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Reducing the CO_2 emissions in Croatian cement industry

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ABSTRACT

Cement industry is one of the largest carbon emitting industrial sectors. It is responsible for about 5% of anthropogenic CO_2 in the world. Therefore, it is a relevant industrial sector for CO_2 emission regulation strategies. Bearing in mind the importance of cement industry in Croatia, and because of the fact that Croatia will soon become an EU member state, the present paper analyses the potential to reduce CO_2 emission in the Croatian cement industry. There are several measures that can reduce CO_2 emissions from the cement manufacturing process: the use of waste heat as an alternative source of energy; CO_2 capture and storage technologies; reduction of clinker to cement ratio; the use of alternative and biomass fuels; the use of alternative raw materials; an energy efficient combustion process. The most energy efficient technology for cement manufacturing today is the use of a rotary kiln together with a multi-stage preheater and a calciner. Since the use of cement calciners is a relatively new technology, further improvement of their operating conditions is still needed. This paper also highlights the results of research in the field of computational fluid dynamic (CFD) simulations that are used for the investigation of process and combustion emissions. The above mentioned measures together with numerical investigations can reduce the effect of cement manufacturing in Croatia on the environment and can make it more competitive with cement manufacturers from the EU.

1. Introduction

There is indisputable evidence that the build-up of man-made greenhouse gases in atmosphere cause changes in the global climate that will have increasingly severe human, environmental and economic impacts over the coming years [1]. Climate change problems are addressed by two major international agreements: the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and the 1997 Kyoto Protocol. The ultimate objective of these agreements is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the global climate system. The Republic of Croatia has been a party of the UNFCCC since 1996 and the Kyoto Protocol was ratified in 2007 with a commitment of limitation of greenhouse gas emission in the 2008–2012 period to the level of 95% of the 1990 base year [2]. In the post-Kyoto period, Croatia, as a future EU member state, has set itself the intermediate goal of reducing the overall greenhouse emissions by at least 20% by 2020, and the long-term goal of reducing its emission to 80% below 1990 levels by 2050. To reach this goal, increase of the energy efficiency comes first, followed by significant increase of the use renewable energy sources for electricity generation, transportation and other sectors [3].

Cement industry is one of the largest carbon emitting industrial sectors in the world, being the third largest carbon emitting industrial sector in the EU [4]. It contributes to about 5% of world's anthropogenic CO_2 [5,6], in the EU it accounts about 4.1% of the total CO_2 emissions [7]. Since the EU has proved to be a frontrunner in implementing the emission reduction targets and addressing climate change, in 2005, the EU Emissions Trading Scheme (EU ETS) for greenhouse gases was launched [8]. Cement manufacturers within the EU are obliged to participate in this trading scheme, due to high CO_2 emissions. Cement production is not only a source of combustion related CO_2 emissions, but it is also the largest sources of industrial process related CO_2 emissions in Croatia, and therefore CO_2 reduction measures will be required to keep cement industry emissions in line with levels set in Kyoto and post-Kyoto period. During the cement manufacturing process almost 90% of CO_2 is emitted from two thermo-chemical processes which occur in the process of cement production. One is the calcination process, which contributes with 50% of CO_2 emission, and the other is the combustion of the solid fuels, which contributes with 40% of CO_2 emission. Remaining 10% of CO_2 are emitted during the transport of raw material and some other production processes. The only way to reduce the CO_2 emission from the calcination process is to use alternative raw materials, but so far there have been no such materials from which that kind of cement, with at least as

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good performance and durability characteristics as the current Portland-based cements, could be produced. Following this fact Gartner [9] studied the alternative hydraulic cements to lower CO_2 emissions. The study showed that with replacing the limestone with different raw materials for cement production, a CO_2 emission reduction can be achieved, but the product will be too expensive to the consumer. That is why, for now, the only way to reduce the CO_2 emission is to use more fuel efficient technologies. The best available technology, the one with the lowest energy consumption, for the cement manufacturing today, is the use of a rotary kiln together with a calciner. Szabo et al. [4] reported that an energy consumption decrease of 8–11% can be achieved if a cement calciner is used prior to the rotary kiln. The calciner is a separate furnace in which the calcination process occurs, and after that the material goes to the rotary kiln where the clinkering process occurs. This improvement in the energy consumption, by simply dividing the calcination and the clinkering process, can be calculated also as a CO_2 emission reduction.

