In developed countries, lime manufacturers become increasingly confronted with the challenge of producing lime in kilns that were designed decades ago when the constraints were different from nowadays. They are therefore required either to upgrade the existing installations or to invest in new equipment. As shown in a practical example, a cheaper alternative can consist of analysing thoroughly the existing process conditions so as to identify the minor improvements to be made in order to comply with the new markets or environmental requirements. In the presented, practical case, a lime manufacturer is operating two single shaft kilns. As the actual CO emissions are exceeding by far the future threshold, various tests and calculations were carried out to optimise the process conditions. As a result the CO emissions could be drastically reduced and the lime quality improved.

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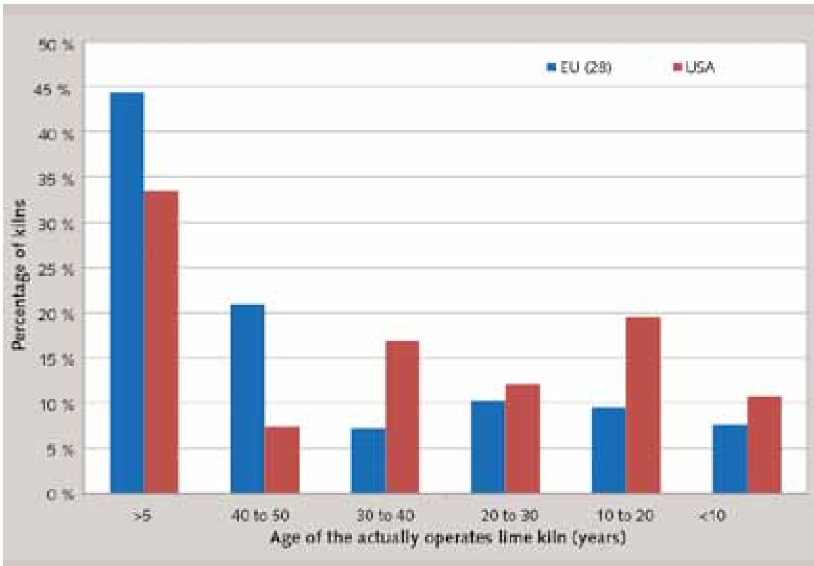
The reengineering of existing lime kilns

1 Introduction

Based on different publicly available information sources (reference lists from lime manufacturers, public statistical reports, company reports, ...) the age of all lime kilns that are operated in the EU(28) and in the USA nowadays was estimated. These data enabled determination of the distribution of the kilns as a function of their age. The results are presented in **Figure 1**.

1 Statistical distributions of the actually operated lime kilns according to their age in EU(28) and USA



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As can be seen from **Figure 1**, 65 % of the lime kilns in operation in the EU(28) are operated for more than 40 years. Although many new kilns were built in the USA in the last decades, there are still 40 % of kilns running for more than 40 years.

As mentioned in the BREF Cement, Lime, Magnesium Oxide manufacturing industries [1], two of the key criteria for selecting and designing lime kilns are the nature of the deposit (characteristics, availability, chemical quality of the limestone) and the lime quality required by the market.

Since many kilns have been in operation for more than 40 years, it can be reasonably assumed that at many locations, the initial quarries are exhausted. They were replaced by new ones, which may have different physical and chemical properties. Besides, in order to maximise the use of the quarry reserves, the stone preparation line was often adapted over time, thus possibly influencing the kiln feed properties. Finally due to new applications and markets for lime products, the requirements in terms of product quality (lime reactivity, residual CO_2, sulphur content, etc...) have evolved.

For these reasons, lime kilns that were well adapted to the external conditions at the time of their erection can become more and more difficult to operate under the actual or future conditions.

In this context, the introduction of new environmental regulations (e.g. lower air emission thresholds or inclusion of new substances) represents an additional challenge. The constraints imposed by these regulations can require process and operating conditions which, in turn, can affect the product quality as shown in the example.

2 Reduction of CO emissions from single shaft kilns

2.1 Initial status

A company is operating two single shaft kilns with a nominal capacity of 80 t/d of lime each. Both kilns are fired with natural gas. They are equipped with a central burner which receives 40 % of the total energy supply. In addition, two levels of seven side burners are used to supply the remaining energy of 60 %. The general layout of these kilns is displayed in Figure 2.

The kilns are fed at the top with 30 to 80 mm limestone pebbles and the lime is discharged at the bottom after being cooled down by an air countercurrent (lime cooling air). The kiln exhaust gas is dedusted in a baghouse and extracted by a fan before being released to the atmosphere via the stack. The central and side burners are fed with air and natural gas. In addition part of the exhaust gas is recycled through the side burners. This recycling has been implemented in order to avoid high temperatures in the area of the side burner that may lead to blockages in the kilns or damage to the refractory.

