Port Hamiltonian systems : Introduction

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Personal introduction to Port Hamiltonian systems

Personal introduction to Port Hamiltonian systems

Hamiltonian formulation of bond graph models ?

At the First IFAC workshop NOLCOS, Capri, Italy June, 1989 discussion with Arjan around the version of the paper that I submitted:, "Geometrical formulation of the Bond– Graph dynamics with application to mechanisms", **Journal of the Franklin Institute**, vol. 328, No 5/ 6, pp. 723– 740, 1991.

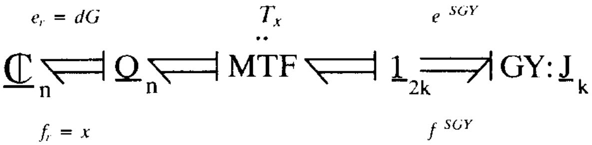


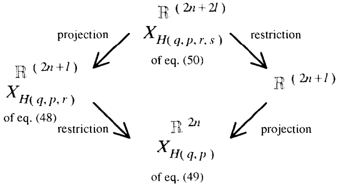
FIG. 6. A complete bond graph.

$$\begin{array}{ccccccccc} \mathcal{N} & \xrightarrow{dG} & T^*\mathcal{N} & \xrightarrow{T_x^*} & T^*\mathcal{M} & \xrightarrow{w^\#} & T\mathcal{M} & \xrightarrow{T_x} & T\mathcal{N} \\ x & \longmapsto & e_r = dG_x & \longmapsto & e^{SGY} & \longmapsto & f^{SGY} & \longmapsto & X_r = f_r \end{array}$$

FIG. 7. Diagram of the symplectic construction of the bond graph dynamics.

Hamiltonian formulation of network models : port Hamiltonian systems

- B. M. Maschke, A. J. van der Schaft and P. C. Breedveld, "An intrinsic Hamiltonian formulation of network dynamics: non– standard Poisson structures and gyrators", **Journal of the Franklin Institute**, Vol. 329, n. 5, pp. 923– 966,



DIAG. 1.

  1992
- B. M. Maschke, A. J. van der Schaft and P. C. Breedveld, "An intrinsic Hamiltonian formulation of the dynamics of LC–circuits", Trans. IEEE on Circuits and Systems, I : Fundamental Theory and Applications, Vol. 42, nº 2, pp. 73– 82, February 1995
- A.J. van der Schaft and B.M. Maschke, Port-Hamiltonian systems on graphs, **SIAM J. of Control and Optimization**, vol. 51, n°2, pp. 906-937, 2013

Port Hamiltonian systems

The fundamental conservation laws :

- mass
- momentum
- energy
- electric field induction
- magnetic field induction

coupled by closure relations :

- thermodynamic properties
- reversible and irreversible laws of fluxes

Complex systems are obtained by coupling through geometric boundaries, multiphase systems, multilevel systems

Systems of balance equations on

- continuous spatial domains : infinite-dimensional Port Hamiltonian systems
- discrete spatial domains: port Hamiltonian systems defined on k-complexes and networks

Some examples of Port Hamiltonian models

Some examples of Port Hamiltonian

Pressure swing adsorption process : scheme

Is constituted by:

- a column packed with
- bidispersed particules of adsorbants
  macroporous binder of
- small microporous crystals

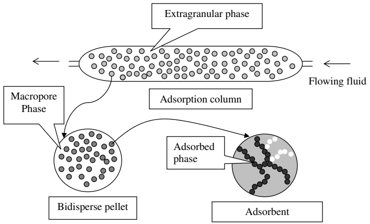
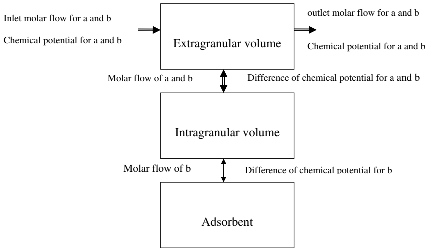


Figure: Schematic representation of a column a), packed with absorbent pellets b), themselves constituted by crystals c), associated with the three scales

Pressure swing adsorption process : 3 level model

It is represented by 3-level mathematical model:

- a fluid flow dynamics at the column scale
- diffusion phenomena at the macroporous medium scale
- diffusion phenomena at the microporous medium scale



Pressure swing adsorption process : 2 scale diffusion

Dispersed two-phase heterogeneous mixture with component α and β.