Because cement calciners are relatively a new technology in the cement manufacturing process, further improvements of their operating conditions are needed. With the aim of improving the operating conditions, different calciners, as well as the chemical and physical processes occurring inside the calciner [10], have been studied. Huanpeng et al. [11] using a two-dimensional model and the kinetic theory of granular flow to represent the transport properties of the solid phase, studied the influence of different parameters on the dynamics of the two-phase flow in a calciner. Iliuta et al. [12] based on the reaction–diffusion approach for combustion and calcination developed a mathematical model for an in-line low-NO_x calciner. Fidaros et al. [13] demonstrated a numerical model and a parametric study of the gaseous flow and the transport processes taking place in a vertical industrial low NO_x calciner. The study showed good predictions for velocity, temperature and distribution of particles.

Aside from the studies investigating the cement production, due to the increased environmental awareness, several studies investigated environmental aspects and in particular, the potential of CO_2 emission reduction in this sector. Hence, in [14] relatively high economic and environmental effectiveness of climate change mitigation measures has been demonstrated for Macedonian industrial sector, including cement industry. Furthermore, Mokrzycki et al. [15] presented the economical and ecological benefits of using alternative fuels in Polish cement plants. The study, for the presented two cement plants, shows that combustion of alternative fuels is an environmentally friendly method of waste utilization. Mokrzycki and Uliasz-Bocheńczyk [16] demonstrated the types of alternative fuels that can be used for the combustion in the cement manufacturing process, showing that the use of wastes as alternative fuels also reduces energy costs of cement production. Fodor and Klemeš [17] studied the use of waste as an alternative fuel and discussed the applicability and limitations of current and developing waste-to-energy technologies. The study focuses on how the different technologies are being developed, to enable energy to be produced from different types of waste, while simultaneously minimizing emissions. Kääntee et al. [18] studied the use of alternative fuels in the cement manufacturing process. The study provides useful data for the optimization of the manufacturing process when alternative fuels, instead of conventional fossil fuels, are used for the combustion. Because shredder dust is an industrial by-product which must be disposed in an environmental friendly way, Kakimoto et al. [19] examined the effectiveness of the use of fine-grained shredder dust as a cement admixture. First they crushed the molten shredder dust and then mixed it with the ordinary Portland cement to form a new cement mortar. The new cement mortar was then tested, and the results of this test showed that the long-term strength of cement was not deteriorated. Bassioni [20] reported that the use of up to 5% limestone as an admixture in the ordinary Portland cement, does not affect its performance, and in the same time minimizes the CO_2 emissions from the cement manufacturing process. In order to reduce the energy consumption in the cement manufacturing process, since approximately 40% of the total input energy is being lost, Wang et al. [21] studied the use of a cogeneration power plant in cement industry. The cogeneration plant in a cement plant could recover the heat lost through hot flue gases and cooler stack, and in that way generate electrical energy and reduce the CO_2 emissions from the cement manufacturing process. Since CO_2 emissions from the industrial sectors, one of them the cement industry, are major contributors to the global warming, Wang et al. [22] studied the capturing the CO_2 from the flue gases. Worrel et al. [23] made an in-depth analysis of the US cement industry, showing that the use of blended cement in cement manufacturing process is the most efficient method for CO_2 emission reduction. Jaber [24] reported that the cement industry in Jordan is the industrial sector with highest CO_2 emissions. To achieve an annual reduction of 90,000 tonnes of CO_2 emitted from Jordanian cement industry, an increase in the energy efficiency of the grinding and the calcination process is needed.

The purpose of this paper is to analyse the current status of Croatian cement industry and the possibilities of reducing the CO_2 emissions. The development of the Croatian cement industry was analysed with different scenarios. These scenarios show that there is a possibility for a more sustainable development of this industrial sector in Croatia. In addition, a previously developed mathematical model of the calcination process [10], which contains the relevant physical and chemical processes as, e.g., Arrhenius rate approach, pressure limitation, diffusion resistance, porosity, tortuosity, pore size and pore efficiency, was used for the numerical investigation of a cement calciner. By using this detailed mathematical model, a progress in understanding of the thermo-chemical processes occurring inside a calciner was made. The results gained by this numerical simulation show that CFD can be a useful tool for the optimization of the calciner's operating conditions. Hence, by using CFD and optimizing calciner's operating conditions, less fuel will be used, and therefore a decrease of CO_2 emissions will be achieved.

