STUDY OF HYDRODYNAMICS AND LIQUID-GAS TRANSFERS IN A STIRRED TANK BIOREACTOR

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INTRODUCTION

CONTEXT: Biohydrogen production by dark fermentation

Besides its important use in the petroleum and chemical industries, hydrogen (H_2) is currently considered as an ideal energetic carrier due to its high energy content and environment-friendly conversion.

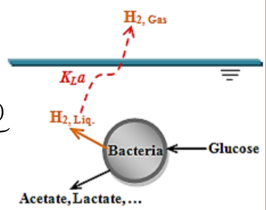
However, today's production technologies are largely dependent on non-renewable carbon-based resources. Hydrogen generation by microorganisms, biohydrogen, turns out therefore to be a more sustainable and cost-effective alternative.

Among the biological mechanisms, dark fermentation appears to be most favourable. This process uses anaerobic bacteria grown on various carbohydrate-rich substrates, such as organic wastes, without the need of light energy.

KEY FACTOR: Hydrogen liquid-gas mass transfer rate

The liquid phase is supersaturated in hydrogen which inhibits its own production. H_2 transfer is then the limiting step; it is usually described by the overall volumetric mass transfer coefficient $K_L a$ [h^{-1}]:

$$Q_{H_2} = K_L a \cdot \underbrace{\left(\overbrace{H_{2\,Liq}^{\rightleftharpoons}}^{Henry's\ Law:\ He\cdot H_{2\,Gas}} - H_{2\,Liq}\right)}_{Driving\ force}$$



- *Nature of the gas*
- *Physicochemical properties of the liquid*
- ***Hydrodynamics***
- *Operating conditions*

OBJECTIVES:

- **Characterization of hydrogen liquid-gas transfer according to agitation conditions**
  - ⇨ Spatial distribution of hydrodynamic and mixing quantities
  - ⇨ Spatiotemporal distribution of dissolved H_2 concentration
- **Simulation of the global performance of the process** by adding physiological and transfer kinetics to a developed hydrodynamic model *(in collaboration with the Walloon Centre of Industrial Biology - CWBI)*

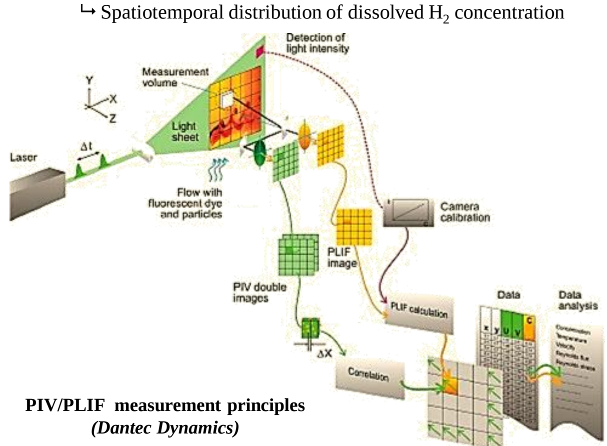
MATERIALS AND METHODS

BIOREACTOR: 20L standard stirred tank

- Scaling-up of 2L-bioreacteor used for fermentation experiments by the CWBI
  - ↳ Gradual modification of the agitation conditions (tank geometry, number and type of impellers …) to select the optimal configuration
- Transparent prototype for PIV and PLIF measurements

ADVANCED EXPERIMENTAL METHODS:

- **Particle Image Velocimetry (2D/3D - PIV)**
  - ⇨ Velocity fields (instantaneous and time-average)
    - ↳ Kinetic energy intensity fields
    - ↳ Shear stress fields
- **Planar Laser-Induced Fluorescence (PLIF)**
  - ⇨ Mixing time
  - ⇨ Spatiotemporal distribution of dissolved O_2 concentration
    - ↳ Spatiotemporal distribution of dissolved H_2 concentration



PIV/PLIF measurement principles
(Dantec Dynamics)

COMPUTATIONAL METHODS: Development of a model based on Euler-Lagrange approach

- Description of the scalar mixing process
  - ↳ Euler approach ⇨ Compartment model based on CFD data
- Description of the microorganism displacement
  - ↳ Lagrange approach ⇨ Stochastic model + Physiological and transfer kinetics

PRESENT PLANNING

PIV measurements:

- The first experiments are designed to get familiar with the technology and its aspects :
  - equipment
  - calibration methods
  - software
  - data analysis
  - results applications
- A first approach is PIV measurements and exploitation performed in an available bioreactor in geometric similarity with an anaerobic sludge bed reactor used during previous studies of the CWBI. The results provide then complementary information to define an optimal configuration and agitation.

Comparison between O_2 and H_2 transfer kinetics:

No technique allowing the determination of the dissolved hydrogen concentration field is currently available. It is then calculated from the measurements with oxygen, which is also a poorly soluble gas, while taking into account the difference of transfer kinetics :

$$(K_L a)_{H_2} = (K_L a)_{O_2} \cdot \left(\frac{D_{H_2}}{D_{O_2}}\right)^n$$

Dissolved H_2 and O_2 sensors are used to monitor their concentrations under the same conditions to check this analogy (estimation of n); the influence of the operating conditions (T°, P …) and physicochemical properties of the fermentation medium (viscosity, composition …) is studied in this way.