



HAL
open science

Soft sensors for a batch crystallization process

Lucas Brivadis, Vincent Andrieu, E Chabanon, E. Gagnière, Nouredine
Lebaz, Ulysse Serres

► **To cite this version:**

Lucas Brivadis, Vincent Andrieu, E Chabanon, E. Gagnière, Nouredine Lebaz, et al.. Soft sensors for a batch crystallization process. Cristal 9, May 2019, Nancy, France. hal-02100158

HAL Id: hal-02100158

<https://hal.science/hal-02100158v1>

Submitted on 23 Jul 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Soft sensors for a batch crystallization process

Lucas Brivadis*, Vincent Andrieu, Élodie Chabanon, Émilie Gagnière, Noureddine Lebaz and Ulysse Serres

LAGEPP, CNRS UMR 5007, Université Claude Bernard Lyon 1, Lyon, France

* lucas.brivadis@univ-lyon1.fr

Introduction

- **Context:** During a batch crystallization process, the online control and estimation of the **Particle Size Distribution** (PSD) is critically important for the industry.
- **Problem:** No online sensor can measure the PSD.
- **Objective:** To build an online soft sensor that estimates the PSD, based on either the **solid concentration** or the **FBRM® technology**.
- **What is new?** No use of a nucleation model.

Model of the crystallization process

Hypothesis:

- $[t_0, t_1]$: Process duration.
- $[x_{\min}, x_{\max}]$: **Spherical crystals** radius range.
- $z(t, \cdot)$: PSD at time t .
- $G(t)$: **Growth kinetic** (McCabe hypothesis).
- $u(t)$: **Nucleation** at x_{\min} .

Population Balance Equation:

$$\begin{cases} \partial_t z(t, x) = -G(t) \partial_x z(t, x) \\ z(t_0, x) = z_0(x) \\ z(t, x_{\min}) = u(t). \end{cases}$$

Measurement : The solid concentration (up to some constant):

$$y(t) = \int_{x_{\min}}^{x_{\max}} z(t, x) x^3 dx.$$

How to estimate the state z from the measurement y ?

Luenberger original idea

Two steps strategy:

- 1 Estimate a function Tz of the state.
- 2 Invert this mapping T .

Designing an online soft sensor (Luenberger-like observer)

Step 1: Estimation of Tz . Consider, for $\lambda < 0$,

$$\dot{\zeta} = \lambda \zeta + y, \quad \zeta(t_0) = \zeta_0.$$

How to have $(\zeta - Tz) \xrightarrow{+\infty} 0$? It is sufficient to satisfy

$$\frac{dTz}{dt} = \lambda Tz + y.$$

For the solution a of some PDE, one can choose

$$Tz(t) = \int_{x_{\min}}^{x_{\max}} a(t, x) z(t, x) dx.$$

Step 2: Inversion of T ?