2. Cement production in Croatia

Production of cement and clinker in Croatian cement plants is based on the dry kiln process. There are five operating cement plants in Croatia (Table 1), which produce Ordinary Portland Cement. Three of them have multi-stage cyclone preheater plus a calciner in their kiln process, and rest two have a multi-stage cyclone preheater kiln process. The general decline in economic activity during the period 1991–1995, particularly because of the war in Croatia, led to a reduction in cement production. However, in 1996, cement production began to rise until 2003, while in the period 2003–2008 the production was almost at same level. The another decline in economic activity, primarily due to recession and the related economic downturn during the period 2008–2010, led

Table 1
Cement plants currently (2011) operating in Croatia.

Group	Plant
Cemex	Sveti Juraj
	Sveti Kajo
	10. kolovoz
Holcim	Koromačno
Nexe	Našice

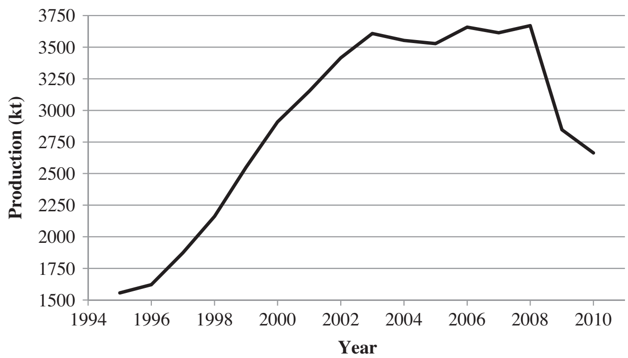

Fig. 1. Cement production in Croatia.

Table 3
Typical electrical energy consumption during the cement manufacturing process [27].

Sub-process/equipment	Electrical energy consumption (kW h/t cement)	Share (%)
Mining, crushing and stacking	1.50	2.00
Raw meal grinding and transport	18.00	24.00
Kiln feed, kiln and cooler	22.00	29.30
Coal mill	5.00	6.70
Cement grinding and transport	23.00	30.70
Packing	1.50	2.00
Lighting, pumps and services	4.00	5.30
Total	75.00	100.00

to a new reduction of cement production with approximately 2.6 million tonnes of produced cement, with an average clinker to cement ratio 0.77. Fig. 1 shows the production of cement in Croatia from 1995 to 2010.

In the operating cement plants (Table 1), various fossil fuels are used, mostly pulverized coal. Due to the increased environmental awareness, cement plant operators are starting to use alternative fuels. So far, used oil and tires have been mostly used as alternative fuels, and their share in the total fuel consumption of Croatian cement industry is around 2% [25], which is still a very modest share.

The energy efficiency of a cement plant is evaluated by comparing the specific energy consumption of that particular cement plant with the specific energy consumption of a benchmark. The specific energy consumption can also be used for the evaluating and tracking of any improvements in the energy efficiency of the production process. The average specific thermal energy consumption of a kiln process is shown in Table 2. It can be noted that the pre-heating of the raw material can reduce energy consumption significantly.

The values of electrical specific energy consumption for different sub-processes of the cement manufacturing process are shown in Table 3. It can be noted that grinding and transportation, together with the kiln and the cooler consume almost 85% electricity needed for the cement manufacturing process.

The reported [25] average value of the specific thermal energy consumption of Croatian cement industry is 3.4 GJ/t clinker and the specific electrical energy consumption is about 113 kW h/t cement.

Cement manufacturers contribute to approximately 4–9% of Croatian total greenhouse gases emissions [25]. Cement industry CO_2 emissions mainly come directly from the calcination process and the combustion of fossil fuels. An indirect amount of CO_2 comes from the consumption of electricity needed for the manufacturing process. As mentioned, approximately half of CO_2 emissions come from the calcination process (see Eq. (2)). In this study, the CO_2 emissions from the cement production systems in Croatia have been calculated for the period 1995–2010, according to the IPCC methodology [28]. The results (see Fig. 2) show that CO_2 emissions from cement manufacturing in Croatia, grew almost steadily until 2008 when the economic crisis started, and due to the decreased cement production, the CO_2 emissions from the cement production decreased.

Table 2
Specific thermal energy consumption of a kiln process [26].

