PhD proposal:

Development of a new process for CO_2 capture from biomass gasification

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Description of the subject

Context: The use of fossil fuels and their CO_2 emissions are at the root of many environmental problems. An ecological alternative to the use of fossil fuels is to develop "green" bio-based fuels. The valorisation of agricultural residues by thermochemical processes such as gasification is of great interest for the production of biogas. Biomass is a green energy source with low nitrogen and sulphur content and could potentially reduce dependence on fossil fuels. Usually, its conversion is considered a carbon-free process, as the resulting CO_2 has been previously captured by the plants. According to life cycle assessment comparisons reported by the International Energy Agency, net carbon emissions from biomass per unit of electricity are less than 10% of those from fossil fuels. Biomass can be converted into heat and electricity by several methods, the simplest being direct combustion via a steam turbine for electricity generation. The carbon dioxide emissions generated by gasification processes can be captured with different technologies depending on the operating conditions and the composition of the gas mixture. This study proposes a new and innovative process for the recovery of CO_2 in biomass gasification by capturing it and reinjecting it into the process. The carbon balance of this process will be negative, thus contributing to balance the residual fossil emissions. The final objective of this project is to contribute to the decarbonisation of energy production processes by relying on the valorisation of biomass.

Objectives: The main objective of this thesis is to develop a new chemical process based on the thermal valorization of biomass and carbon dioxide capture.

Within the context of the new French and European energy policy aimed at decarbonizing energy production methods, the thermal recovery of biomass and the capture of carbon dioxide are essential and complementary tools that will make it possible to achieve carbon neutrality by 2050 (Ademe 2021). Biomass currently provides about 10% of the world's energy, a figure that is constantly increasing, and this with a carbon balance of almost zero. Carbon dioxide capture allows to limit CO_2 emissions into the atmosphere and thus to improve the carbon balance (Liew et al., 2021) of a process. The coupling of these two tools makes it possible to obtain a negative carbon balance on the process, meaning that the quantity of carbon captured is greater than the quantity of carbon initially used (Naqvi et al., 2018, Shahbaz et al., 2021, Fajardi et al., 2021). In addition, this coupling is expected to significantly improve biomass processing to produce higher-quality syngas (Reyes et al., 2021).

The objective is to take advantage of the coupling of these two operations to improve the biomass treatment by CO_2 re-injection, to use an RWGS type operation to modify the gas composition at the gasifier outlet, to use a high-temperature carbon dioxide capture medium based on ionic liquids.

The main objective can be divided into several sub-objectives:

1. To experimentally realize a process coupling a thermal treatment unit (gasification type biomass based on a fluidized bed of activated char), a water gas reaction unit (RWGS) and a packed column type physical/chemical absorption unit

2. Select an absorption medium for carbon dioxide capture. The objective is to successfully capture carbon dioxide at a temperature close to that of the gas outlet of the WGSR unit (typically...). This objective will also include the study of absorption kinetics (Qian et al., 2017)

3. Perform process modeling and environmental performance assessment (Abdelouahed et al., 2012).

We propose a combined approach mixing experimentation and modeling.

Three scientific issues are identified in this project:

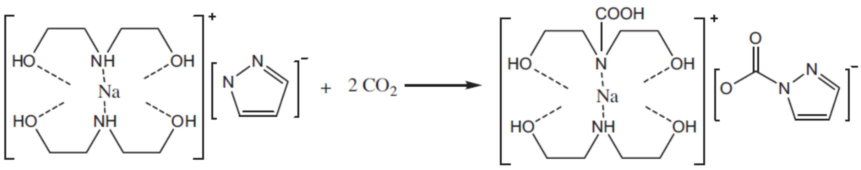
- On the gasification part, we will have to successfully model the kinetics of biomass gasification in a char bed reactor. The laboratory has developed several models of biomass decomposition in semi-continuous or drop reactors. The use of this new type of reactor will require new developments.

- On the carbon dioxide capture part, once the capture medium is chosen, it will be necessary to estimate the absorption kinetics of this solvent. The laboratory has two units to study the kinetics (a lewis cell and a packed column). These devices will have to be adapted to carry out measurements in a higher temperature range.

- The implementation of the whole unit: gasification/WGRS/Capture is the last part. It will be necessary to make the temperature and flow characteristics of each unit compatible to obtain a unit operating continuously.

The development of a process with a negative carbon balance (globally the unit will capture CO_2) and producing syngas with a high calorific value rich in hydrogen is completely in phase with the development of the hydrogen sector.

The scientific scope concerning the coupling of bioenergy/(capture and storage/valorization of CO_2) is still confidential. If the focus is now put on the experimental approach, it must be noted that the scientific production is then very confidential. To our knowledge, the configuration considered in this project based on the use of a biomass gasification reactor (with char as bed material and CO_2 as oxidation agent) coupled with a WGSR section and a CO_2 capture unit has not been treated in the literature. In terms of objectives, this project proposes a work that goes well beyond a simple coupling of the process by considering an energy integration and a material integration. The energetic integration will be obtained by trying to use CO_2 capture media that allow working at temperatures higher than the classical ones. For this, the properties of some ionic liquids combining a good affinity with carbon dioxide and a good temperature resistance will be used. We plan to work mainly with dual functionalized ionic liquids linked to alkanolamines (Qian, W et al., 2016) such as pyrazole coupled to diethanolamine.



Example of a CO_2 absorption scheme by a diethanolamine

From a material point of view, the originality of this work will be to use all or part of the captured CO_2 to participate in the gasification of the upstream biomass. This will be coupled with the char bed itself formed in situ by biomass decomposition.

Supervision:

For the successful execution of this thesis, three supervisors with competencies related to biomass gasification, catalyst characterization, process simulation and CO_2 absorption will be involved.

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Collaboration:

Collaboration with the University of Extremadura in Spain (IACYS institute) more particularly the development of new catalysts and their characterization. Also, a collaboration with colleagues of the COBRA laboratory (INSA de Rouen, France) on the aspects of in-depth chemical analysis is expected.

Candidate:

The candidate must have a background in industrial chemistry. Skills in chemical and process modeling and basic knowledge of technical analysis are an advantage. Ideally, a candidate motivated for renewable energy and sensitive to global warming.

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