Integration of Electric Plasma Calcination in Pulp and Paper Plants

Background and problem description

The calcination of limestone is an important reaction in kraft pulp and paper mills since it allows the recovery of lime (CaO) from limestone ($CaCO_3$). The lime in turn is necessary to recover chemicals used in the pulp cooking process. The lime calcination process is one of the main fuel consumers and emitters of CO_2 in a pulp mill.

Traditionally, calcination of limestone into lime occurs in lime kilns fired with fossil fuels such as natural gas or fuel oil. In some cases, wood-based biomass (wood chips, pellets, sawdust etc.) is used as alternative fuel. One disadvantage with conventional lime kilns is that the heat recovery potential is limited and that CO_2 emissions (fossil or biogenic depending on the fuel) are released to the air.

A novel concept for lime calcination in pulp and paper plants is to adopt plasma technology in which renewable electricity provides the energy for the calcination process rather than the combustion of fuels [1]. Furthermore, this concept results in very pure CO_2 streams that can be captured and sent to storage or used as a raw material to produce so-called electro-chemicals or electro-fuels by reacting the CO_2 with hydrogen from water electrolysis. The electric plasma calcination process provides surplus heat that can be recovered to produce process steam and/or electricity. In comparison with traditional lime kilns, a higher heat recovery rate can be expected due to the high temperature of the plasma process. Further advantages of the plasma calcination concept include the smaller size, lower capital cost, rapid regulation, as well as low on-site CO_2 emissions. Also, the conversion efficiency from electricity to plasma is very high. Using plasma to replace traditional lime kilns is not only proposed for the pulp and paper industry [2,3], but also for the cement industry [4].

Existing studies describe the process design [5] and compare the electric plasma calcination with an oil-fired lime kiln [6]. The latter study recommends replacing conventional kilns that are at the end of their lifetime by the new electric plasma concept. A follow-up study [7] developed a generic design for the plasma calcination process and indicated that the captured biogenic CO_2 could be converted to methane in a Sabatier reaction during periods with low electricity prices (since the required hydrogen would be produced by water electrolysis).

So far, the integration of electric plasma calcination into existing stand-alone pulp plants and integrated pulp and paper plants has not been studied in any detail. Consequently, there is a lack of knowledge about how the integration of this concept affects the mass and energy balances of such plants, as well as the economic feasibility when integrating the concept.

Objective and tasks

The objective of this thesis project is to assess the impact of integrating electric plasma calcination in a stand-alone pulp mill and an integrated pulp and paper plant in terms of mass and energy balances, cost, as well as greenhouse gas emissions.

The students are expected to perform the following tasks:

1. Literature review about lime calcination in pulp and paper plants (including the novel electric plasma calcination process), water electrolysis and Sabatier reaction.
2. Establish mass and energy balances for the plasma calcination process based on an existing study and establish input data for process integration studies.
3. Investigate integration of the plasma calcination process with pulp mills plants using existing pinch data and models for one stand-alone pulp mill and one integrated pulp and paper mill. For this purpose, process streams in existing data that are related to the conventional lime kiln need to be identified and replaced by streams related to the electric plasma calcination.

A key point in this task is to identify how the surplus heat from the electric plasma calcination process can be integrated into the existing steam system of the plant and how this affects electricity generation, fuel demand and CO_2 emissions. This requires setting up the correspondent mass and energy balances.

4. Process integration studies for an electro-fuel concept by adding a Sabatier reaction and water electrolysis to the combined model from point 3 in order to produce methane. This is an extension of the previous task including mass and energy balances related to the added process steps.
5. An assessment of avoided greenhouse gas emissions from integration of the new processes, where future energy market scenarios should be considered.

If possible, depending on time availability and results of the preceding steps, a first economic assessment of the plasma calcination process and the production of electro-fuels could be included.

Organization

The thesis project should preferably be carried out by two students with a background in mechanical or chemical engineering (or equivalent). The students are expected to be familiar with the concepts of process integration and pinch analysis. Swedish language skills are beneficial since two fundamental references are in Swedish. The timeframe of the project is 20 weeks, starting in January 2020. The work will be performed at the Division of Energy Technology at Chalmers.

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References

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