Towards Recycling of Concrete: a Parallel Simulation of a Cement Kiln

Presenter: Fernando M. Cucchietti, Barcelona Supercomputing Center, Spain
Email: fernando.cucchietti@bsc.es
Contributor: Mariano Vazquez, Barcelona Supercomputing Center, Spain
Email: mariano.vazquez@bsc.es
Contributor: Guillaume Houzeaux, Barcelona Supercomputing Center, Spain
Email: guillaume.houzeauz@bsc.es
Contributor: Eugene Skouras, Foundation for Research and Technology Hellas, Greece
Email: eugene@iceht.forth.gr
Contributor: Vasilis N. Burganos, Foundation for Research and Technology Hellas, Greece
Email: vbur@iceht.forth.gr

ABSTRACT

The recycling of end-of-life concrete into new cement is one of the most interesting options for reducing worldwide natural resources use and emissions associated with the building materials sector. The production of the cement used in concrete, for example, is responsible for at least 5% of worldwide CO2 emissions. After segregation from other demolition waste and some pre-processing, re-using the recovered concrete has the potential to cut carbon dioxide emissions in the production of new cement by a factor of two. At the heart of the cement production process lies the kiln, a tilted rotary oven where raw materials are heated to reaction temperatures to form small cement pellets called clinker, which is then ground to make cement powder. In addition to reducing its raw material consumption, improving the efficiency of cement kiln is a main concern of the industry, as the kiln is the main consumer of energy in the production process. Therefore, in the last decade there has been growing interest towards the numerical modeling of cement kilns. CFD techniques are a promising approach due to the scale and complexity of the system [1,2].

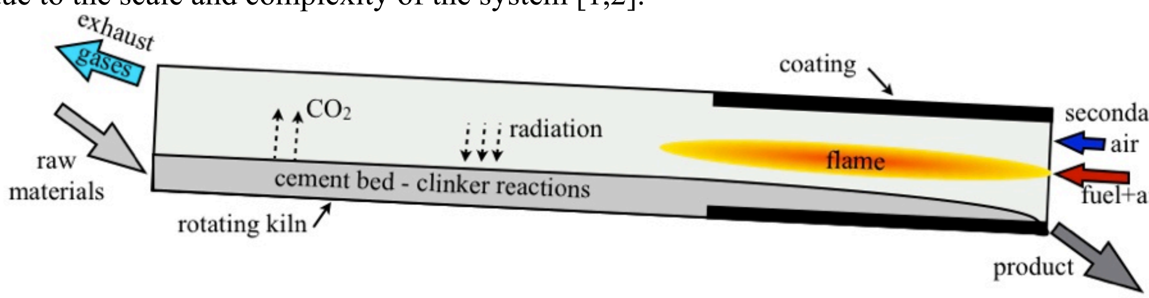

Figure 1. Schematics of a cement kiln.

A kiln is a tilted cylindrical vessel rotating at a fixed frequency of about 5 rpm. Its length ranges between 50 and 180 meters, and its diameter between 2 and 4 meters. On the high part of the kiln the raw material is input, sometimes as a dry powder and others as a wet sludge, where it begins the clinkerization process. On the lower part of the kiln a large burner ejects fuel, typically pulverized coal or waste material. The burner has a primary air injector, and secondary and tertiary injectors that add swirl to the flow and help stabilize the flame, which can be up to 10 meters long. The walls of the kiln are a mixture of refractory bricks and metal. Furthermore, cement stuck to the walls forms a coating shell around the lower third of the oven that is critical for the kiln operation. The raw material, mostly clay and limestone, enters from above and undergoes many chemical reactions when heated, most important calcination and alite formation (Ca_3OSiO_4). The material is heated directly by the hot gases and the walls, and indirectly through radiation. Gases (mostly CO_2) are released from the cement bed into the gas zone. Other minerals and burnt material from the pulverized fuel also enter the cement bed and must be taken into account to correctly predict the quality of the final product.

The main physical problems coupled in the kiln system are: compressible fluid dynamics, thermal and radiative heat transfer, chemical reactions, and combustion. We have worked with the multiphysics CFD package Alya, for which we developed radiation and combustion modules, and performed simulations on the Mare Nostrum computer at Barcelona Supercomputing Center. Specifically, for the fluid dynamics we use a low Mach number expansion of the Navier-Stokes equations, expressing energy conservation as a temperature transport equation. Because of the high scattering and absorption of char and soot inside the kiln, radiation in the gas can be well approximated as locally isotropic, which leads to the P1 model of radiation heat transfer. The cement bed is approximated as a pseudo-fluid of high viscosity, and its chemistry is computed by coupled species conservation equations. As is standard in the literature, we retain only the most important chemical reactions [2], $CaCO_3 = CaO + CO_2$, $2CaO + SiO_2 = C_2S$, $C_2S{+}CaO{=}C_3S$, $3CaO + Al_2O_3 = C_3A$, and $4CaO + Al_2O_3 + Fe_2O_4 = C4AF$. We simulate pulverized coal particles in the gas region using a Lagrangian frame of reference approach. The fuel in the particles is simulated with an equivalent methane quantity, which volatilizes at a temperature dependent rate on. We approximate the combustion by a single-step reaction, $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. We also consider longer reaction chains, and a flamelet manifold approach to improve the quality of the flame.

We solve iteratively the cement bed region and the gas region, using the results from one as a boundary condition for the other. We also iterate the flow, temperature, radiation, and chemistry solvers until convergence. Our parallel implementation of all these coupled problems shows linear scaling up to 2000 processors. Preliminary results show a realistic representation of the clinker production process. In particular, the composition of clinker was found to be within 10-20% of the measured one. After fine-tuning of the models and scaling the mesh to include finer detail, our simulator will be able to predict the response of the kiln operation to changes in the raw material distribution, in particular the partial substitution by recycled concrete.

ACKNOWLEDGEMENTS

Work was funded by the European Commission in the framework of the FP7 Collaborative project "Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste (C2CA)". Grant Agreement No 265189.

REFERENCES

[1] E. Mastorakos, A. Massias, C.D. Tsakiroglou, D.A. Goussis, V.N. Burganos, and A.C. Payatakes, “CFD Predictions for Cement Kilns Including Flame Modeling, Heat Transfer and Clinker Chemistry”, Appl. Math. Model., 23, 55-76 (1999).

[2] Mujumdar and Ranade. “CFD modeling of rotary cement kilns”. Asia-Pacific J. of Chem. Eng., vol. 3 (2) pp. 106-118 (2008).