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COAL COMBUSTION IN THE MIXTURE OF O_2/CO_2

This paper provides the review of research that has been carried out in the field of the coal combustion in the mixture of O_2/CO_2. It presents the most important advantages and disadvantages of such a combustion compared with air combustion. This study deals with the emission of nitrogen oxides, sulphur oxides and ash in the fuel gas from coal combustion in the mixture of O_2/CO_2. This combustion is a very important technology because of an easy CO_2 recovery, low NO_x emission and high desulphurisation efficiency.

1. INTRODUCTION

The coal combustion in typical technologies is connected with high emission of greenhouse gases – the dominant contributor being CO_2. There are some international agreements on controlling carbon dioxide emissions. In our part of Europe, electricity production based on coal combustion will continue to play a major role in energy market. The scientists have studied new methods for reducing the emissions of CO_2 from coal-fired power plants [1]. The capture and storage of carbon dioxide seem to be an effective means for reducing coal utilization in power plants. There are several ways of injecting CO_2 into ocean whose environmental impact, particularly on an ecosystem around the injection area, is not well known. Taking into account the large capacity of ocean to accumulate CO_2, it is possible to point to its future importance in reducing radioactive CO_2 [1].

There are some technologies that are being developed for capturing and sequestering CO_2 from the combustion of coal [2]:

- PCC – the post-combustion capture, CO_2 capture from plants of conventional pulverized fuel technology with scrubbing flue gas for CO_2 removal.
- IGCC – integrated gasification combined cycle in a shift reactor to convert CO to CO_2, followed by CO_2.

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• Oxy-fuel combustion with combustion in oxygen; the oxygen is diluted in an externally recycled flue gas to reduce its combustion temperature and then is added to provide the combustion energy through the heat transfer operations in the current first generation technology.

• Oxy-combustion with an internally recycled stream induced by the high oxygen jets in place of external recycling.

• Chemical looping – a metal oxide is used as a bed material providing the fuel reactor with oxygen for combustion.

CO_2 from conventional combustion processes is present as a dilute gas in the flue gas (typically about 14 vol% on a dry basis). The gas separation is very important. O_2/CO_2 coal combustion is one of new technologies associated with CO_2 mitigation. The process uses pure oxygen instead of air and recycles most of the flue gas. CO_2 concentration in the conventional coal-air combustion is too low to consider carbon sequestration economically feasible. But it is the major reason that allows the removal efficiency to be achieved in general. The cost of gas separation can be reduced by increasing the concentration of CO_2 in the flue gas. This can be achieved by increasing the oxygen in the feed gas or by recycling the flue gas [3]. Coal combustion at a higher oxygen concentration seems to be very attractive, since it can reduce the cost of CO_2 sequestration in the flue gas; however, it also reduces the volume of inert gas, i.e. nitrogen. The amount of NO_x produced as a result of combustion may be reduced NO by the elimination of atmospheric nitrogen fixation.

It ought to be stressed that during coal combustion in O_2/CO_2, CO_2 has higher specific heat than nitrogen. This is responsible for lower combustion temperature profiles in the mixture of $O_2 + CO_2$ than in $O_2 + N_2$, at the same concentration of the oxygen. To obtain the same temperature profile as in oxygen combustion the oxygen concentration in the mixture of $O_2 + CO_2$ ought to be about 42% [4]. Taking into account the gas properties (density, viscosity), O_2/CO_2 stream required to provide favourable conditions of the process is lower than that of O_2/N_2 mixture at the same oxygen concentration. The stream of oxygen ought to be invariable to obtain the same boiler power. In this case, the oxygen concentration in the mixture of $O_2 + CO_2$ will be higher than that in $O_2 + N_2$ [4].

There is little description of pulverized coal combustion in environments with high concentrations of CO_2, especially in terms of combustion performance and the emissions of nitrogen oxides, sulphur oxides and ash [5]–[9]. Therefore, this paper provides the review of research showing the most important advantages and disadvantages of O_2/CO_2 combustion.

2. NO_x AND SO_2 EMISSIONS

Nitrogen oxides (NO_x) are one of the most important substances produced during combustion of fuels. Typical combustion gases contain NO and NO_2. Other kinds of nitrogen oxides are N_2O, N_2O_3 and N_2O_5, but they do not play any essential role. In typical combustion gases from boiler, the volumetric share of NO amounts to about 95% or even more, the rest being NO_2 [10]. NO_2 is a greenhouse gas and one of the California-type smog. In the presence of stream water and in the case of atmospheric discharges, NO_2 forms nitrous acid. NO is not as toxic as NO_2. Furthermore NO is the main source of NO_2, because it is emitted into the atmosphere. Nitrogen oxides are the most harmful substances for environment, that is why researchers study how to reduce NO_x emission. All new technologies of the combustion are developed to reduce NO_x emission.

