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# CONTROL ENGINEERING IN DRYING TECHNOLOGY FROM 1979 TO 2005: REVIEW AND TRENDS

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# Outline

1. What are Online Control Tools useful for ?
2. Some Benefits previously obtained with Online Control Tools in Industrial Drying Technology
3. Some Basis for Control: keywords
4. Main Results of the Survey of 71 Papers dealing with Control in Drying Technology

# What are Online Control Tools useful for ?

Open questions during industrial drying operations are:

- How to always produce the desired properties/quality ?
- How to minimize off spec production induced by changes in some of the drying condition (set-points, feed characteristics or atmospheric conditions) ?
- How to optimize the cost of production: decrease the drying time and increase the energy efficiency ?

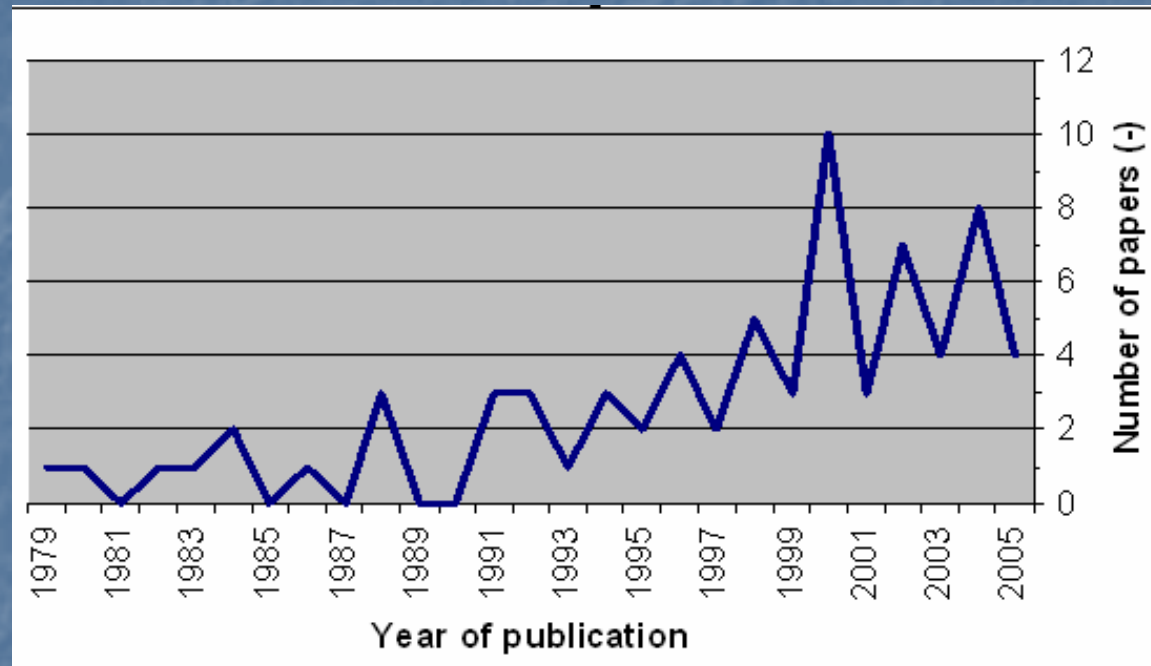
# What are Online Control Tools useful for ?

In control engineering, these open questions may be summarized as a single one:

- How to adjust some of the experimental drying conditions (manipulated variables) during the drying while achieving the specified performances (for the controlled variables) ?

Efficient solutions exist in control engineering and will be outlined in the next slides

# Number of publications dealing with control in drying versus the year of publications



39 % of the 71 papers were published in 19 years (1979 - 1997).

61 % of the 71 papers were published in the last 8 years (1998 - mid 2005)



Interest of papers dealing with control in drying engineering has increased since 1998.

# Some Benefits obtained with Online Control Tools in Industrial Drying Technology (1)

Applications	Drying cost	Energy consumption	Various
Grain dryer (Ryniecki and Nellist, 1991)	2.29 £/t to 1.52 £/t = -34%	Airflow : -30% Heater : -85%	
Grain dryer (Mc Farlane et al., 1996)	-1.3%	Fuel : -6%	Drying time : -18%
Beet sugar factory (CADDET, 2000)	-1.2% (- 18,900 £/year)	- 14,000 £/year	Off spec. production : From 11% to 4% Payback : 17 months
Rotary dryer (Iguaz et al., 2002)	-7%		Throughput : +1.4% = +105 845 US\$/year profit. Payback : 9 months <sub>6</sub>

# Some Benefits obtained with Online Control Tools in Industrial Drying Technology (2)

(Conclusion from previous table):

- (+) the use of control tools allows to:
  - to decrease off-specification production
  - to minimize drying time
  - to decrease energy consumption
  - to improve benefits
- (+) return on this investment is relatively short : < 1.5 years.



# Some Basis for Control: keywords

Questions to answer before starting a control study:

- What can be tuned ?:  
design variables (dryer dimensions, ...)  
or manipulated control variables (flow rates, cooling temperature)
- When is the value of the tuning variables calculated ?:  
Off-line control (open loop=before operation)  
or on-line control (closed loop=during operation)
- How is this value calculated ?  
Manual control  
or automatic control

In control engineering, "Online control" = automatic on-line tuning of the manipulated control variables.

