THERMAL PLASMA IN PILOT-SCALE, ROTATING FURNACES

Master thesis project at the Energy Technology division, Chalmers.

For 1-2 students from Mechanical, Chemical or Chemical Engineering with Engineering Physics.

Main supervisor: Adrian Gunnarsson
Supervisors: Thomas Allgurén, Farzad Moradin & Bodil Wilhelmsson
Examiner: Klas Andersson

Background: The increasing global warming caused by human activity and the continuing emissions of greenhouse gases, mainly CO_2, is one of our times greatest and most urgent engineering challenges. Heavy emitting industries must rapidly and drastically change their processes to lower their emissions in order to reach nationally set goals and a sustainable future. One potential option for several different industrial processes with inherent combustion, such as aluminum recycling and cement production, is to exchange burners used for conventional combustion with electrically generated plasma using plasma torches. Ensuring that the electricity is from renewable sources, fossil fuels could be removed from such industries. However, such plasma reaches temperatures far higher than a conventional flame and could cause some uncertainties in how to operate the process.

For aluminum (Al) production, a significant fraction of Al is today produced through recycling of Al scrap, since Al recycling requires only about 5% of the energy being used in aluminum production from ore. This makes aluminum recycling an attractive choice in terms of economic standpoints, environmental benefits, as well as circular economy. Stena Aluminum, located in Älmhult, recycles Al by melting scrap in batches in a rotary furnace to which heat is supplied from the combustion of propane with pure oxygen. To minimize oxidation of the aluminum at the surface, salts are added as a protective layer in the furnace. The drawbacks of the technique used today are: (1) a salty slag by-product which is a hazardous waste, (2) a fraction of Al will oxidize mainly due to formation of oxidizing agents in the furnace, and (3) CO_2 emission due to utilizing fossil propane.

Cement production is globally one of the heaviest emitting industries and Cementa's production site in Slite is Sweden's second largest single emitter of CO_2. While emission of carbon dioxide is inherent within the cement production due to the calcination step ($CaCO_3 \rightarrow CaO + CO_2$), combustion of fossil fuels is used to supply the process with the required heat for the calcination and clinker formation and causes additional emissions of CO_2. The clinker formation occurs today in a rotary kiln through which the bed material continuously passes as it is heated. Since Cementa aims to reach climate neutrality already in 2030, i.e. with no CO_2 emissions during the lifetime of the cement product, they are looking into several solutions to lower their emissions.

The two industrial processes differ in many aspects, but they both utilize rotating furnaces in which a fossil fuel burner could be exchanged with plasma torches. However, such process changes are expensive and could affect how the process should be operated. It is therefore of great interest to have access to modelling tools where such a change could be more easily examined. Though, the heat transfer within a rotating furnace is complex since it includes convective, conductive and radiative heat transfer as well as a moving bed material and wall. Additionally, the bed chemistry in either process is complex and challenging to combine with the heat transfer problem.

Once such a modelling tool is constructed it must be validated to experimental data. Both Stena Aluminum and Cementa are planning for such exeperimental campaigns in pilot-scale furnaces, which are planned to be conducted in the near future (2021-2022), hence, there is a big industrial interest in such modelling tools.

Suggestion for the Master thesis work:

Construct a modelling tool for the heat transfer and bed chemistry in pilot-scaled rotating furnaces for cement production and Al recycling:

- The modelling tool will be based on an in-house model of a full-scale rotary kiln used for cement production, developed in Matlab.
- The model available today describes a continuous flow of the bed material (suitable for cement production) but should also be able to handle batchwise production (which is the case in Al recycling).
- Substitute the fossil fuel burners to plasma torches. Changing from a fossil fuel burner to a plasma torch will be connected to changes in gas and material flows as well as on the total heat transfer of the process.

