Industrial Ecology Open Online Course (IEooc)

Part II: Methods

Methods Part 2 (Basics of material flow analysis)

http://www.teaching.industrialecology.uni-freiburg.de/

IEooc_Methods2_Exercise1: Cement production – systems analysis

This exercise is a modified version of an original developed by Daniel B Müller (NTNU Trondheim), and used with permission.

***Goal**: Consolidate understanding of basic quantitative system analysis. Transfer of detailed knowledge about energy use and greenhouse gas emissions of the cement industry.*

Concrete contains 10 to 15 % of cement, which serves as the binding agent. With a global production volume of 4 billion tons (2014) it is the most widely produced material worldwide. The biggest producer is China, which supplies a little more than half of the global production volume. Germany produces about 30 million tons of cement annually. The cement industry is one of the biggest industrial energy users as well as greenhouse gas emitters worldwide. About 7 % of all anthropogenic CO_2 emissions stem from the production of cement; that's three times the total emissions of global air transport.

Concrete's composition is following:

49% gravel / 31% sand / 13% cement / 7% water

Cement is produced by grinding cement clinker and aggregates (gypsum for the rate of binding, furnace slag and fly ash as clinker substitute) (fig. 1). The share of clinker in cement is about 86 %.

Cement clinker is produced through the calcination of a mixture from ground raw material of limestone ($CaCO_3$ releases CO_2 during the heating process), clay (SiO_2, Al_2O_3, MgO, others) and iron ore (Fe_2O_3) at 1450°C inside a kiln (rotary furnace). Cement clinker is composed of:

65% CaO / 22% SiO_2 / 6% Al_2O_3 / 3% Fe_2O_3 / 1% MgO / 3% others

The production of clinker in the kiln is a significant source of process-related CO_2 emissions. The energy demand for the kiln is about 3 MJ/kg of clinker and is released from the combustion of coal dust, natural gas, or garbage (used tires, plastic trash). The heating value of this fuel is 36 MJ/kg on average and its carbon content is 90 mass-% on average. The remaining 10 % of the fuel are inert and don't combust. The energy demand for the grinding of the raw material is not considered.

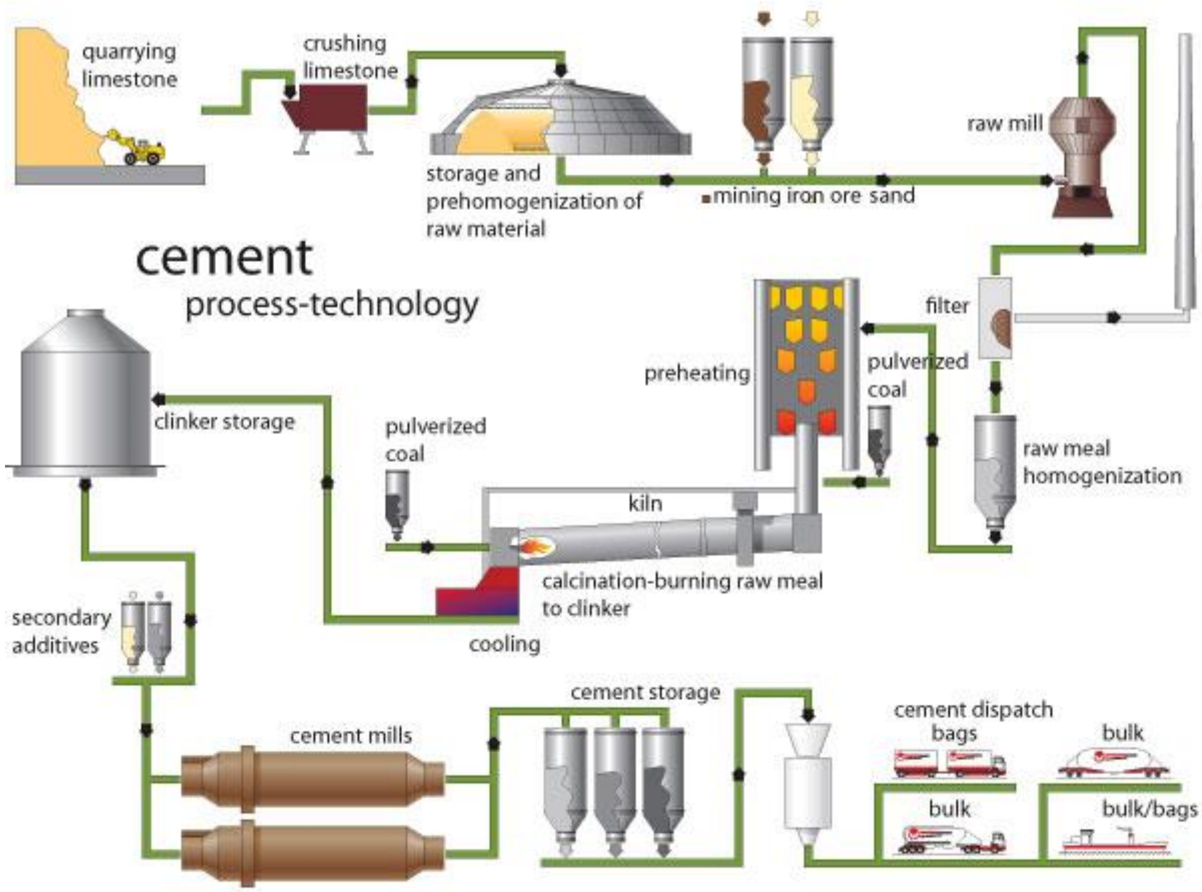

Fig. 1. Schematics of the cement production. Image source: http://constructioncost.co/images/img/cement-plant-process.jpg

Exercises:

1) Draft a simplified system diagram 'cement production and use' including the process steps 'preparation/mixing', 'rotary furnace (kiln)', 'cement mill' and 'buildings'. Identify the central material and fuel streams that are important for the process balance. Identify the system variables.

2) How many system variables are present? How many information units do you need to quantify the entire system? Compile a list of model parameters that are required to solve the system! Trace back your listed model parameters to the information in the text (using equations)! What additional information is required?

3) Determine the analytical solution of the entire system for a random quantity X of concrete demand!

4) Quantify your solution using given data and required additional information for the global cement production of 4 Gt/yr! How do the overall total emissions distribute across process and fuel emissions?

Since the cement industry is one of the biggest industrial CO_2 emitters, emissions will have to be substantially reduced in the future. Several strategies exist, and the emissions savings potential of the different strategies shall be quantified here.

5) Calculate the process and fuel related CO_2 emissions of a hypothetical global cement production of 4 Gt/yr at some point in the future assuming the following improvements:

a) a potential reduction of the specific energy requirement of the rotary furnace from currently 3 MJ/kg to 2.7 MJ/kg (‚best' possible energy intensity for large new dry kilns. 5. IPCC-Assessment Report III, page 758).

b) potential reduction of clinker share in cement to 66 % (through increasing use of CaO rich slag from other processes like power plants and furnaces)

c) large scale application of natural gas as fuel for rotary furnaces (energy content 55 MJ/kg, C content 75 %)

d) potential reduction of demand for cement through increased material efficiency and longer durability of buildings and infrastructure of 25 %.

e) Options a) to d) combined.

How do overall emissions determined in sections a) through e) split among process and fuel emissions? How do the improvements compare to global and EU wide climate goals?