The quality specifications of the quicklime that are summarised in Table 1 correspond to the local requirements of the market.

The CO emissions of the kilns were ranging between 700 and 5000 mg/Nm³. With the enforcement of the Industrial Emissions Directive (IED), it is anticipated that an Emission Limit Value[1] (ELV) for CO of 500 mg/Nm³ will be set at the latest in April 2017. Consequently several tests were carried out internally by the company in order to evaluate the possibilities to reduce these CO emissions.

Some of these tests led to significant reductions of the CO level but resulted in a degradation of the lime quality. Thus the procedure had to be changed.

2.2 Methodology used for solving the issue

Following its assignment, EESAC firstly proposed performing a parametric study aimed at determining the main process factors that influence the CO emissions of these kilns. The proposed methodology consisted of carrying out special quick tests (i.e. during a maximum of two hours) in order to assess the impact of some process changes on the CO emissions. Only one test was performed every day in order to maintain a good stability of the kiln.

Once the key parameters were identified, it was decided to test new kiln set-ups during at least one week, in order to assess the impacts of the new process conditions on the lime quality and on the kiln behaviour.

2.3 Initial kiln parameters

In order to understand the initial kiln burning conditions, a heat and mass balance was conducted. The main results that are of interest for this study are displayed in Table 2. In this table, an air ratio of 1 represents the burning stoichiometric conditions.

As mentioned in Table 2 all burners were operated in sub-stoichiometric conditions mainly in order to minimise the temperatures in the kiln. However due to the addition of cooling air at the bottom of the kiln, the global air ratio of the kiln is above the stoichiometric value. Such conditions at the side burner level are in line with the standard process parameters applied on other shaft kilns. However the global air ratio is then rather in the range of 1.5 to 2.0.

Such kilns typically emit less than 100 mg CO/Nm³. It follows that at this stage CO reduction levers might exist and should be tested.

2.4 Short duration tests

As indicated before, each short test was performed during a maximum of two hours on one of the two kilns. During these tests, the main kiln process parameters (temperatures, pressures, air and gas flow rates, etc…) were recorded together with a continuous monitoring of the kiln emissions. The main results of these tests are summarised below.

» Central burner turned off:
This test was made to assess the contribution of the central burner to the CO emissions. It resulted in a decrease of 99 % of these emissions (concentration below 100 mg/Nm³), mainly because of the increase of the global air ratio in the kiln from 1.23 to 2.29.

» Side burners turned off:
Similar to the previous test it was targeted to measure the contribution of these burners to the CO emissions. A 98 % decrease of these emissions was observed; the global air ratio thus increased from 1.22 to 3.44.

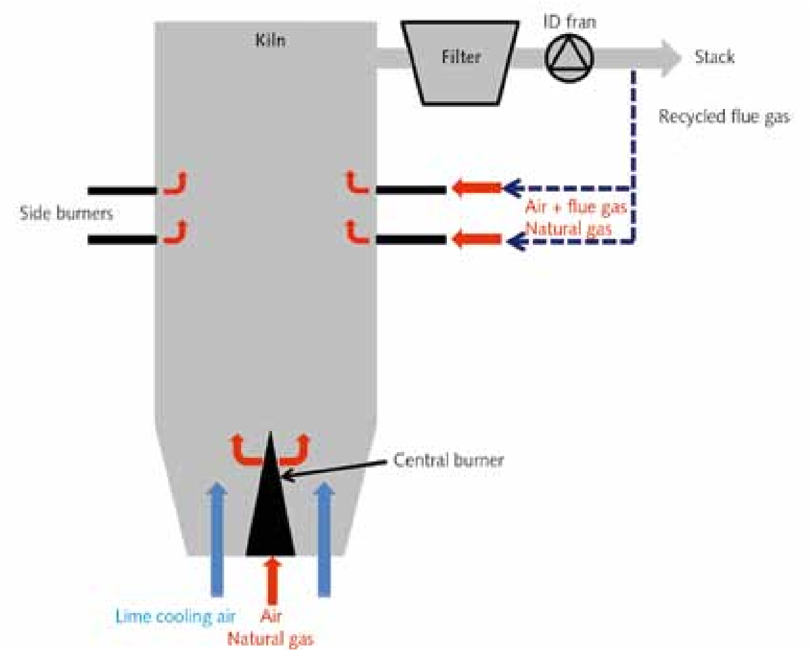
	Residual CO_2	Lime reactivity
Specifications	< 7%	Temperature >60°C after 25 minutes

Table 1 Quality specifications

Air ratio – Central burner	0.44 – 0.48
Air ratio – Side burners	0.39 – 0.42
Global air ratio	1.20 à 1.23

Table 2 Main results of the heat and mass balance

[1] All concentrations mentioned in this article refer to a reference oxygen concentration of 11 %.



