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Development of Advanced Oxyfuel-CFB Combustion Leading to Zero Emission Power Generation

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1. Introduction

Advanced power plant designs will play a major role in the reduction of CO2 emissions from fossil fuel-based power generation. As world leaders discuss ways to minimize climate change due to greenhouse gas emissions, Foster Wheeler is developing power plant designs of CFB boilers that reduce carbon-dioxide emissions through oxyfuel combustion where the air, as oxidant, has been replaced by nearly pure oxygen from an air separation unit (ASU) and the nitrogen in the air has been removed. As a result, the product gas from the combustion process is free of nitrogen and contains a concentrated product gas stream. The concentrated gases enhance reaction kinetics and mass transfer, and potentially suppress the formation of contaminants and pollutants. Flue-gas recirculation is incorporated in the design to control furnace temperature and to optimize boiler operation. This recirculation helps to reduce emissions by enhancing re-burning and re-capturing in the boiler. In the present example, simulation results indicate that the NOx from the recycled gas is consumed in the fuel rich combustion zone, and that sulfur capture is enhanced either in-bed or in the downstream FGD.

True zero-emissions power generation can be achieved under the oxyfuel combustion if all of the product gases can be recirculated to the boiler, and undergo re-burn and re-capture within the closed-loop system. A new process has been investigated by Foster Wheeler, where all vent gas streams from the downstream CO2 purification unit (CPU) have been designed to flow back to the boiler. To avoid accumulation of nitrogen and argon (N2+Ar), a pressure swing adsorption (PSA) process has been applied to the vent gas before recirculation, where purified N2+Ar passes through the PSA, and the other gases, including part of the N2+Ar regenerated from the adsorption process, are recirculated back to boiler. The beauty of this zero-emissions process is in that it achieves 100% CO2 removal without increasing the ASU duty. NOx control, under this process, does not require any conventional deNOx processes, such as SCR or SNCR, and it potentially relaxes the requirements for combustion staging. The cost for emissions controls is significantly reduced due to the relative0060 simplicity of this process. The results of this investigation have demonstrated that the incorporation of a closed-loop zero emissions system into an oxyfuel combustion process will result in a lower cost of electricity (COE) and lower cost of CO_2 removal. This approach is applicable for both Greenfield and retrofit applications.

2. Zero Emission Process Description

A new multi-emissions control process producing zero emissions was originally developed by Foster Wheeler in 2007 and has been steadily improved since then. In the present context, the term, "emissions", refers specifically to all gaseous and liquid pollutants (SO_x, NO_x, CO, CO_2, VOC, HCl, Hg etc.). This new zero emission process employs vent gas treatment to enhance CO_2 capture, where a PSA type sorbent bed is applied to adsorb CO_2 and the other gases at vent gas condition, which is very similar to the hydrogen purification method in hydrogen production through reforming. The un-adsorbed or less adsorbed gases, mainly purified Ar, N_2 and O_2 are purged, or forwarded to ASU (if oxygen concentration is high enough to save ASU power and if Ar concentration is low enough to avoid accumulation in system). The PSA adsorbed gases with all emission components including CO_2 are released by pressure reduction (flashing) and, after coolant recovery, forwarded to boiler as part of recirculation gases, where any emission gases will flow through the boiler and undergo re-burn and re-capture processes during gas recirculation.

During research, it has been found that recirculating flue gas through the boiler induces re-burn and re-capture of many pollutants. For example, the NO_x in recirculation gas can be well destroyed (nearly 100%) in the high temperature zone under fuel rich conditions, and about 60-70% destroyed under fuel lean conditions. Furthermore, SO_3 can be reversely converted back to SO_2 in the high temperature zone. CO and VOC in the recirculation gas are primarily burned out in the high temperature zone and will not cause any accumulation in circulation. This re-burning brings another advantage that the boiler can be operated at low excess oxygen despite the CO level as long as the UBC (unburned carbon) is not significantly increased. These re-burn effects greatly reduce the concentration of emission components in gas. The re-capture is another function induced by gas recirculation, where gases pass repetitively through emission control devices such as for SO_x capture. The vent gas, flowing through the boiler, become part of recirculation gas and undergoes both re-burn and re-capture. Without the re-burn and re-capture, gas components reach 4-5 times higher due to N_2 dilution free combustion.