Kiln process	Thermal energy consumption (GJ/t clinker)
Wet rotary kiln	5.86–6.28
Dry long rotary kiln	4.60
Dry rotary kiln with 1-stage cyclone preheater	4.18
Dry rotary kiln with 2-stage cyclone preheater	3.77
Dry rotary kiln with 4-stage cyclone preheater	3.55
Dry rotary kiln with 4-stage cyclone preheater and calciner	3.14
Dry rotary kiln with 5-stage cyclone preheater, calciner and high efficiency cooler	3.01
Dry rotary kiln with 6-stage cyclone preheater, calciner and high efficiency cooler	<2.93

3. Mitigation scenarios

Currently, the cement industry worldwide is facing increscent challenges in conserving raw material and energy resources, as well as reducing the CO_2 emissions from the cement manufacturing process [29]. There are several different effective measures which can reduce the CO_2 emissions from the cement manufacturing process. The most effective way is to capture CO_2 from the flue gases and store it. This can reduce carbon emissions by 65–70%, but due to high cost of this technology, and because so far only laboratory size CCS devices are available, CCS technologies have not yet found wide application in the industry [30]. Additionally to high cost of the CCS technologies, Roddy [31] analysed the development of CO_2 networks which can accommodate CO_2 emissions from industrial facilities. Another effective measure, which can reduce CO_2 emissions significantly, is the reduction of clinker to cement ratio with the addition of different additives. Replacing fossil fuels with alternative fuels may play a major role in the reduction of CO_2 emissions as well. The use of alternative raw materials can reduce CO_2 emissions as well. Improving the energy efficiency of the kiln process is also one of the possibilities of CO_2 emissions reduction. Most of these measures are influenced to a large extent by environmental policy and legal framework and integration of

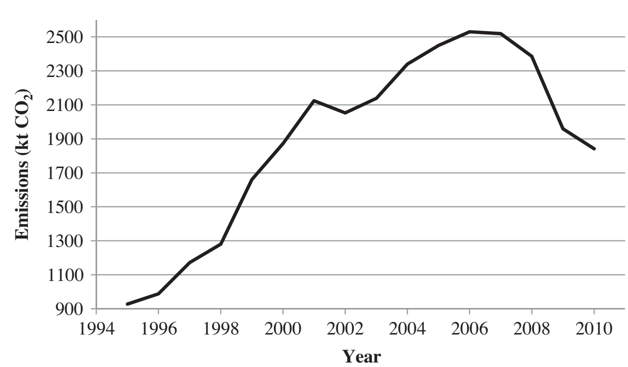

Fig. 2. CO_2 emissions from cement production.

these measures will only be possible if the policy framework will foster the cost-effective deployment of the best available technology.

The projected development of Croatian cement industry is presented through three different scenarios. The first scenario, BAU scenario, anticipates deployment of technological improvements that would have occurred regardless of the need to reduce CO_2 emissions, this can be considered as a "black" scenario. The other two scenarios, mitigation scenarios, integrate appropriate mitigation measures that will lessen the CO_2 emissions from cement production.

3.1. Specific mitigation costs

For the mitigation scenarios three different measures that reduce the CO_2 emissions from the cement manufacturing process were considered: (a) reduction of clinker to cement ratio; (b) the use of alternative fuels; (c) an energy efficient combustion process. The mitigation cost *MC* for each of the named measures was calculated according to the following equation:

$$MC = \frac{C_m - C_{BAU}}{E_{BAU} - E_m}, \quad (1)$$

where C_m is the equivalent annual cost of the mitigation scenario, C_{BAU} is the equivalent annual cost of the business as usual scenario, E_{BAU} is the annual CO_2 emission of the business as usual scenario, and E_m is the annual CO_2 emission of the mitigation scenario. When calculated, the specific cost of reduction of clinker to cement ratio is between (−0.4) and 0.5 €/t CO_2 reduced. For the use of alternative fuels the specific cost is between (−7) and (−5) €/t CO_2 reduced, while the specific cost of an energy efficient combustion process is between 8 and 17 €/t CO_2 reduced. From this figures it can be concluded that in the case of Croatian cement industry, named measures for CO_2 emissions reductions are economically viable.

3.2. Scenario definition

In these three scenarios an assumption was made that a steady growth of 2.5% in cement production will be achieved until 2020. The forecast for the development of the cement industry and the growth of cement production until 2020 was made based on the data obtained from the cement factories development plans.

3.2.1. Business as usual scenario

The BAU scenario is based on the exploitation of the existing resources, and includes the programs aimed at the market adjustments. The BAU scenario does not include the implementation of any measures to reduce CO_2 emissions. This scenario represents a reference level of CO_2 emissions, in relation to which, potential of CO_2 emissions reduction is calculated. The predicted CO_2 emissions for the BAU scenario until the year 2020 are shown in Fig. 3. From Fig. 3 it can be seen that according to the BAU scenario, in the period 2010–2020, an increase of 582 kt CO_2 in CO_2 emissions from the cement manufacturing process will be achieved.

