Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes the PhD subject and supervisor proposed by the French Polytech network of 14 university engineering schools. Please contact the PhD supervisor by email or Skype for further information regarding your application.

Supervisor information	
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Country	France

PhD information	
Title	Ex-situ biomethanation in the hydrogen storage, CO2 reuse and power-to-gas strategies
Main topics regards to CSC list (3 topics at maximum)	V-5. Energy of hydrogen and technology of hydrogen storage

Required skills in science and engineering	Chemical engineering, biochemical engineering

Subject description (two pages maximum)

CONTEXT
Methanation consists in the two following exothermic reactions: $CO_2+4 H_2 \rightarrow 2 H_2O + CH_4$ and $CO+3 H_2 \rightarrow H_2O+CH_4$. It can be driven through catalytic and biological processes. Catalytic methanation is carried out in the gas phase at high temperature (> 300°C) and high pressure (5–20 MPa). Although catalytic methanation has been the subject of intensive research in the 20th century up to recently, technological and economic issues related to catalyst and dynamic operating conditions have are still to be solved. Thus, biological methanation (biomethanation) constitutes an attractive and environmental friendly alternative. This is based on hydrogenotrophic methanogens playing the role of a biocatalyst and convert the reactant gasses in a liquid medium. The biocatalyst consists of strictly anaerobic microbes of the Archaea domain, which usually drive the final step in the liquid or solid-state anaerobic digestion process. The optimal activity of the autotrophic methanogens ranges between 15°C and 98°C and low pressure (< 10 bars). While the production of methane by hydrogenotrophic methanogenic Archaea is a well-known natural process, research on biomethanation as an industrial process has been stimulated only recently. Biomethanation can use two technical pathways:

1. The first one is the direct injection of H_2 only into an anaerobic digester for biogas upgrading through the utilization of internally produced CO_2 (in-situ biomethanation).
2. The alternative is the direct conversion of H_2/CO_2 mixtures close to the stoichiometric ratio 4:1 in compact specific bioreactors using pure cultures of methanogens or mixed cultures from sewage sludge or from a working biogas plant, the so-called ex-situ biomethanation.

Ex-situ biomethanation is more flexible and can be adapted to a fluctuating H_2 production and any source of CO_2 (fumes…). Methane productivity in ex-situ methanation bioreactors is also high in comparison to methane produced from biogas upgrading in digesters. However, as it operates at lower temperature and pressure than catalytic methanation, biomethanation is slower and kinetically-limited, so that a process intensification strategy involving both the biocatalyst and the process (bioreactor technology, operating conditions…) is compulsory. In addition, the opportunity to implement biomethanation in H_2 storage, CO_2 reuse, and Power-to-Gas strategies is still to be explored:

1. An alternative to methanation is the direct injection of H_2 into the gas grid. However, the amount of H_2 in this gas grid is limited by country specific standards and regulations (< 6% in France). Thus, conversion to CH_4 offers a real synergy with existing gas grid.
2. The ex-situ biomethanation process can be envisioned as a substitute to CO_2 purifier using any CO_2 source, including e.g. clean coal combustion, by recycling the main greenhouse gas due to burning of fossil resource for energy storage.
3. Power-to-Gas (P2G) has emerged among the most attractive energy storage technologies. P2G links the power grid with a gas grid by converting excess power from renewable sources

(solar, wind…) into a grid-compatible gas, either hydrogen (Power-to-H2) through electrolysis, or methane (Power-to-CH4) by combining electrolysis and methanation. Biomethanation thus also emerges as a technology brick in P2G.

As a conclusion, the biomethanation process appears to be an attractive solution for simultaneous H2 energy storage and CO2 capture, in relation (or not) to the P2G strategy, but demonstration scale must still be reached.

PhD WORK

In this context, the aim of the PhD programme is to develop an intensified technology for ex-situ biomethanation process based on a bubble column bioreactor in terms of conversion yield and productivity. A pressurized bubble column facility designed from preliminary lab-scale experiments operated at atmospheric pressure in 2018 will be available in Institut Pascal (Clermont-Ferrand, France) in early 2019. The strategy will consist in combining a theoretical and an experimental multidisciplinary approach based on microbial ecology and microbial engineering in the field of anaerobic digestion on the one hand, and biochemical engineering and chemical engineering technology applied to anaerobic bioreactors on the other hand. In detail, the research objectives can be summarized as follows:

1. The acquisition of fundamental knowledge through the measurement of thermodynamic and transport properties of H2 and CH4 (solubility, diffusivity…) in typical biological environments of ex-situ systems as a function of operating temperature, pressure and pH;
2. The intensification of the biological processes by a screening strategy to identify the most efficient hydrogenotrophic methanogen species in pressurized cultures;
3. The optimization of the design of the bubble column facility (gas sparger…) and its operating conditions (temperature, pressure, gas flow rate, liquid recirculation flow rate…) through a process intensification strategy involving also the monitoring and, if necessary, the enrichment of the microbial consortium in mixed cultures in order to enhance gas-to-liquid mass transfer and reaction rates at the same time;
4. The development of a bioreactor model involving biological kinetics, gas-to-liquid mass transfer rate, and thermodynamic data, so that the design of a demonstration facility oriented towards H2 energy storage and CO2 capture could be proposed at the end of the PhD.

RESEARCH ENVIRONMENT

The work wil be carried out in the Chemical Engineering, Energy engineering and Biosystems research group (GePEB, staff 24, people 60) of Institut Pascal (staff 120, people 400) which deals with bioprocess engineering through a multi-scale approach where "process" characteristics are discussed with the aim of system modeling. In the last decade, GePEB has been involved in many national and international projects. From 2013 to 2016, GePEB has published 108 international papers, 27 books or book chapters, 95 conference papers. The PhD student will benefit from the presence of several high-skilled researchers (h-index > 20) in chemical technology, biochemical engineering, process modeling, thermodynamics and microbiology. The exploitation of this research will be conducted through attending international conferences, and scientific publications in international relevant journals of high standard, with the aim to promote the personal career development plans of the PhD fellow.