This configuration results in is a system with closed-loops to emission components, producing only purified (N_2+Ar+O_2) gas, solids drain from CFB, and purified CO_2. This process does not require a sharp cut or separation by PSA and can reach 100% CO_2 removal. It does not require any deNO_x process as NO_x can be adsorbed with CO_2 together by PSA. For the same reason, the emissions control of VOC, CO and other pollutants are complete if they can be adsorbed by PSA and recirculated back to boiler after regeneration.

The key for success to this zero-emission approach is a sorbent bed to purify (N_2+Ar) and to send all emission gases to boiler-island. Recently, CO_2 adsorption has become a hot topic for CO_2 removal aiming at reducing energy penalty from regeneration and lowering capital costs . Different sorbents such as active carbon, molecular sieve, and zeolite, have been tested. Research is required to find a good sorbent which selectively adsorbs or absorbs CO_2 from fluegas while possessing a high capacity in loading in term of lb-CO_2/lb-sorbent to lower sorbent circulation rate and the extra heat requirement for regeneration. The purity of regenerated CO_2 from adsorption relies highly on the CO_2 selectivity during adsorptions. The relative CO_2 selectivity therefore becomes important for sorbent evaluation and development.

The present zero-emission approach uses PSA for vent gas treatment, which functions as a guarding device to prevent any emission components to be vented. Since the regenerated gas from the vent gas treatment will be forwarded to boiler-island as part of recirculation gas for emission control, the PSA used in the zero-emission process prefers, but does not require, a high selectivity of CO2 from the other gases. Instead, it just requires a good selectivity between (Ar+N2) and the other gases to reduce PSA size.

The beauty of vent gas treatment by PSA is that it not only increases CO2 recovery efficiency to 100% with reduced cost per CO2 removal, but also forms closed-loops for the emission components to reach true zero emissions. This zero-emission approach also allows relaxation of boiler operational parameters, such as low excess oxygen in spite of potentially high CO concentration. It could be expected that the zero emission system can tolerate the ingress of air into CO2 stream. For the same reason, it can also tolerate a low oxygen purity, which is a big advantage to reduce ASU auxiliary power and cost, as well as to promote application of advanced ASU methods with low oxygen purity.

3. Investigation

This zero-emission concept is applicable for both PC and CFB power plants. A nominal 450 MWe oxycombustion boiler was applied for analysis. The furnace performance is simulated by Foster Wheeler 3-D CFD furnace models, which include calculations for SOx, NOx and CO as well as UBC under different excess oxygen levels and gas recirculation rates. The effects of the re-burn and re-capture from gas recirculation are included in the modeling. The over-fired air (OFA) has been turned off due to application of the zero-emission where the furnace itself functions for NOx reduction. The system heat and material balances are simulated by Aspen Plus® commercial software. A fixed total gas recirculation rate was maintained in the model for the parametric study.

A parametric study was conducted to evaluate the effect of PSA selectivity, air ingress, and furnace excess oxygen on the zero-emission performance in terms of specific power and emissions. The CO2 capture power penalty depends upon the power plant heat integration, the ASU and CPU configuration and design, and raw CO2 purity to CPU. For simplicity, a relative specific power of (ASU+CPU) per tonne of CO2 removed is calculated.

4. Conclusions

True zero-emissions power generation can be achieved under the oxyfuel combustion if all of the product gases can be recirculated to the boiler, and undergo re-burn and re-capture within the closed-loop system. A new process has been investigated by Foster Wheeler, where all vent gas streams from the downstream CO2 purification unit (CPU) have been designed to flow back to the boiler. To avoid accumulation of nitrogen and argon (N2+Ar) in system, a pressure swing adsorption (PSA) process has been applied to the vent gas before recirculation, where purified (N2+Ar+O2) passes through the PSA, and the other gases, including part of the (N2+Ar+O2) regenerated from the adsorption process, are recirculated back to boiler.

The advantage of this zero-emissions process is that it achieves 100% CO2 removal without increasing the ASU duty, and it performs a simple control to reach zero emissions through a closed-loop gas recirculation system. NOx control (including N2O) does not require any conventional deNOx processes, such as SCR or SNCR, and it potentially relaxes the requirements for combustion staging. It allows the boiler to be operated at low excess oxygen in spite of CO level due to re-burn effect from gas recirculation, which significantly reduces the overall CO2 removal specific power from 100% to 91.7% for 5% boiler air ingress. Because of downstream PSA gas separation, it does not require high efficiency emission control equipment for tight emission control. It relies on the boiler and scrubber as well as gas recirculations in oxyfuel combustion to reach the zero-emissions. This approach is applicable for both Greenfield and retrofit applications.