1. Introduction

The cement clinker burning process is a high temperature process, which produces CO₂ emissions deriving from fuel combustion and material reactions. The reduction of these emissions is of great importance in the cement industry. For this reason the potential of the traditional measures - like the increase of energy efficiency, the application of alternative fuels or the reduction of clinker fraction in cement - are already exhausted to a great extent. In this context the capture of carbon dioxide and its geological storage, often referred to as “carbon capture and storage” (CCS) or its reuse in e.g. chemical products (CCR) is seen today as an emerging technology capable of reducing CO₂ emissions significantly. A promising capture method constitutes the Oxyfuel technology. This technology is an integrated methodology and as a consequence of this, both the material conversion in the kiln system and the operational specifications of the overall process are different from those in conventional kiln operation.

In contrast to the power sector no Oxyfuel testing facility exists in the cement industry, so that still basic research is performed. The interaction of the changed gas atmosphere with the material in combination with highest possible energy efficiency of the process complicates the task. Within the ECRA CCS project the different aspects are investigated by model calculations, laboratory tests and designing first plant components.

2. Design principle

The clinker burning process is operated in counter flow principle. The material is preheated by kiln exhaust gas in stacked cyclones and burned in a rotary kiln. Clinker coolers are simultaneously cooling the hot clinker and preheat the combustion air. Within the ECRA project a principal configuration of a full Oxyfuel cement plant has been developed, which leaves the conventional plant in most parts unchanged (see figure). The basic principle is based on kiln operation with pure oxygen as oxidant. As this would lead to too high process temperatures a part of the CO₂-rich kiln gases is recycled to the kiln, mixed with the pure oxygen and the resulting O₂- and CO₂-rich gas is used as oxidizer in the kiln firings. The recirculation rate has proven to be an important controlling parameter in order to adapt the process to different conditions. The remaining part of the recycled waste gases are removed from the process, cleaned, compressed and prepared for transport and storage or re-use.
In terms of retrofitting an existing kiln plant the initial geometry of the equipment rotary kiln, preheater tower and calciner is kept unmodified. The grate cooler stays implicated in the gas flow, in order to avoid a separate preheating of the recycled flue gas. The recuperation of heat is an important issue concerning the energy demand of the whole process. In order to prevent CO₂ emissions with the cooler waste air/gas the cooler has to be split in two stages. The first cooler stage is operated with recycled flue gas, which is needed in the burning process. As this stage alone would cause too high clinker temperatures - which would reduce overall efficiency significantly - a second cooler stage, which is operated with ambient air, is considered. This air leaves the cooler as exhaust air and can be used for raw material drying or fuel preparation. The required gas-tightness of the two stages could be matched by two possible design concepts. Both concepts rely on the separation of the stages by dynamic devices in the hot clinker zone. With reference to a potential retrofit, a concept using two heat shields has been selected as the most promising solution.

Waste heat emitted by the preheater exit gas and cooler exhaust gas is usually used for drying raw materials. The integration of the raw meal drying and fuel preparation constitutes an issue in oxyfuel operation. To avoid the necessity of an air tight raw mill (which is technically difficult) the cooler exhaust air from the second cooler stage is used for drying. By adding a heat displacement system to the layout energy from the flue gas can be recuperated by the cooler exhaust gas in order to increase the energy level and enhance the drying potential.

In general the switching from conventional to oxyfuel conditions without adaption of the burner design would result in significant changes in clinker quality - due to a flame on lower temperature level and higher gas velocities. However, an adjustment of the burner design and the associated parameters to the Oxyfuel conditions could re-establish comparable flame characteristics to the conventional conditions. In general only few modifications of the plant technology had to be implemented and the necessary redesign of plant components (cooler, burner) does not set limits to the retrofitting. But prerequisite of the retrofitting is sufficient space in the surrounding of the plant.

3. Impact on the cement quality

The essential issue of constant product quality has been proven in laboratory tests. In this context, different clinkers were burnt under oxyfuel conditions in a laboratory oven and were used for the production of cement samples. It was concluded that the calcination reaction is shifted to higher temperatures by up to 80°C due to the higher CO₂ concentration in surrounding. Testing of the cement characteristics resulted in only slight variances (below 3 %) in properties like strength development and compressive strength compared to standard cements. According to this, negative impacts of oxyfuel combustion on the product quality seem to be negligible.
4. Impact on the clinker burning process

A simulation study on the basis of a numerical process model showed the impact of the Oxyfuel mode in terms of the parameters: recirculation rate, oxygen concentration, plant structure, type of fuel or humidity of the recirculated gas on the process operation.

As the erection of greenfield cement plants is unlikely in Europe and more common in fast developing countries, it might become important to offer solutions for retrofitting existing plants. Therefore, the concept has been evaluated with regard to the ability for retrofits. For this purpose the recirculation rate is limited to a certain range.

With regard to new installations the design of the kiln itself, the calciner and the preheater cyclones can be optimized with respect to energy efficiency. Furthermore, the recirculation rate can be varied in a wider range.

The recirculation rate influences the thermal energy demand. Thus with decreasing the recirculated amount of gas the energy demand is reduced to a certain point and then increases in parabolic form due to the capacity stream ratio, which is not sufficient to preheat the material.

In general the wet flue gas recirculation likewise reduces the thermal energy demand by a higher radiation fraction in the heat transfer. Nevertheless it is not advised due to an increase of the electrical energy demand by higher fan performance and of the affection of corrosion by enrichment of corrosive elements.

Heat transfer and resulting temperature profiles in the kiln are an important influencing parameter on material conversion and product quality and affect the incrustation formation. Although the heat transfer mechanisms are significantly influenced by the changed burning atmosphere, CFD modelling showed that the flame characteristics could be readjusted to conventional ones. However, energy is shifted from the sintering zone towards the kiln inlet. In addition, the capacity stream ratio in the preheater tower between gas and material flows is influenced resulting in higher heat losses with the flue gas.

In order to increase the overall efficiency, the integration of waste heat recovery aggregates like heat exchangers or installations for electricity production by waste heat recovery gain in importance. Thus the waste heat utilization can be matched to the individual specifications of the kiln plant (e.g. raw material moisture). In summary the thermal energy demand is kept constant compared to conventional production while the electrical energy demand is doubled.

5. Impact on Flue Gas Purity and Capture Rate

Based on the modelling results the capture rate is at least 89 % and maximum 99 % (at higher electrical input) using the considered concept of full oxyfuel operation. Against the expectation the effort for the CO₂ purification is only slightly increased by higher false air ingress to the plant. However, an optimum between the effort for sealing the plant and purification is assumed to be at 6 % air ingress by improved maintenance of inspection doors, man holes etc..