The β-phase is dispersed in the α one.

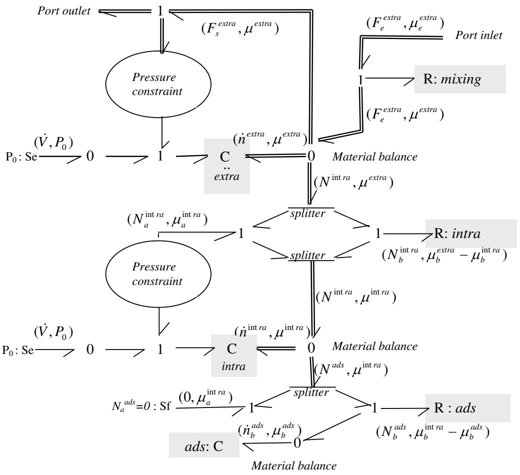
Assume there is a volume v_α, characterized by a length L_α, for the α-phase for which:

$$\lambda_\alpha << L_\alpha << \Lambda_\alpha \text{ and } \Lambda_\beta \sim \lambda_\alpha, \tag{1}$$

where:

- λ_i is the distance over which ϕ_i varies significantly
- Λ_i is the characteristic length of the i-phase

Pressure swing adsorption process:mass transport model



Application to the identification of diffusion parameters

The experimental set-up of LAGEP :

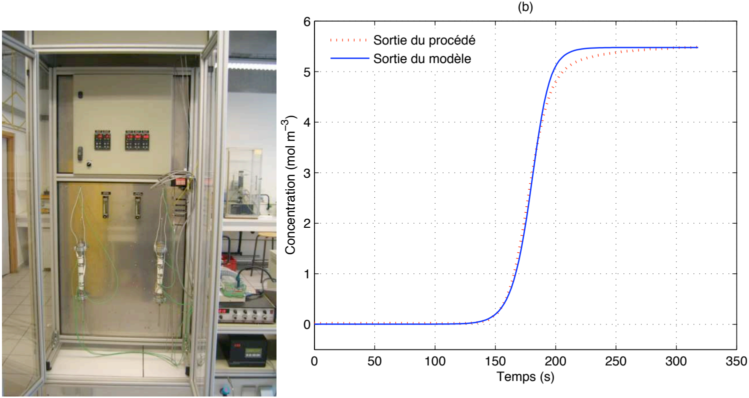


Figure: Pressure Swing Adsoprtion Process of LAGEP

Model of a microchannel

Model of a microchannel

A 1-D model of fluid flow: shallow water equations

One-dimensional fluid flow: the shallow water equation

- state variables: $x(t) = \begin{pmatrix} p \\ q \end{pmatrix} \begin{array}{l} \text{momentum} \\ \text{section area of the water} \end{array}$
- total energy : $H_0(p,q) = \frac{1}{2}\int_a^b \frac{\rho g}{W} q^2 + \frac{1}{\rho} q p^2 \, dz$
- co-energy variables :
  $$\frac{\delta H_0}{\delta x} = \begin{pmatrix} \frac{qp}{\rho} \\ \frac{p^2}{2\rho} + \frac{\rho g}{W} q \end{pmatrix} \begin{array}{l} \text{volumic flow} \\ \text{hydrodynamic pressure} \end{array}$$
- Port Hamiltonian systems w.r.t. canonical Stokes-Dirac structure

