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Overview of process optimization in laundries

Outline

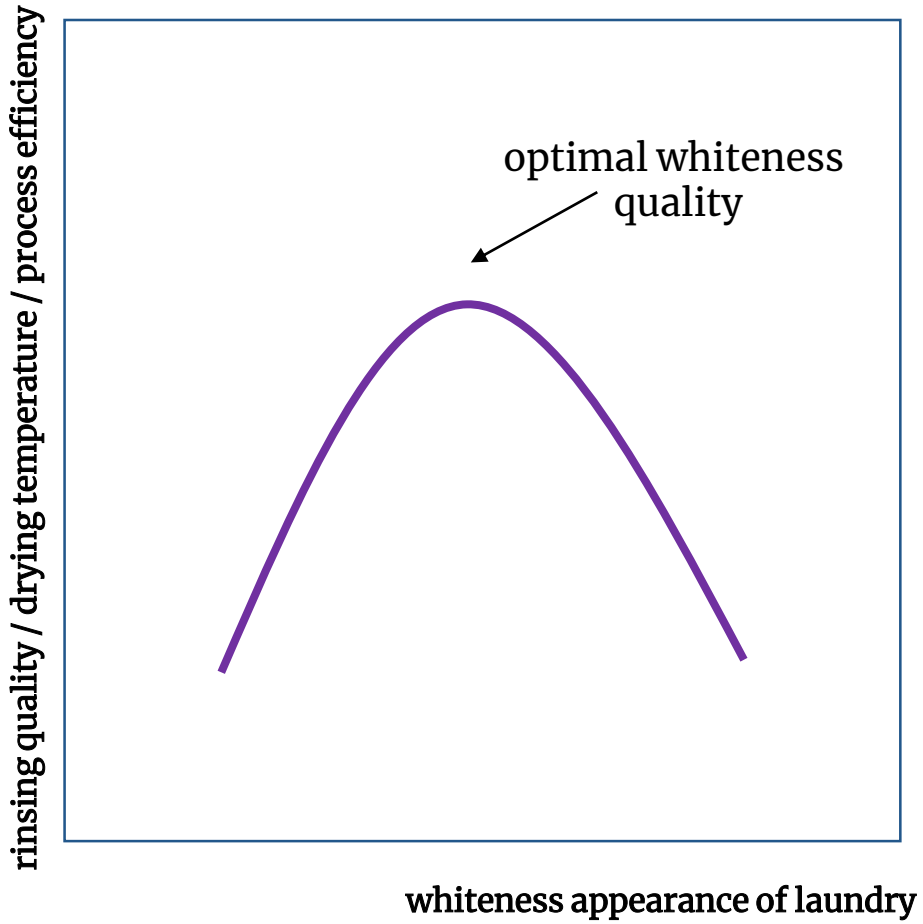
- What do we meant by optimal conditions?
- Workflow of optimization task
- Statistically planned optimization experiments
- Which tools may be used?
- How complex and cost-intensive are such projects?
- Application cases

Process optimization

- "A (laundry) process can be represented by some equations or perhaps solely by experimental data, e.g. titration protocols. You have a single performance criterion in mind such as minimum cost or minimum rewash rate. The goal of optimization is to find the values of the variables in the process (i.e. temperature, amount of detergents) that yield the best value of the performance criterion. The described factors-process or model and the performance criterion-constitute the optimization problem/task."

  derived from T.F. Edgar, D. M. Himmelsblau, L. S. Lasdon, Optimization of Chemical Processes, 2nd edition, **2001**.

- The optimization problem can also consists of questions like: At which process conditions the laundry operates in the most ***sustainable*** or the most ***quality-conscious*** way?



Optimization obstacles in laundries

- The optimization of laundry processes happens occasionally, because systematic investigations are lacking.
- **For example:** A plant for sorting of soiled linen was installed in the „anonymous“ laundry. Afterwards, the rewash rate, complaints and process inefficiency drastically increase. The laundry try empirically to adjust the chemistry and process workflow (e.g. additional draining step in the prewash process). After dosing enormous amount of peracetic acid and highly concentrated hydrogen peroxide as well as using additional draining steps, the process become more stable, but the laundry pieces still smelled bad.

