO_2 concentration in the flue gas is about 77 vol.-% wet.

Some minor changes have to be done on various components of the steam generator. At the $DeNO_x$ plant, CO_2 replaces air for the injection of ammonia water. The oxidizing air in the FGD absorber is replaced by pure oxygen and the sealing systems in the coal mills use CO_2 as sealing gas instead of air. The comparison of the flue gas composition in air and in the oxyfuel mode is shown in Table 1. Summarizing it can be stated that an oxyfuel retrofit for producing a flue gas with a high CO_2 content can easily be done without major changes in the existing boiler and with only slight changes in the overall process.

Table 2: Comparison of flue gas composition

gas species	air mode, composition after ESP vol.-% wet	oxyfuel mode, composition after ESP vol.-% wet
N_2	74,3	9,3
O_2	2,9	3,9
H_2O	6,9	11,9
CO_2	14,9	71,1

2.2. Raw lignite

Not only bituminous coal fired steam generators but also raw lignite fired plants can be retrofitted to oyxfuel operation. As an example a 500 MW_{el} plant may serve which is designed for similar steam parameters as the hard coal unit described above. The design parameters are listed in table 3.

Table 3: Design parameters of the state-of-the-art raw lignite power station

design parameters	temperature [°C]	pressure [bar]
superheated steam	603	293
reheated steam	609	51

In figure 4 a) the flow scheme of the oxyfuel retrofit is shown. The additional components are marked in red. The retrofit design is the same as for bituminous coal. Due to its high water content the flue gas recirculation after FGC is the best option for an oxyfuel retrofit to avoid water accumulation in the process. The recirculated flue gas is divided in primary and secondary gas. After preheating the primary gas is mixed with oxygen (see position (1) in figure 4 a)) to set a defined oxygen content in the pulverizing and drying system. The amount of the primary gas depends on the required flow rate.. The mass flow of the secondary gas and its oxygen content are variable and have to be set in this way that minimum changes in the overall process and no changes in the existing boiler design for the oxyfuel operation are necessary. Detailed calculations of the heat transfer have shown that the same steam parameters are reached with an oxygen content of roughly 27 vol.-% wet (see position (2) in figure 4 a)) in the recycled secondary flue gas. This leads to a slightly lower adiabatic temperature and nearly the same flue gas flow velocity in the convective path.

As shown in the flow scheme the oxygen can also be preheated with extracted turbine steam and a part of the heat of the flue gas downstream of the boiler can be used in a by-pass for the high pressure feed water preheating as it is the case for bituminous coal and dried lignite. One of the biggest challenges for an oxyfuel retrofit is the adaptation of the pulverizing and drying system of raw lignite. The coal is dried with hot flue gas, which is taken from the end of the furnace, see figure 4 b). Particularly the transition between the furnace and the hot gas off-take but also the coal distributor and mill itself are associated with a high entry of leak air. Altogether the leak air entrance is about 10 % according to the total oxidant mass flow in air mode. This amount would lower the CO_2 concentration in the flue gas dramatically down to about 62 vol.-% wet. To avoid a high entry of leak air the hot gas off-takes must be sealed primarily.

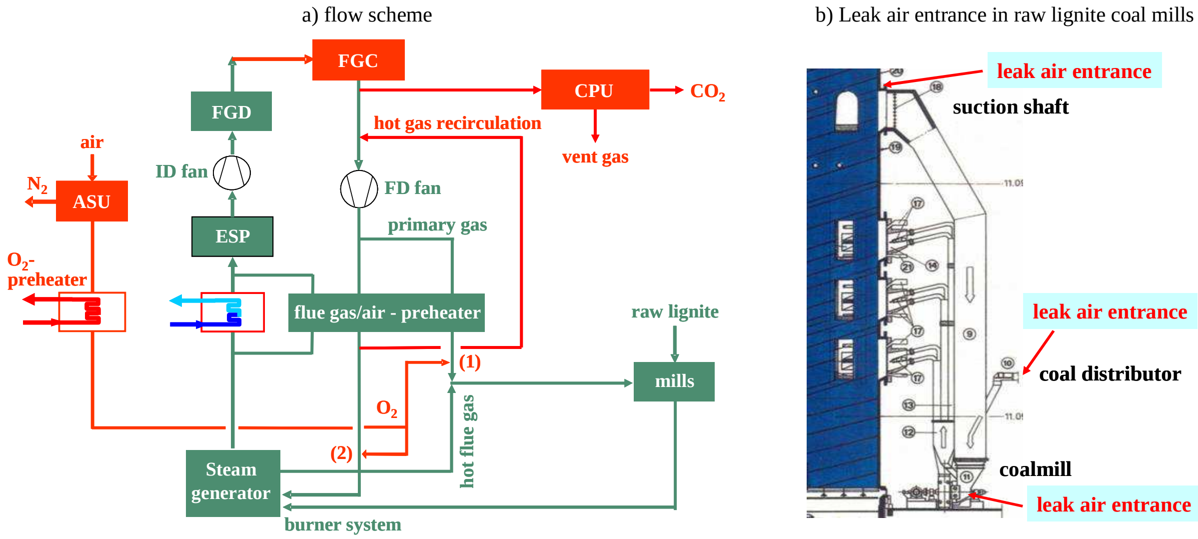

Figure 4: Oxyfuel system details and flow scheme for raw lignite

Ideally without air ingress the CO_2 concentration of the flue gas would rise to 85 vol.-% as shown in table 4. Furthermore the mills have to be adapted to the higher density of the gas in oxyfuel case which will lead to larger drives and a higher speed of the beater wheel**.** Summarizing it can be stated that the success of an oxyfuel retrofit for a raw lignite fired power plant is primarily addicted to the amount of leak air entrance of the pulverizing and drying units. By means of a sealed system the retrofit can be also done without major changes in the existing boiler and with only slight changes in the overall process.

gas species	oxyfuel mode, composition after FGC in vol.-% wet 10 % leak air entrance	 0 % leak air entrance
N_2	29.1	5.9
O_2	3	3.3
H_2O	4.2	4.2
CO_2	62.4	85

Table 4: Comparison of flue gas composition according to the amount of leak air ingress

It is also possible to re-design an existing raw lignite fired power plant for an oxyfuel operation with pre-dried lignite. The coal mills and existing coal bunkers are no longer required. The missing water vapour in the flue gas has to be substituted to get a heat transfer in the furnace and in the convective path similar to the combustion with raw lignite. The recirculation rate of the flue gas can be increased to about 80 % for this purpose.

3. Summary

The commercial implementation of CCS could be realized by building new oxyfuel plants in future. But the vast majority of existing coal power plants in the next two decades will consist of “young” plants e.g. in Japan, China, India and Europe running with steam temperatures between 580 °C and 600 °C. They will operate up to the 2040 or even 2050 and oxyfuel retrofits to these plants should be considered to fully apply the potential of CCS for climate protection. Hitachi has investigated all different types of coal power plant designs actually delivered to the market and developed oxyfuel retrofit strategies which can be applied to all of them. No turbine modification is necessary. Steam generator modification basically comprises the installation of the new flue gas recirculation line, the new flue gas cooler and the oxygen supply system besides some minor equipment changes. Such a retrofit of the oxyfuel process to existing plants offers the potential of cost-effective and economically feasible CO_2 reduction. It provides a fast chance to reduce CO_2 in many fossil fuel fired power plants.