Shallow water equations : control design

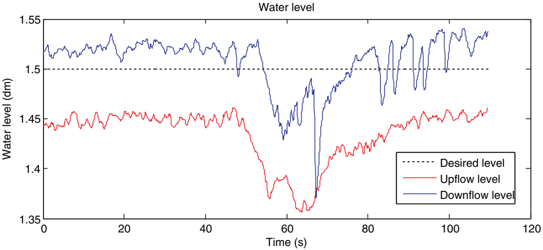
- The control acts through motion of the gates : inversion of the weir equation
- The control design is to "shaping the energy in closed-loop" by using Casimir functions :
  - the total volume
  - the total kinetic momentum

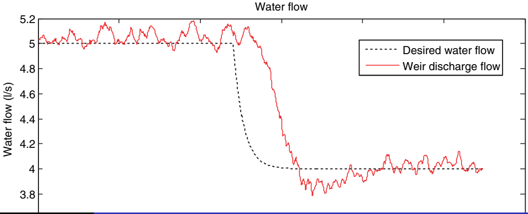
Controller :

- The feed-forward action shapes the energy of the system and stabilizes the total volume and momentum of the system
- the feedback action introduce a proportional correction for the closed loop (shaping the Dirac structure)
- an integral action is added

Shallow water equations : experimental results

Microchannel of ESISAR (Valence)





Ionic polymer metal composite *(IPMC) [Nishida, Takagi]*

ionic polymer metal composite

Ionic polymer metal composite *(IPMC)*

A polyelectrolyte gel (*electro-active polymers* (EAPs)) between metal electrodes

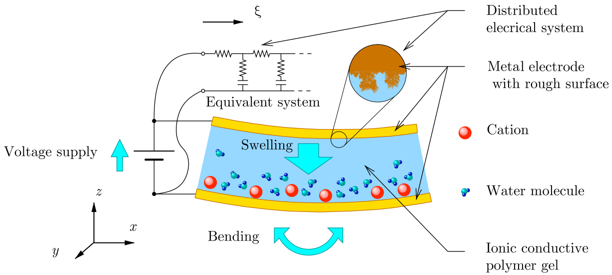


Fig. 2. Physical structure of IPMC.

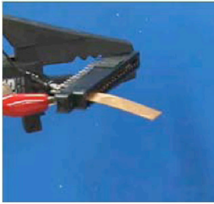


Fig. 1. IPMC (left:

The IPMC : physical phenomena

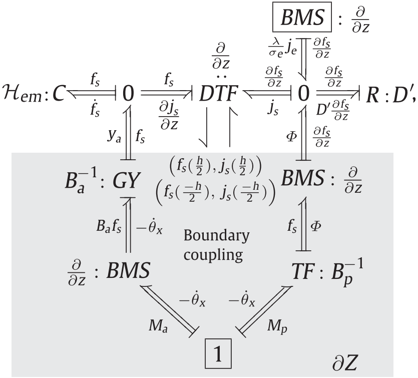
Model is the coupling of physical phenomena at three spatial scales

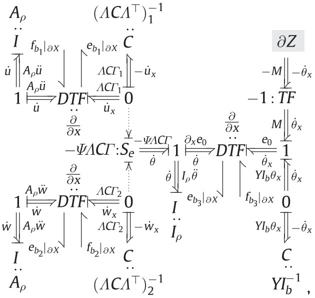
- the electric double layer on the interface between the polymer and the metal electrodes: spatial scale is of the order of nanometers, and the time constant is about 0.001 [s](Na^+) -1 [s](TEA^+)
- the electro-stress diffusion coupling with bending and relaxation dynamics that describe polyelectrolyte gels: scale of 100 [μm], and their time constant is about 1 [s](Na^+) -100 [s](TEA^+)
- large mechnical deformations : beam model: scale is 10 [cm], and their time constant is about 0.03 [s].

Boundary Port Hamiltonian system: conservation laws coupled by interface relations on pairs of extensive-intensive variables.