  What do we learn? Non-systematical optimization leads only rarely to success as we not really understand the process optimization issues.

Optimization strategy

The six steps used to solve optimization problems

1. Analyze the process itself so that the process variables and specific characteristics of interest are defined; that is, make a list of all of the variables.
2. Determine the criterion for optimization, and specify the objective function in terms of the variables defined in step 1 together with coefficients. This step provides the performance model (sometimes called the economic model when appropriate).
3. Using mathematical expressions, develop a valid process or equipment model that relates the input–output variables of the process and associated coefficients. Include both equality and inequality constraints. Use well-known physical principles (mass balances, energy balances), empirical relations, implicit concepts, and external restrictions. Identify the independent and dependent variables to get the number of degrees of freedom.
4. If the problem formulation is too large in scope:
   (a) break it up into manageable parts or
   (b) simplify the objective function and model
5. Apply a suitable optimization technique to the mathematical statement of the problem.
6. Check the answers, and examine the sensitivity of the result to changes in the coefficients in the problem and the assumptions.

T.F. Edgar, D. M. Himmelsblau, L. S. Lasdon, Optimization of Chemical Processes, 2nd edition, **2001**.

Different mathematical tools

- As you seen at the prior slide, the optimization tasks can be very complex from mathematical point of view
- Different mathematical tools exist to handle optimization problems, among others:

→ description of the process with mathematical equations and solving the optimization tasks with numerical solvers

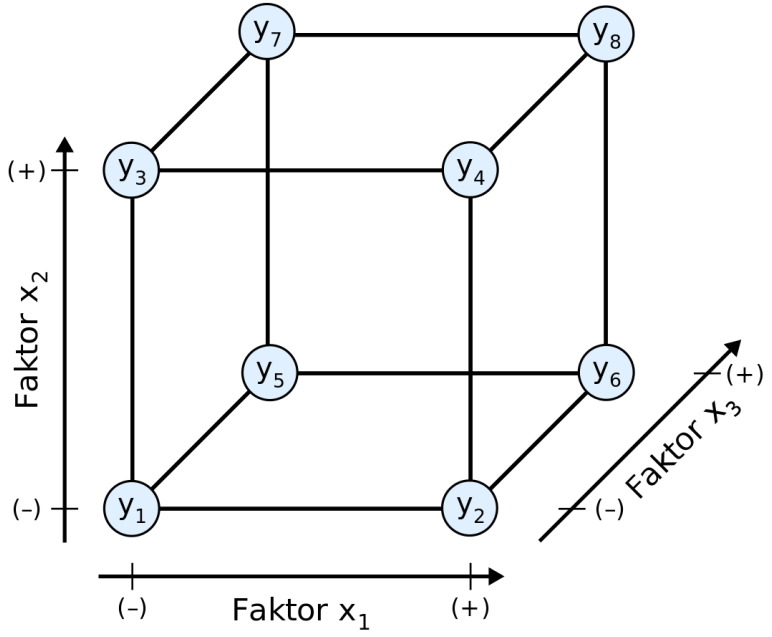
→ solving the optimization problem by using statistical evaluation tools;

we will focus on the last one as in our opinion it is more accessible for laundries

Utilization of „Design of Experiment (DOE)“ for solving optimization problems

- DOE uses statistical evaluation of certain number of experiments in order to find the optimal process conditions
- The optimization problems in laundry are less complex than in pharma or food industries (due to less harsh regulations)

  →Already with invest of <10.000 €, laundry staff engineers can use basics of DOE, what would be (in our opinion) enough to solve the most optimization issues