# Some Basis for Control: keywords


Online control is based on a control target, which is either:

- Regulation: the controlled variables have to track as best as possible their respective constant set-point and with a minimum variability during the operation.
- Optimal behavior: minimize a dynamic criteria based on online measures + a model + constraints s.t.:
  - process limitations (e.g.: actuators magnitude have upper and lower bounds)
  - process safety (e.g.: a maximum temperature beyond which operation becomes hazardous)
  - process specification (e.g.: a maximum temperature beyond which final quality is too altered)

# Number of papers versus the type of control problems solved in drying and versus the years of publication

Years	Regulation	Optimal behavior
1979-1997	22 p=1.16 p/year	5 p=0.28 p/year
1998-2005	25 p=1.39 p/year	20 p=2.85 p/year

\*1.2      \*10 !!


 This underlines the recent needs to really optimize the dryer efficiency, which is today possible with still more efficient computer-based optimization control tools.

# Type of control tools used for regulation and optimal control in drying

Type of control tool	Regulation	Optimal behavior	Regulation + optimal behavior
Closed-loop optimal control	<u>15</u>	<u>16</u>	31
PID	<u>25</u>	1	26
Open-loop optimal control	4	<u>12</u>	16
Feed-forward	<u>15</u>	0	15
IMC	<u>4</u>	<u>6</u>	10
Fuzzy	<u>8</u>	0	8
Observer	2	<u>5</u>	7

# Type of control tools used for regulation and optimal control in drying

- Advanced optimal control algorithms like MPC, successfully used in the chemical industry since 30 years, are now also used in drying.
- The 60 year old PID control algorithm is still the main control tool used in drying for regulation issue: due to easy implementation and tuning, as well as its ability to lead to relatively good performances.

 Optimization of the drying conditions has recently become more important than regulation: indeed, optimization allows:

- improving final product quality
- and decreasing cost and energy consumption.

# Type of control tools used for regulation and optimal control in drying

- Fuzzy controller, usually based on data analysis, is a control algorithm used for regulation purpose but is not suitable for optimal control in drying.
- Observer is also an interesting tool, since it is a model based software sensor which aims at estimating unmeasured variables and unknown model parameters.

# Type of control tools used for regulation and optimal control in drying

- In drying, the effects of some disturbances over the controlled variable (e.g. the change in the moisture content of the product at the dryer inlet) is usually very strong in drying.

Feed-forward control is the basic control structure to handle such disturbances.

- Concerning Internal Model Control, it is a simple and powerful control structure that has the ability to correct errors due to modeling errors and uncertainty.

# Number of papers versus the type of model used in the control strategies versus the years of publication.

Control algorithm are based on a model:

- black-box models: very quick to obtain, basic and simple to use in a control strategy.
- first principle models: more accurate to model complex behavior, but usually more complex to obtain.

Years	Black-box	First principles
1979-1997	19 p=1 p/yr	<u>6 p=0.33 p/yr</u>
1998-2005	15 p =1.87 p/yr	<u>26 p=3.25 p/yr</u>

\*1.8                      \*10 !




Since 1998, more first principle models are used.



# Type of models used in the control tools in drying versus the control objective

Control objective	Black-box model	First principles model
Regulation	<u>28</u>	14
Optimal control	5	<u>18</u>

- Regulation: black-box models are more often use than complex but more accurate first principle models.
- Optimal drying conditions: an optimal controller usually based on a first principle model is preferred.

 Therefore, stronger production needs specified through the control objective requires the development of more accurate first principle models.

# Conclusions and perspectives

- 1979: use of control tools in drying started.
  - Since 1998: new trends based on optimal control.
  - Since 1998: joined development of optimal control and first principle model.
  - Use of modern control tools allows:
    - improving benefits,
    - decreasing the energy consumption and the off-specification production.
- Moreover, the return on this investment is relatively low.
- More first principle models are now needed !
  - 60 000 products dried + 100 dryer types: a real potential of new collaborations between control and drying communities exist to improve dryer efficiency !

Thank you  
for your attention

Much more details on this survey in:

Dufour P.,  
"Control Engineering in Drying Technology: Review and Trends"  
special issue of Drying Technology,  
on Progress in Drying technologies  
(5), 24(7), pp. 889 - 904, 2006.

Please: some questions ?

# Number of papers where control tools are used in drying and year of the first publication, both versus the type of applications domain

Application domain	Number of papers (percent)	Year of the first publication
Food	<u>66,1 %</u>	1983
Painting	8,5 %	<u>2002</u>
Pharmaceuticals	6,8 %	<u>1998</u>
Paper	6,8 %	<u>1996</u>
Wood	5,1 %	<u>1998</u>
Bio-cell	3,4 %	1992
Mineral	1,7 %	1994
Textile	1,7 %	2001

# Number of papers where control tools are used in drying and year of the first publication, both versus the type of applications domain

66.1 % of the control applications in drying deal with food:

- not a surprise, since food has a direct impact on daily life
- at least eight times more applications in food than in any other domain !

Since 1992, emerging applications have appeared in painting, pharmaceuticals, paper and wood applications. This also clearly underlines the real emergence of control in drying today.