The IPMC : bond graph

Bond graph submodels





Experimental results: setup

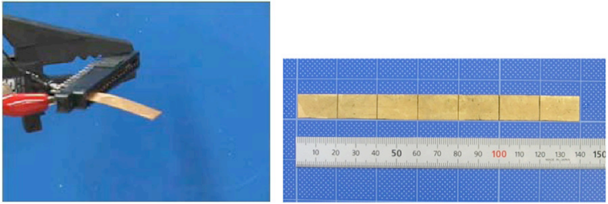


Fig. 1. IPMC (left: actuation with power supply, right: dimensions).

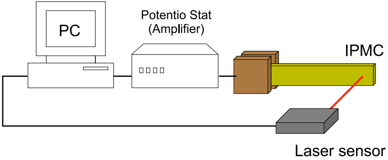


Fig. 4. Experimental setup.

Experimental conditions

- The IPMC sample was made of Nafion117 (DuPont Inc.).
- The two faces in the xy-plane of the IPMC were plated with gold Au five times.
- The dimensions of the IPMC were 45 [mm] length L, 5 [mm] width b, and about 0.20 [mm] membrane thickness h.
- The deflection w at about 35 [mm] from the fixed end was measured with a laser displacement meter.
- The IPMC actuator was operated in air. In order to hydrate the IPMC sufficiently, we used a pipette for dropping deionized water during the experiment. The excess water was wiped by a disposable nonwoven fabric.
- The counterions were exchanged by soaking the sample in 0.1 [mol/l] NaOH solution or 0.2 [mol/l] TEA-Cl solution for more than 12 hours.

Experimental results: parameters

Table 1
Physical parameters (Bar-Cohen, 2004; Yamaue et al., 2005).

	Na^+	TEA^+
z	1	1
c (/m^3)	2.487×10^{27} (4.131 mol/l)	3.228×10^{27} (5.363 mol/l)
q (C)	1.602×10^{-19}	1.602×10^{-19}
ϕ_p	0.7	0.7
a (nm)	0.164	0.260
ξ_b (nm)	0.96	0.88
ρ (g/cm^3)	1.633	1.633
Y (MPa)	90	90
ν	0.3	0.3

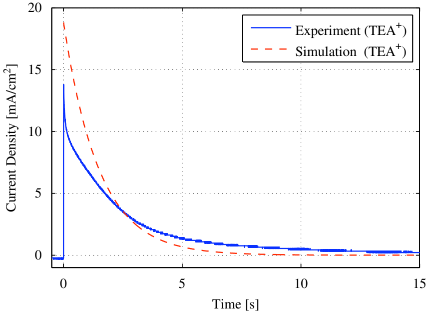
Table 2
Calculated parameters.

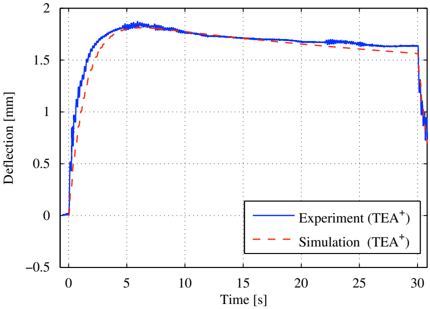
	Na^+	TEA^+
σ_e (Ω^{-1}/cm)	0.3334	0.3274
λ	9.654×10^{-9}	16.60×10^{-9}
κ	5.487×10^{-18}	8.530×10^{-18}
D'	3.262×10^{-10}	1.375×10^{-11}

Table 3
Identified parameters.

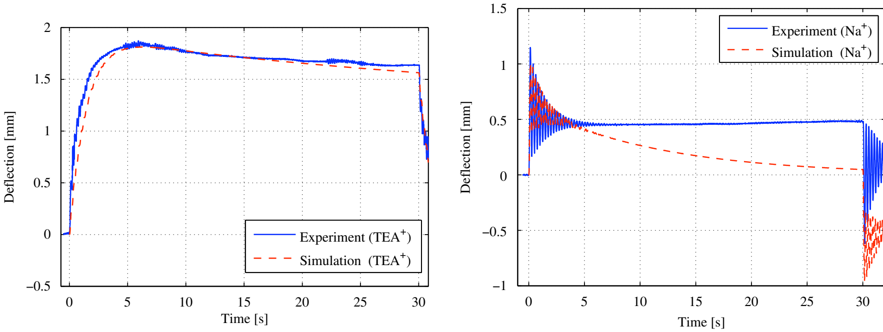
	τ_e (s)	R_m (Ω cm^2)	C_2 (mF/cm^2)
Na^+	0.0308	13.8	2.25
TEA^+	1.73	71.4	24.2