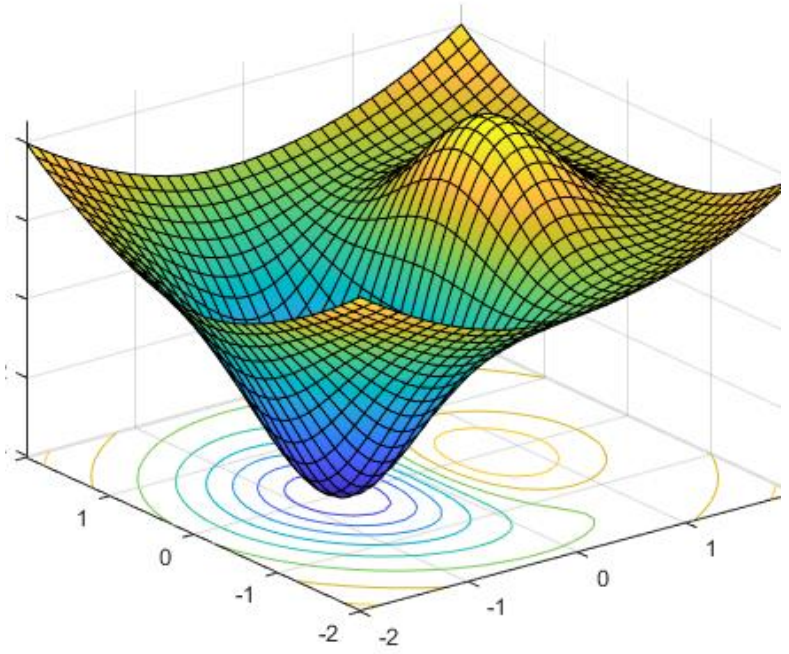


DOE: Full factorial screening design (https://de.wikipedia.org)

Novel screening designs

- Screening of parameters which should be chosen for subsequent optimization can be very time-consuming
  → this is one of the major reasons why this methods are not well accepted
- In this research field, several novel screening & optimization designs were proposed, which makes the work easier:
  → For example with **definitive screening design** one can carry out a screening with only few experiments, but even use this data for subsequent optimization tasks

C. P. Santos *et al.,* Design of Experiments: A comparison study from the non-expert user's perspective, Journal of Chemometrics, **2018**.