The modelling tool may then be used to:

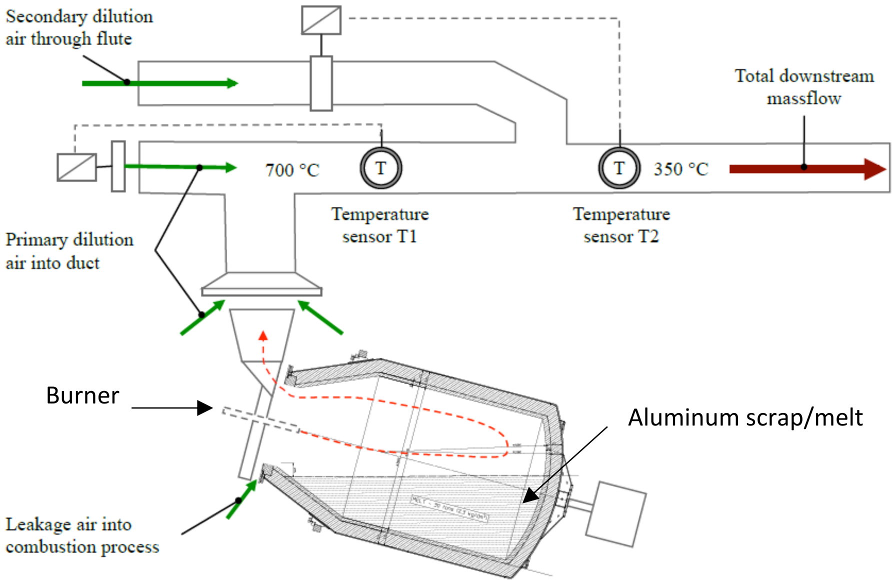
- Examine the potential to lower the CO_2 emissions in the present processes by exchanging the present burners with plasma torches.
- Examine how the production time of either Al recycling or cement clinker could be affected by changing the fossil fuel burners to plasma torches.
- Perform energy and mass balance analysis of the system to calculate electrical input, energy consumption, energy lost, recovered and lost aluminum, etc.

If experimental data will become available, validation work of the modelling tool could be started.

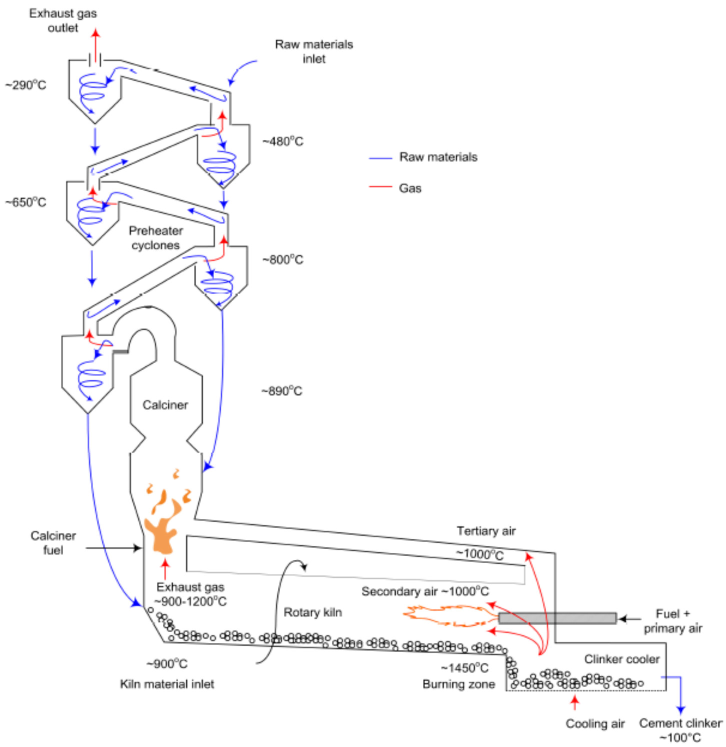
The thesis would aim to close the energy and mass balances of the pilot-scale processes and further increase the understanding of the heat transfer using a plasma torch in such industrial processes and to examine suggestions for how the process could be operated using a plasma or other means of electrification.

The thesis will be conducted at the division of Energy Technology, Chalmers, with supervision from Chalmers, Stena and Cementa. The results of the master thesis work must be presented as a Master Thesis report. There might be an opportunity to visit either the Stena Aluminium recycling site at Älmhult or the cement production site at Slite.

Contact info: Adrian Gunnarsson adriang@chalmers.se



Figur 1. Schematic of the present aluminum recycling process used at Stena Aluminum



Figur 2. Schematic of the present cement production process used at Cementa.

Contact info: Adrian Gunnarsson adriang@chalmers.se