Experimental results: TEA+





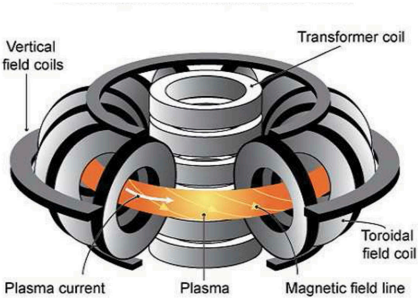
Experimental results: TEA+ versus Na+

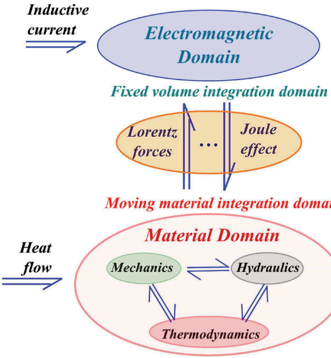


Tokamak : Thermo-Magneto- Hydro- dynamical model (Lefèvre and Vu)

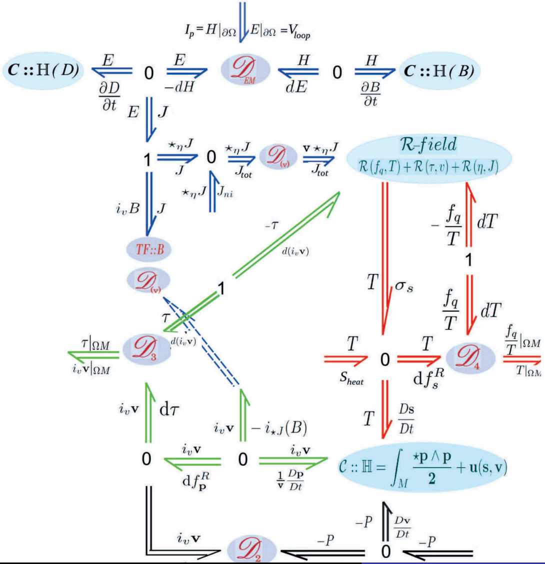
Thermo- Magneto- Hydro- dynamical model

Tokamak : word Bond graph

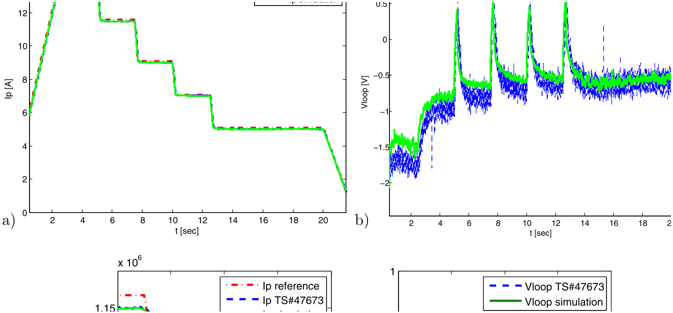




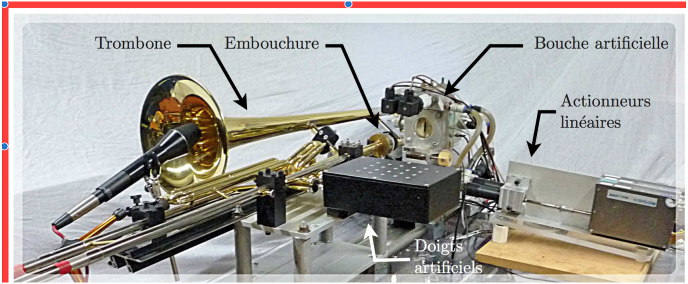
Tokamak : Bond graph

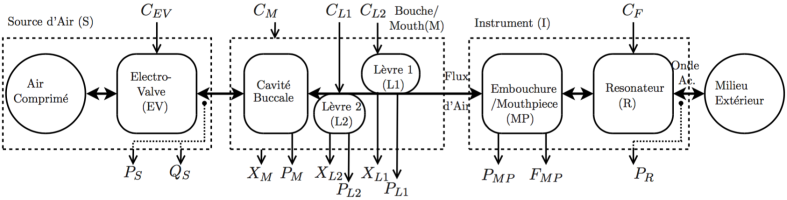


Tokamak : experimental results



Port Hamiltonian systems for a robotic system playing trombone [N. Lopes, IRCAM, Ph.D. defense 15 June 2016].



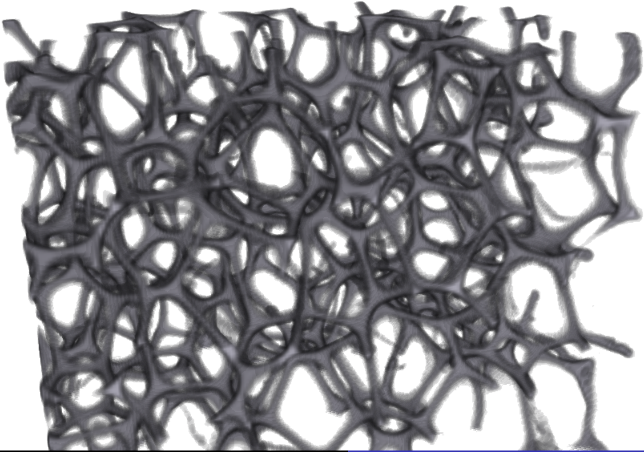


Heat and mass transfert in catalytic foams

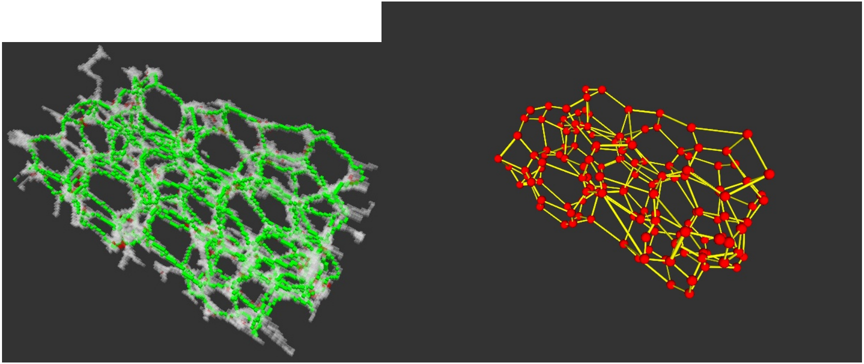
Heat and mass transfer in catalytic foams

Motivational example 1 : foam structures for catalytic reactors

1. Continuous material with high porosity avoiding pressure loss and enhancing solide ffective heat conductivity in reactors .



Foams : from X-Ray tomograph to Graph representation



Pic

obtained by Pierre Gueth (LIRIS) and David Coeurjoly (LIRIS), Foam pieces experimented and provided by Marie-Line Zanota (LGPC) and Isabelle Pitault (LAGEP) during the ANR DIGITALFOAM project (2013-2015)

Foam structures : test banks

Mass, energy and momentum balance equations

1. Chemical Engineering pathway :
   1. Consider the packing as an isotropic media
   2. estimate state and parameters
      fails for highly exo-(endo-)thermic reactors
2. Fluid Mechanics" pathway :
   1. discretization of balance equations over meshing
   2. extreme refinement of meshing at contact points
      fails to simulate complete bed and pressure drop

From 60.10^6 to 700.10^6 PDEs for "solid" phases and 6.10^6 and 70.10^6 PDEs for