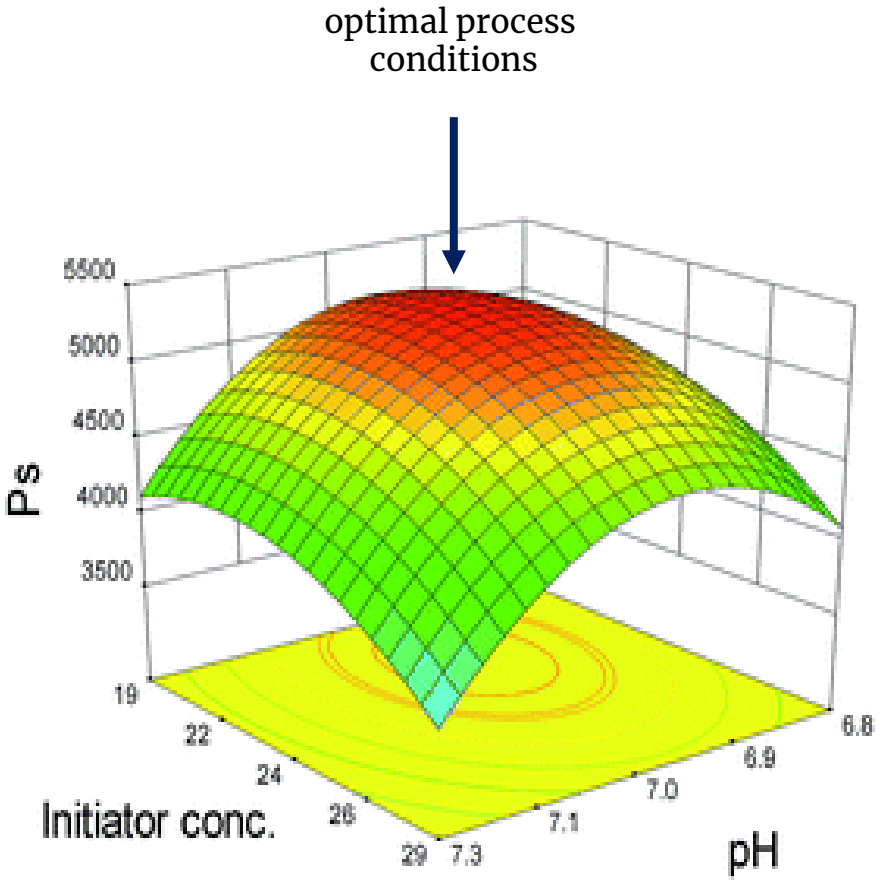
mathworks.com

2 important application cases for DOE

- After running several statistically planned experiments, one can derive different information:

→ screening which process parameters (factors) have statistical significant influence on value of interests (e.g. energy consumption); typically 3-20 parameters can be used in screening process

→ running several statistically planned experiments to find optimal conditions (for example see the study of B.S. Kaith *et al.* on the right)



B.S. Kaith *et al.*, RSC Adv.,4, 40339-40344, **2014**.

Learning R vs. using commercial tools

- Several commercial tools exist; Design Expert, JMP, MiniTab, which can handle nearly all DOE tasks
- With non-commercial programming language R is the handling of all DOE issues also possible
- Programming in R can be adapted to several optimization and process analytical tasks (e.g. combination of DOE and multivariate analysis)
- But not all functions presented in commercial software may easily be adapted in R language
- **For example:** Definitive Screening Design in R (daewr-package by John Lawson) can handle only 12 numerical 3-level parameters, whether commercial versions can handle >15 parameters

Further application cases related to laundry & textile industry

- Optimization of fabric manipulation during Pick/Place operations

  J.W. Eischen *et al.* International Journal of Clothing science and Technology, Vol. 5, **1993**.

- Data mining and machine learning in textile industry

  Yildirim *et al.,* WIREs Data Mining Knowl Discov, Vol. 8, **2018**.

- Optimization of load distribution in washing machines using bio-inspired computational methods

  Mahmud *et al.*, M.Sc. Thesis, Chalmers University of Technology, **2010**.

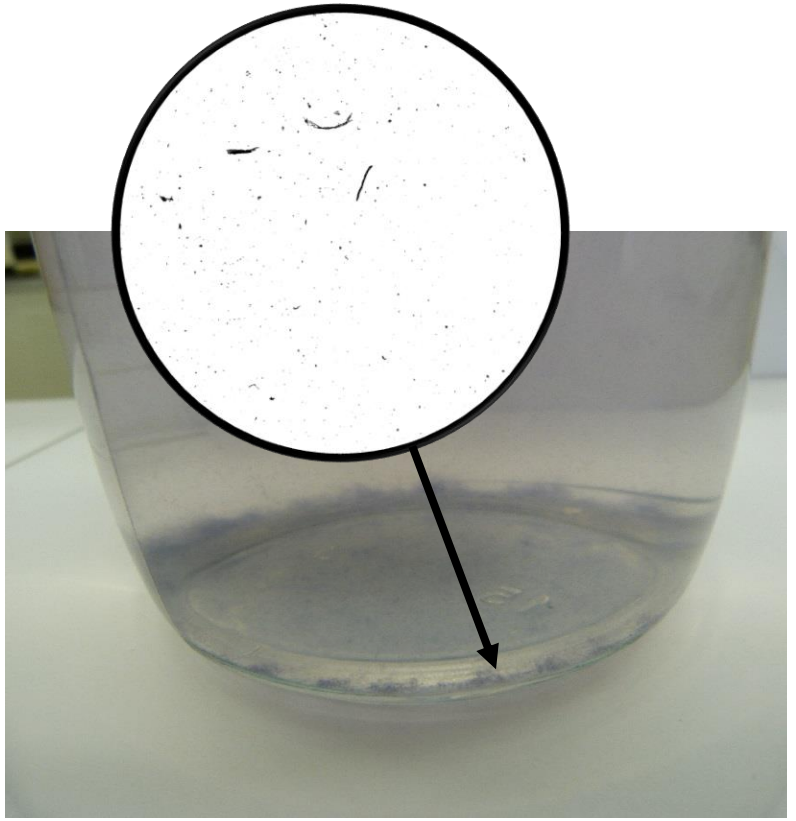
Example case: Fiber release in laundries