3.2.2. First mitigation scenario

This scenario assumes the inclusion of mitigation measures to fulfil the CO_2 emissions reduction obligation. The first assumption of this scenario is that the specific energy consumption of a current benchmark will be achieved until the year 2020. The second one is that waste will be used as an alternative fuel for co-combustion in calciners and rotary kilns, and the last one is that an average clinker to cement ration of 0.7 will be achieved in 2020. The predicted CO_2 emissions for the first mitigation scenario until the year 2020, and the comparison with the BAU scenario, are shown in Fig. 4. From Fig. 4 it can be concluded that in the period 2010–2020, first mitigation scenario in comparison with the BAU scenario decreases CO_2 emissions for 331 kt CO_2.

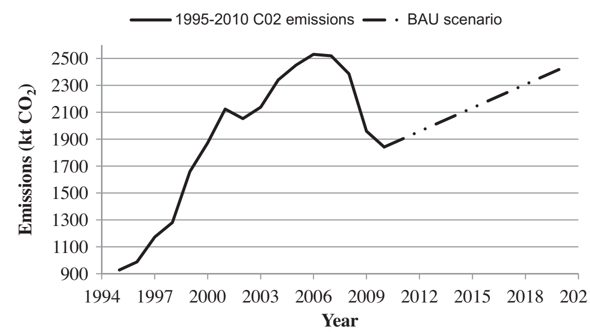

Fig. 3. BAU scenario CO_2 emissions.

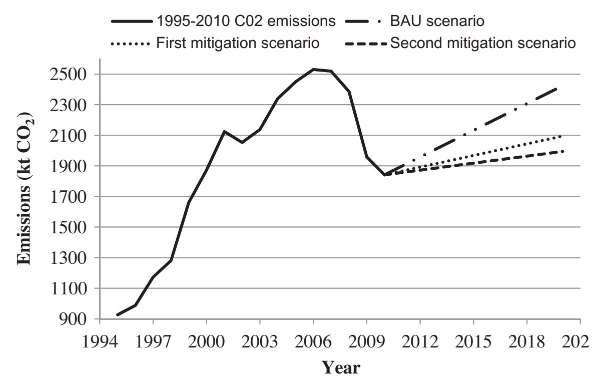

Fig. 4. Mitigation scenarios CO_2 emissions.

3.2.3. Second mitigation scenario

In this scenario assumption was made that even lower, to the one assumed in the first mitigation scenario, average clinker to cement ration of 0.65 will be achieved in 2020. The predicted CO_2 emissions for the second mitigation scenario until the year 2020, are also shown in Fig. 4. From Fig. 4 it can be seen that in the period 2010–2020, second mitigation scenario in comparison with the BAU scenario decreases CO_2 emissions for 429 kt CO_2.

4. Numerical investigation of a cement calciner

In order to reduce the atmospheric concentration of CO_2, an important environmental target for cement producers worldwide is the reduction of CO_2 emissions from their manufacturing process. As mentioned, there are several possibilities of CO_2 emissions reduction from the cement manufacturing process. Some of these measures are: the reduction of clinker to cement ratio; carbon capture and storage; use of alternative fuels; more energy efficient production, etc. The latter two can effectively be investigated with numerical simulations. To simulate the CO_2 emissions from the combustion of alternative fuels, models for the combustion of alternative fuels have to be developed. To have a more energy efficient combustion process, in-depth understanding of thermochemical processes, occurring in cement manufacturing devices, is needed. The understanding of the complex nature of combustion and calcination processes in experimental investigation is limited and can be significantly improved by computer simulation tools. Numerical models developed for cement calciners [10], can be used for numerical simulations of process and combustion emissions. Numerical simulations can be used to gain detailed knowledge and required information about operation of devices in order to help cement manufactures to operate in a more energy efficient way. In this paper just the operating conditions for a cement calciner, for a more efficient cement production, is investigated.