During the oxy-fuel combustion, the amount of NO_x exhausted from the system can be reduced to less than one-third of that produced with combustion in air [5]. The NO_x reduction is thought to be a result of high CO_2 concentration in the furnace and NO_x recycling together with CO_2, but these effects are not clearly separated in research studies [11]. BUHRE et al. suggest that NO_x reduction is thought to be a result of several potential mechanisms [12]: a) a thermal decrease in NO_x due to a very low nitrogen concentration in the air in a combustor, b) the reduction of recycled NO_x in the section of a volatile matter release, c) the interactions between recycled NO_x and fuel nitrogen and hydrocarbons released from coal which can make further NO_x formation difficult.

It is obvious that higher oxygen concentration in the feed gas increases NO_x emission rates. CHEN et al. [6] have shown that the concentrations of CO_2, SO_2, NO_x in the flue gas coal combustion differ, depending on feed gas composition. They affirmed that the formation of NO_x in conventional air combustion or oxygen-rich combustion is not significant, but the concentration of SO_2 generated from O_2/N_2 combustion is higher than that obtained as a result of O_2/CO_2 combustion and is increased by O_2 concentration in feed gas [6].

CROISET et al. [3] have reported that SO_2 emissions appear to be affected mainly by the sulphur in the coal, not by the oxygen or carbon dioxide concentration in the feed mixture which confirms that sulphur conversion is limited by the reaction equilibrium, not by its kinetics. They observed that the conversion of coal sulphur to SO_2 decreased from 91% for the air to about 64% for oxy-fuel combustion. SO_2 concentration from O_2/CO_2 combustion is known to be higher than that from air combustion due to flue gas recirculation [3]. The same results were described in another studies [13]. Coal combustion in the air and in the mixture of O_2/CO_2 was also experimentally investigated at the University of Leeds. The results obtained clearly indicate that SO_2 emissions are almost independent of combustion media under the conditions investigated, unlike the NO_x emissions that are closely related to the combustion media [13].

LIU et al. [14] studied the kinetics of desulphurisation reaction in CO_2-enriched atmosphere, the contributions of various factors to a high desulphurisation efficiency and the effect of sorbent types. They reported that the desulphurisation efficiency during O_2/CO_2 pulverized coal combustion in O_2/CO_2 system increased by about four to six times and was as high as that obtained in a conventional pulverized coal combustion [14].

Another studies by CROISET et al. [15] showed that if the flue gas were recycled without the removal of SO_2 there would be a significant accumulation of SO_2 and consequently an increase of SO_3 in the recycled stream which had a serious implications for the corrosion of boiler systems [15].

3. ASH PARTICLE FORMATION

The path of ash formation during coal combustion can be different due to the changes in a combustion atmosphere. The composition of ash depends on the composition of coal, which comprises both organic matter and inorganic matter (mineral). There is little description of ash-related issues in oxy-fuel combustion. FURIMSKY [16] studied trace element emissions from coal combustion based on equilibrium calculations being made in the Equilib program [16]. The amount and type of compounds containing alkalies and chlorine depend on a chemical composition of the coal's mineral matter. Chlorine in coal has a positive effect on the emissions of Pb and Hg but only a small effect on the emission of trace elements [16].

ZENG and FURIMSKY also used thermodynamic calculation to assess coal combustion in O_2/CO_2 mixture compared with that in the air. They concluded that a combustion medium had a small effect on ash chemical composition [17]. However, the gaseous phase concentration of volatile constituents such as Hg, Se and As is expected to be higher for the combustion in an O_2/CO_2 mixture than that in air. SHENG et al. [7] found that O_2/CO_2 combustion did not significantly affect the size distribution of the residual ash, but had a significant effect on the mass and size distribution of both the submicron particles and finely fragmented particles [7]. The enrichment of CaO and Fe_2O_3 was observed in the fine fragmentation mode, which confirmed the contribution of the fragmentation to the formation of fine ash particles. SHENG et al. [7] have affirmed that compared with O_2/N_2 combustion, the combustion in the O_2/CO_2 mixture after increasing the oxygen concentration had a more significant impact on the formation of the fine ash particles, both in the case of submicron and the fine fragment sizes [7].

4. CONCLUSIONS

The oxy-combustion is now widely used in the glass industry and, to a lesser extent, in the steel industry [2]. This process consists in coal combustion in an oxygen-enriched atmosphere by using pure oxygen diluted in recycled flue gas. The most important advantages of oxy-combustion are a high potential for a step-change reduction in CO_2 separation and the costs of capturing the exhaust gases. They all can be captured and sequestered.

The oxy-combustion technology allows reduction of CO_2 emitted into the atmosphere as a greenhouse gas; moreover, it can readily be applied to the new coal-fired power plants, conventional equipment can be used.

The combustion of pulverized coal in O_2/CO_2 mixture is a promising advanced technology that enables a global environment to be protected.

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