- Fiber released during different laundering steps (prewash, main wash and rinsing)
- The fiber release has mostly negative effect on:

→ increasing the load of organic pollutions in wastewater

→ Recovery of rinsing water for prewash and main wash processes: if the concentration of fiber particles is high, it could lead to inappropriate washing results

→ Via combination of novel “fiber release” detection methods (J. Haap, Water, 11(10), 2088, **2019**) and DOE the process can be understood and optimized



Screening of the fiber release during the washing process

Process parameters*	Unit	Level -1	Level 0	Level 1
Temperature	°C	40	60	80
Duration of washing process	min	30	60	90
Detergent concentration	g/l	0	2	4
Mechanics (number of metallic spheres)		0	50	100
Washing liquor to cotton fabric ratio		1:7	1:14	1:21

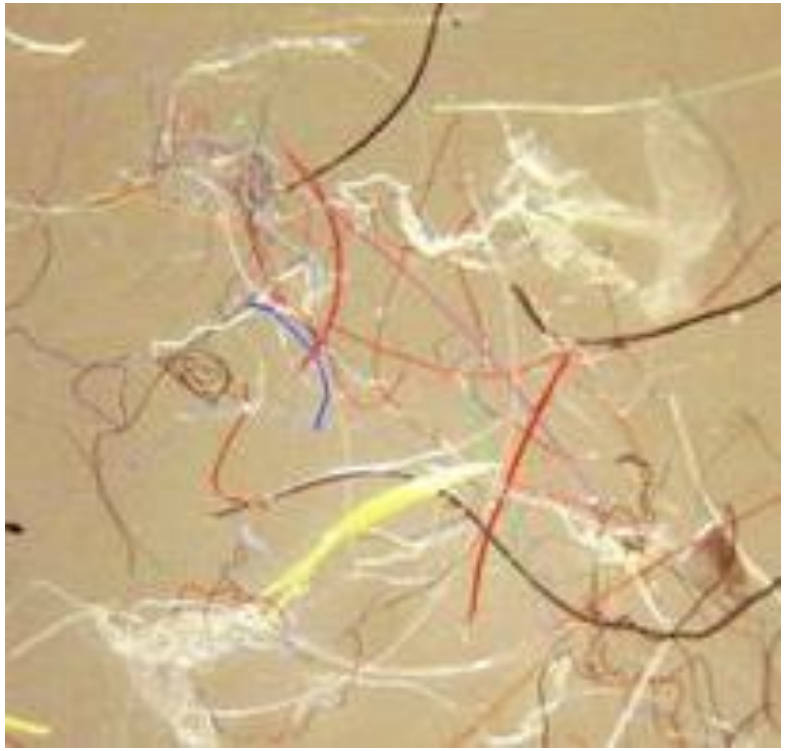
* Data were acquired in a lab washing machine

Jasmin Haap, Ph.D. thesis, Hohenstein, **2020**.

- Screening via DOE shows that e.g. an increase in ratio of washing liquor to fabric has no influence on the fiber release
- But an increasing mechanical stress in interaction with washing process duration have a statistically significant influence on the release of fibers

Optimization of fiber release in industrial laundries?

- Yet, the fiber release process is still investigated by different research groups, due to dramatic increase of plastic/microplastic pollution in hydrological cycle
- The systematic understanding of influence parameters of fiber rerelease and subsequent optimization of conditions at which only a minimum of fibers would be transmitted into the process would be highly beneficial



plasticoceanproject.org

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