4.1. Mathematical model

For an effective investigation of the operating conditions of a cement calciner the decomposition of limestone and the process providing the reaction enthalpy, e.g., the combustion of coal must be treated. The Lagrangian formulation is used for the motion and transport of solid particles through the cement calciner, and the Eulerian formulation is used for the solving of the gas phase [32]. The developed mathematical model [10] used for the calcination calculation is treated in the Lagrangian spray module, where thermo-chemical reactions occur inside a particle as well as between the particle and the gas phase. The developed calcination model was integrated into the commercial CFD code FIRE [33], and applied together with additional user functions for providing thermo-physical properties of limestone and lime as well as a particle radiation model [34–36]. The model takes into account the effects of temperature, decomposition pressure, diffusion, and pore efficiency. The model is detailed enough to contain the relevant physical and chemical processes, yet robust enough for detailed CFD simulations of calcination devices, i.e. cement calciners.

In general the calcination process can be presented by following equation:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g) + 178\ kJ/mol. \tag{2}$$

Fig. 5 shows the validation of the developed calcination model. Large experimental error bars are due to the uncertainty in experimental measurements, however as can be seen, predicted numerical results are in good agreement with the mean experimental data. Thus, the developed calcinations model can be used for the investigation and optimization of calcination devices for cement production.

The coal combustion is modeled as a two stage process. Generally complex combustion systems, in FIRE solver, are treated by pre-tabulation or similar methods [37], but in this case the coal combustion is calculated directly. The coal particle, which is composed of pit-coal and ash, is first undergoing the pyrolitic decomposition into volatiles and char particle. In a subsequent step treated in parallel to the pyrolysis, the char particle is oxidized to CO and CO_2 taking into account a mechanism factor depending on temperature and particle size. A very simple composition, represented via chemical formula C_3H_4, for the pit coal is assumed. The treated heterogeneous chemical reactions are:

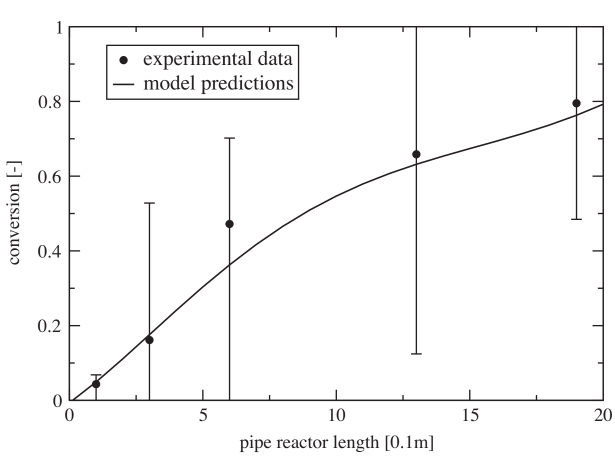

Fig. 5. Validation of the developed calcination model.

$$C_3H_4 \rightarrow 2C + CH_4, \tag{3}$$

and

$$C + \frac{1}{f_m} O_2 \xrightarrow[-110kJ/mol]{-395kJ/mol} \left(2 - \frac{2}{f_m}\right) CO + \left(\frac{2}{f_m} - 1\right) CO_2 \tag{4}$$

here f_m denotes the mechanism factor [38], which ranges between 1 and 2, causing predominant production of CO_2 for temperatures below about 900 K and predominant generation of CO for higher temperatures.

The homogeneous reactions of CO oxidation [38] and the combustion of methane, which is treated via the four step Jones–Lindstedt mechanism [39], are treated within the gaseous phase. Eq. (4) and (5) represent the CO oxidation and the four step Jones–Lindstedt mechanism for methane combustion.

$$CO + \frac{1}{2} O_2 \rightarrow CO_2 \tag{5}$$

$$\begin{aligned} &CH_4 + \tfrac{1}{2} O_2 \rightarrow CO + 2H_2 \\ &CH_4 + H_2O \rightarrow CO + 3H_2 \\ &CO + H_2O \leftrightarrow CO_2 + H_2 \\ &H_2 + \tfrac{1}{2} O_2 \rightarrow H_2O \end{aligned} \tag{6}$$

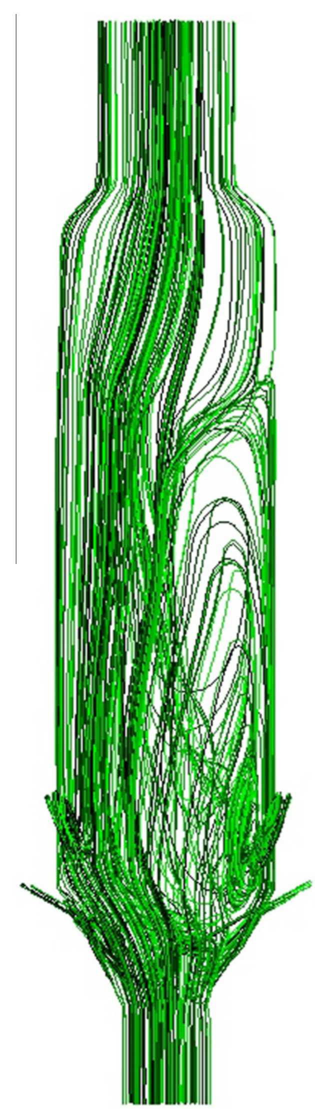

Fig. 6. Preview of flow characteristics inside a calciner.