2 General layout of the single shaft kilns

» Increased rate (25 % and 40 %) of the combustion air in the central burner:
This measure led to a maximum decrease of the CO emissions of 10 % only.

» Increased rate (25 % and 40 %) of the combustion air in the side burners:
A decrease of up to 29 % of the CO emissions was measured, but the concentrations remained above 2000 mg/Nm³.

» Replacement of the recycled flue gas by air in the side burners:
The goal was to increase significantly the air ratio (i.e. from 0.39 to 0.73) in these burners. It followed a 74 % reduction of the CO emissions with concentrations remaining between 1000 and 1300 mg/Nm³.

» Increase of the amount of lime cooling air:
In this test the global air ratio in the kiln was increased from 1.21 to 1.47. It resulted in a decrease of 94 % of the CO emissions with a concentration below 300 mg/Nm³.

Finally these tests highlighted the fact that two major process changes were significantly influencing the CO emissions:

Table 3 Evolution of the lime quality over time

	Residual CO_2	Lime reactivity Temperature after 25 min
Period #1	3.7 %	67 °C
Period #2	2.7 %	71 °C
Period #3	3.6 %	68 °C
Period #4	5.2 %	62 °C
Period #5	2.5 %	57 °C
Period #6	1.2 %	77 °C

1. the increase of the amount of air in the side burners
2. the increase of the global excess air in the kiln, especially by increasing the amount of lime cooling air. These promising results were used to prepare the next step of the study where tests should be performed over longer periods.

2.5 Tests with new process parameters

These tests were carried out on one kiln during two months. This time span was divided into five periods as described below:

» Period #1, duration 5 days: In this step the amount of lime cooling air was increased by 20 %.
» Period #2, duration 5 days: During this period the amount of lime cooling air was increased by 30%. Due to the limitation of the ID fan this air flow rate could not be further increased.
» Period #3, duration 5 days: The kiln was brought back to the initial standard running conditions.
» Period #4, duration 10 days: In this phase the flue gas that is usually recycled through the side burners was replaced by air in order to reach an air ratio of about 0.60. After 5 days the same process conditions were maintained except that the amount of lime cooling air was increased by 20%.
» Period #5, duration 5 days: The kiln was brought back to the initial standard running conditions.
» Period #6, duration 11 days: In this step the amount of lime cooling air was increased by 30 % similar to the amount used during period #2. In fact the goal of this test was to validate the results monitored during period #2 and to stabilise the kiln as much as possible.

As done during the short duration tests, the main process parameters and the composition of the kiln flue gas were recorded. In addition the lime quality was controlled three times per day.

Figure 3 and Figure 4 respectively display the CO emissions of the kiln and the temperatures measured in the area of the side burners.

The testing results can be summarized as follows:

» Period #1: The CO emissions decreased from 4300 to 2000 – 3000 mg/Nm³. The temperatures in the side burner area were not influenced by this process change.
» Period #2: During this period the CO level dropped to 350 – 1500 mg/Nm³. The variations of the CO level over this period are unexplained. Actually the kiln process conditions remained unchanged and the kiln temperatures were stable. On average however a decreasing trend of the CO concentrations was observed during the whole period.

» Period #3: When the kiln was put back to its initial settings, the CO emissions rose to 4000 – 6000 mg/Nm³.
» Period #4: During this test phase, the monitoring data indicated that the process conditions, in particular the kiln pressure and the temperatures, were always unstable. At the side burner level, all the temperatures increased significantly by 200 °C within 4 days. In the same time the CO level decreased from 6000 slowly to an average value of 1500 mg/Nm³.
» Period #5: The kiln came back to stable conditions with a decrease of the kiln temperature in the second part of the period. The CO average concentration again reached 5500 mg/Nm³.
» Period #6: The kiln remained very stable during this period, and a better homogeneity of the temperature in the side burner area was measured. The CO emissions dropped to an average of 340 mg/Nm³. Table 3 shows the evolution of the lime quality over time.

