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**Citation for published version (APA):**

**Document status and date:**
Published: 01/01/2015

**Document Version:**
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

**Please check the document version of this publication:**
- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
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Download date: 18. Oct. 2020
Plasma assisted nitrogen fixation process

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Abstract: Chemical nitrogen fixation process is one of the most important chemical processes. In this research, plasma assisted nitric oxide and ammonia synthesis is investigated. Especially, the nitric oxide is synthesized in a Gliding Arc discharge reactor and the ammonia in a dielectric barrier discharge (DBD) reactor. The complete processes for nitric acid and ammonia synthesis by plasma were simulated and evaluated.

Keywords: plasma nitrogen fixation, nitric oxide, ammonia, energy efficiency

1. Introduction

Chemical nitrogen fixation is one of the most important chemical processes. Haber-Bosch process for ammonia synthesis consumes almost 1 - 2% of the world’s total energy consumption[1]. Nitric oxide and ammonia synthesis by plasma as an alternative energy form have been studied in the last 100 years. For example, the Birkeland-Eyde electric arc process was successfully developed in 1903, which contains three main steps from nitrogen/oxygen to nitric oxide, followed by further oxidation to nitric dioxide and finally to nitric acid by absorption [2-3]. However, the process had poor energy efficiency as compared to the classical Haber process of ammonia synthesis and also needed a high mechanical maintenance; hence it was eventually abandoned from the industry [2, 4].

In this research, a Gliding Arc reactor is used for nitric oxide synthesis and a DBD reactor is tested for ammonia generation. The catalyst was applied to enhance the conversion and also aiming for a higher energy efficiency [5-19]. In order to evaluate the plasma technology from the viewpoint of energy, cost and environmental profile, the whole process including the upstream and downstream units is simulated.

2. Experiments

The power supply system with a wide range of voltage and frequency allows us to operate both the Gliding Arc reactor and DBD reactor. The FTIR and QMS are used to analyse the components of gas products in-line.

The flow rate, mole ratio of reactants, power input, pressure, etc. are the main parameters which will be studied in this research.

Besides the experimental study, a flow sheet including upstream and downstream units for the plasma assisted nitrogen fixation process is simulated in Aspen Plus.

3. Results and discussion

The latest experimental results till the end of June, 2015 (before ICPS2015) will be presented in the conference.

The process simulation for the conventional process for nitric acid synthesis as well as the plasma process is shown in Fig. 2. The conventional process starts with ammonia as one main reactant which causes the high energy consumption and high pollution. The plasma process uses electricity as the main energy resource which is much more expensive than heat from fossil fuel.

The electricity from renewable energy, like solar/wind/biomass energy, is integrated in the plasma process. The idea is to use and easily store/transport the renewable energy in the chemicals (see Fig. 3). The productivity of such process is defined to be 6 TPD.
Take the wind energy as an example, the electricity from wind turbines is analysed based on the different locations in The Netherlands and Spain. The number of wind turbines for defined productivity of HNO₃ is calculated based on different energy efficiency of plasma assisted nitric oxide synthesis (see Fig. 4).

Then the Life Cycle Assessment (sustainability analysis) of the conventional process as well as the plasma process are carried out based on the system boundary defined below in Fig. 5.

The latest results for this part will be presented in the conference. An initial normalized LCA result is shown in Fig. 6.

4. Outlook

Plasma technology has been successfully industrialized in the ozone production, air/water cleaning, as well as material modification. However, gas conversion by plasma is still under research without any industrialized process available till now. The experimental study is aiming for higher energy efficiency and the holistic evaluation will be able to give green and cheap solutions for the future industrialization of plasma assisted nitrogen fixation process. In order to apply the renewable energy resource, a modular plant for plasma technology is the final aim for a small-scale process development.

5. Acknowledgements

This research is kindly funded by the EU project MAPSYN: Microwave, Acoustic and Plasma SYNtheses, under grant agreement no. CP-IP 309376 of the European Community’s Seventh Framework Program.

6. References