The heterogeneous reactions cause mass transfer sources and sinks to the gas phase and particles, which are described by rate equations for pit coal consumption, char production from pyrolysis and consumption from oxidation.

4.2. Numerical simulation

Calciner geometry available in the literature [13], was used to investigate the thermo-chemical reactions occurring inside the calciner. The entire model is 32 m high, with three different diameters of cylinders, which make the calciner geometry, and two conical sections connecting them.

To discretize the computational domain 95000 cells were employed. The differencing scheme used for momentum and continuity balances was central differencing, and for turbulence, energy balances and scalar transport equations an Upwind scheme was applied. Turbulence was modeled by the standard $k-\varepsilon$ model. For practical engineering applications this is the most widely used turbulence model. It is numerically robust, and it is widely accepted that the $k-\varepsilon$ model yields reasonably realistic predictions of major mean-flow features in most situations.

5. Results and discussion

Fig. 6 shows the streamlines of the flow inside the calculated calciner. As can be seen, a region with recirculation occurs in the right part of the calciner, and afterwards continues with the higher velocity stream in the left part of the calciner to the upper outlet. Understanding of the flow characteristics inside a calciner is of essential importance for a plant operator, because limestone needs several seconds to completely decompose.

Fig. 7 shows the particle residence time. For a plant operator it is important to know the flow characteristics, particle residence time, and their distribution inside the calciner. It can be noted that the calculated residence time of particles inside of a calciner is around 3.5 s, and that the majority of the particles is in the lower part of the calciner. Together with the gaseous hot stream, particles go to the upper part of the calciner and exit the calciner.

Fig. 8 shows the temperature field for the calculated calciner. As can be seen, the highest temperature occurs in the region in the upper part of the calciner, where all limestone has already decomposed, and in that region the average temperature is around 1100 °C. In the central and in the lower part of the calciner, where the calcination takes place, the temperature is around 950 °C. This is the desirable temperature for the calcination process, which is slightly higher than the decomposition temperature of limestone, and that is why it ensures a stable calcination process.

From Fig. 9 it is clear that the highest concentration of CO_2 is in the lower part of the calciner, in the region where calcination takes place. What can also be seen from this figure is that the concentration of CO_2 decreases towards the calciner's outlet, because almost all of the limestone has decomposed.

Although the comparison of numerical predictions with experimental data is crucial for such kind of studies, experimental measurements are not available for this calciner. It should be noted that the placement of the appropriate instrumentation for specific data recording is not possible in a fully operational devices. Though there are no experimental data available for this calciner, the results obtained by this calculation show that the developed model for the calcination process [10] coupled with the commercial CFD code FIRE, is a suitable and promising tool for cement calciner optimization. Since energy efficiency is one of the mitigation measures for CO_2 emissions reduction, by using CFD as a tool for optimization

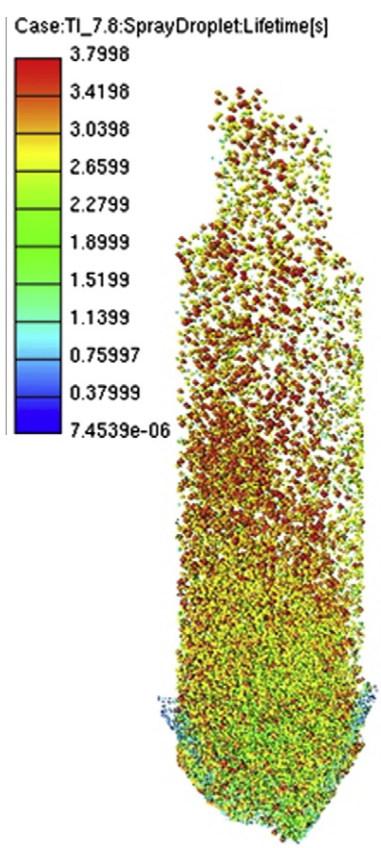

Fig. 7. Particle residence time.