During the first three periods, the lime quality was stable, with good residual CO_2 values and reactivity values far above the quality requirement. These results are in line with the stable temperature measurements recorded over the same periods. However the quality started to decrease during period #4 (especially the reactivity) and continued with the same trend until the end of the period #5. This development is certainly a consequence of the huge temperature increase in the kiln that was observed during period #5. It probably generated overburned lime. Finally the lime quality came back to suitable values during period #6.

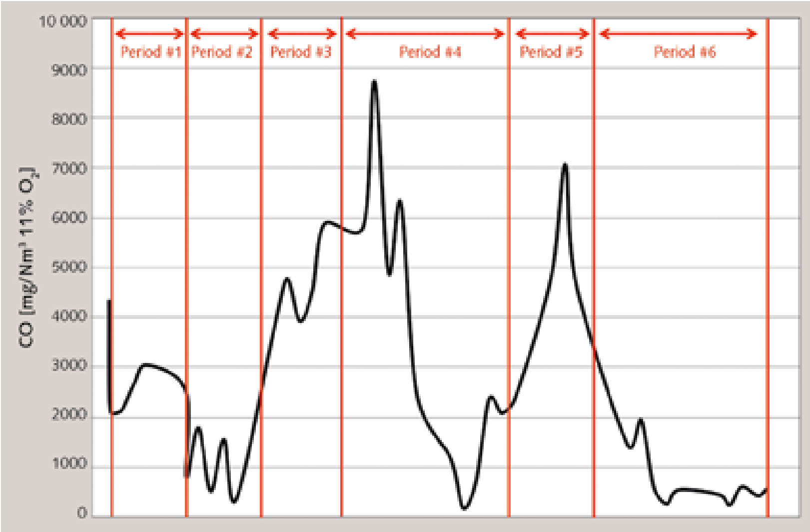
During the whole testing period, the best quality of lime was thus obtained during the periods #2 and #6, when high amounts of cooling air was fed into the kiln.

Actually, as indicated by the measurements in the kiln (see Figure 4) a better homogeneity of the temperatures was observed especially during the period #6. It then provided smooth burning conditions, favourable for the production of reactive lime.

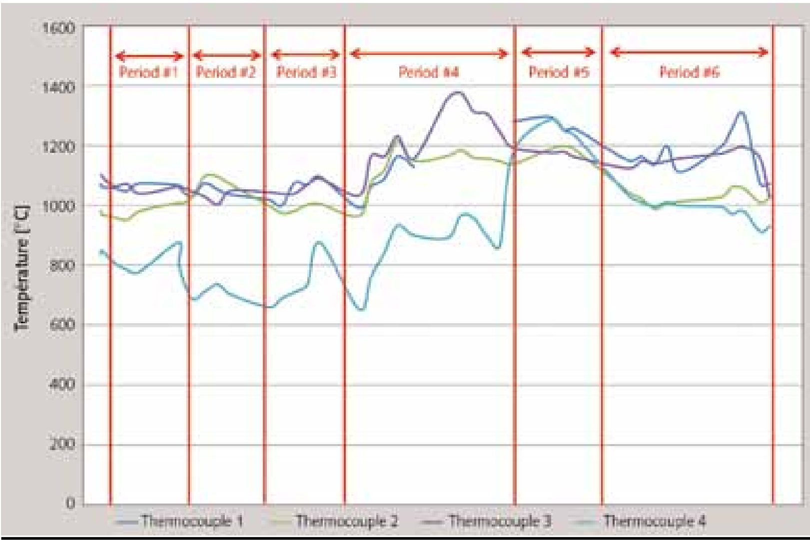
2.6 Perspectives

The increase of the cooling flow rate of 30 % led to a reduction of more than 90 % of the CO emissions. Those emissions reached an average and long-lasting concentration of 340 mg/Nm³. At the same time, a small increase in the NO_x emissions was observed, but they remained below 75 mg/Nm³, i.e. levels well below the emission threshold.

With such process conditions the measurements indicated very stable kiln behaviour, with homogeneous temperatures and pressures. In addition the lime quality met the required specification with an improvement compared to the initial situation. Therefore this kiln setting was definitely applied to the kiln, enabling compliance with the future regulatory requirement (CO < 500 mg/Nm³) with no kiln modification. This solution will also be applied to the second kiln in the forthcoming months.



3 CO emissions of the kiln over the testing period



4 Temperatures in the side burner area over the testing period

3 Conclusion

The case described in this article shows one possibility to adapt older lime kilns to new production requirements or recent environmental standards. The tailor-made solution offered the possibility to maintain the production in the existing installation without triggering significant investment costs.

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REFERENCES

[1] Reference Document on Best Available Techniques in the Cement, Lime, Magnesium Oxide manufacturing industries, European Commission, May 2010.