Tikhonov regularization method

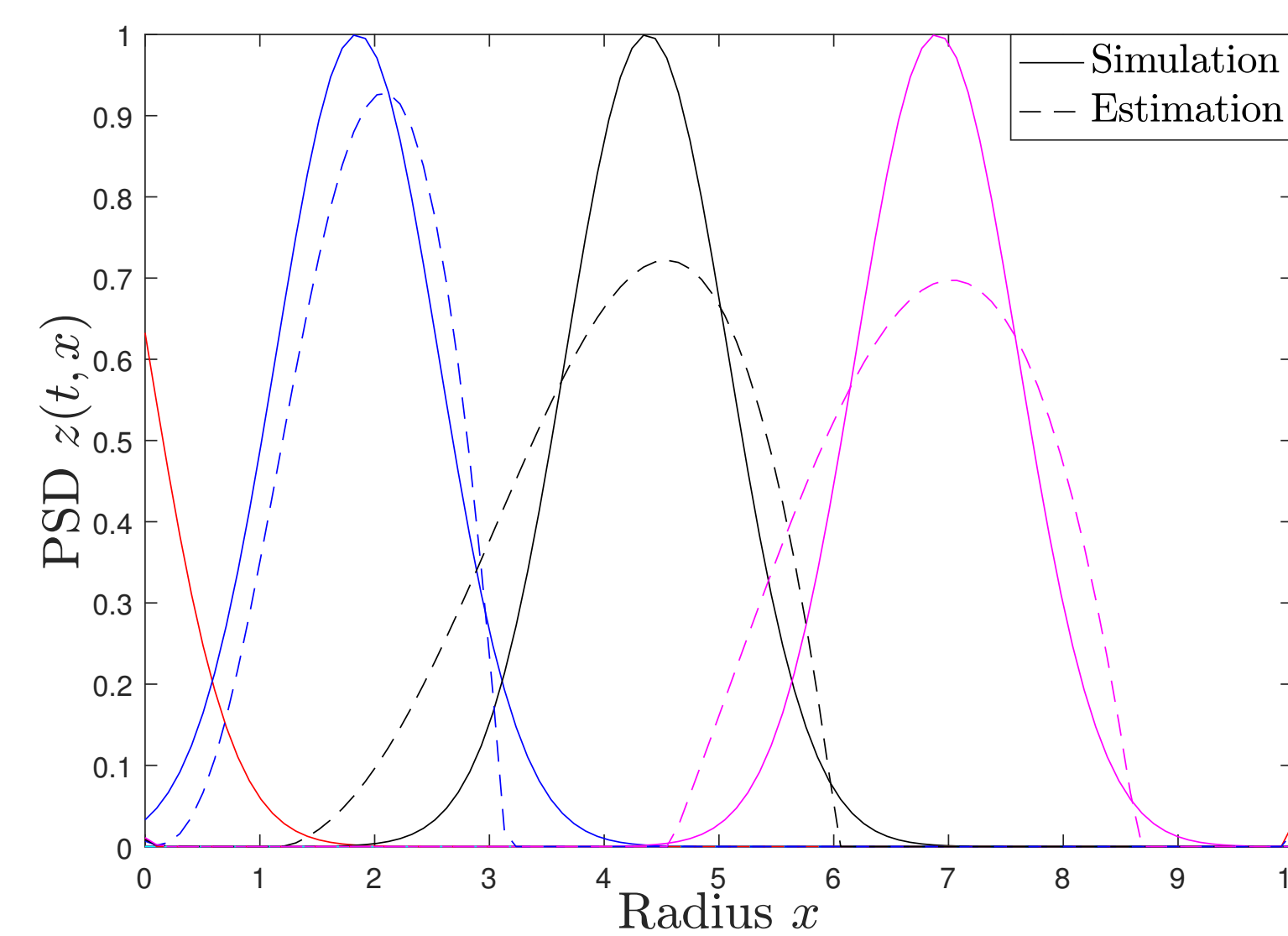
▪ **Problem:** Numerically estimate the solution of

$$\operatorname{argmin}_{\hat{z}(t)} \|T\hat{z}(t) - \zeta(t)\|_2^2$$

▪ **Idea:** Add a regularization term (**measure confidence**):

$$\operatorname{argmin}_{\hat{z}(t)} \|T\hat{z}(t) - \zeta(t)\|_2^2 + \delta^2 \|\hat{z}(t)\|_2^2$$

From solid concentration to PSD



Soft sensor based on the solid concentration with $\delta = 0.05$

Limits of the soft sensor:

- Need an estimation of the growth kinetic G .
- Choice of δ .
- Proof that y is not sufficient to determine z uniquely (**no injectivity**).
- Need a new physical sensor.