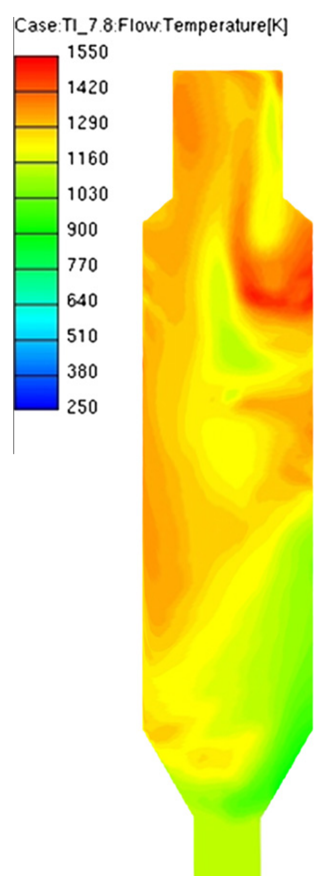

Fig. 8. Temperature field in vertical plane.

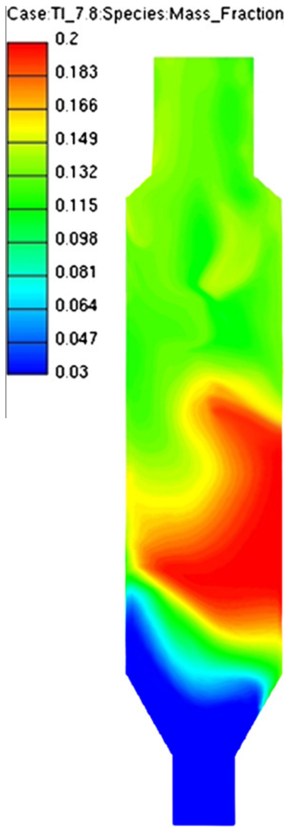

Fig. 9. CO_2 mass fraction in vertical plane.

of calciner's operating conditions, a decrease of CO_2 emissions can be achieved. Results obtained by this study are essential for better understanding of achievable CO_2 emissions reductions and the understanding of thermo-chemical processes occurring inside a cement calciner.

6. Conclusion

Climate change is one of the most serious challenges facing modern society and a reduction of CO_2 emission in cement industry is one of the important measures for achieving the EU climate targets for 2020 and beyond. The paper analyses the potential for achieving CO_2 emission reduction in the Croatian cement industry. In the Croatian cement industry, there are three economically viable measures for reducing CO_2 emissions. The reduction of clinker to cement ratio by adding different additives, the replacement of fossil fuels with alternative and biomass fuels, and a further improvement in the energy efficiency of the existing kiln processes, are the economically viable measures which can decrease CO_2 emissions of the cement industry in Croatia. Three different scenarios were calculated to predict the achievable CO_2 emission reduction until the year 2020. The first scenario, BAU scenario, shows that if the current practices in Croatian cement industry are to be continued, an increase of 582 kt CO_2 in CO_2 emissions from the cement manufacturing process will be achieved until 2020. The other two scenarios, mitigation scenarios, show that if appropriate mitigation measures are to be used, a decrease of CO_2 emissions of 331 kt CO_2, for the first mitigation scenario in comparison with the BAU scenario, and a decrease of CO_2 emissions of 429 kt CO_2, for the second mitigation scenario in comparison with the BAU scenario, will be achieved until 2020. These figures show that the implementation of mentioned measures results in a considerable decrease of CO_2 emissions by 2020, thus the mentioned measures are to be used to have a more sustainable cement production in Croatia.

Furthermore, since one of the named measures for CO_2 emissions reduction is energy efficient combustion process during the cement production, the paper highlights the results of research in the field of computational fluid dynamic (CFD) simulations. These results can be used for further investigation of CO_2 emissions coming from the calcination and combustion processes. The paper deals with the development of concepts for the numerical simulation of calcination and combustion processes, which are used to investigate and improve the understanding of the complex interacting physical and chemical phenomena occurring in calciner systems. The presented paper shows that CFD is a promising tool for the optimization of calciner geometry and operating conditions in order to increase the combustion efficiency and to reduce CO_2 emissions, both of which are essential in meeting future emission restrictions. The measures concerned here together with numerical investigations can reduce the effect of cement manufacturing in Croatia on the environment and can make it more competitive with cement manufacturers from the EU.

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