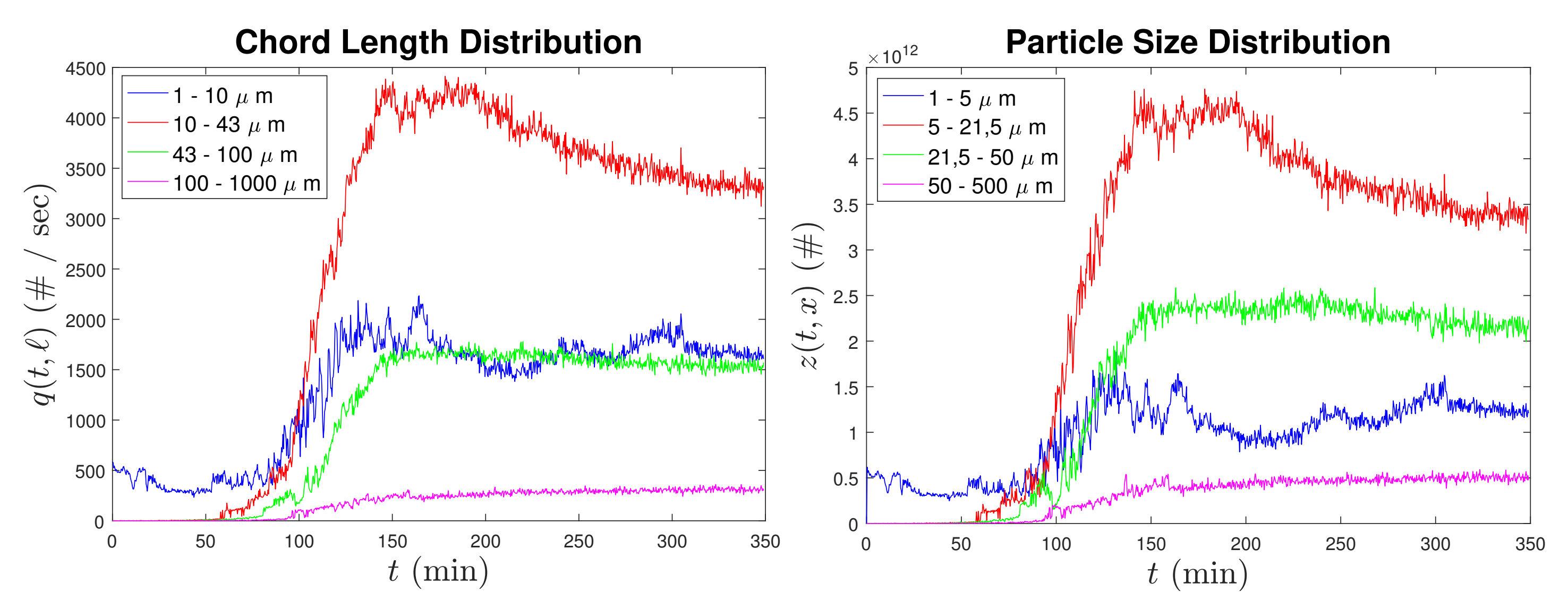
Model of the FBRM® technology

The probe uses a focused laser beam that scans across the particles. We model the measure as the **Chord Length Distribution** (CLD):

$$q(t, \ell) = C \int_{x_{\min}}^{x_{\max}} k(\ell, x) z(t, x) dx.$$

- $k(\ell, x)$ can be determined through a probabilistic analysis.
- C is an unknown constant. The solid concentration can be used to estimate C .
- One can apply the Tikhonov method directly on q , without using a soft sensor.
- Proof that q is sufficient to determine z uniquely (**injectivity**).

From CLD to PSD



Conclusion

- We propose two new soft sensors for the online estimation of the PSD in a batch crystallization process.
- The first one is based only on the solid concentration. This method has been tested on simulations. For better results, we prove that a new sensor is required.
- The second one is based on a mathematical modeling of the FBRM® technology, and has been experimentally tested. It allows to reconstruct the PSD from the CLD, both numerically and theoretically.

References:

- [1] L. Brivadis, Rapport de stage de fin d'études, École Centrale de Lyon, LAGEPP, 2018.
- [2] V. Andrieu, L. Praly, SIAM J. Control and Optimization, Vol. 45, Issue 2, Pages 432-456, 2006.
- [3] Basile Ucheddu, Thèse, Université Claude Bernard Lyon 1, 2011.
- [4] M. Li, D. Wilkinson, Chemical Engineering Science, 60:3251-3265, 2005



Acknowledgments:

This work has been funded via the project PEPS CNRS ELTaCriB Défi INFINITI.