Spray Dryer Digital Twin

Achieve production excellence with physical science-based digital twins
Sam Wilkinson – Strategy Director F&B, Siemens gPROMS
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Food & Beverage Industries

Today’s challenges and opportunities

- Empowered Consumers
- High Quality Demand and Cost Pressure
- Sustainability & Responsibility
- Emerging Markets and Global Setup
The F&B Industry is evolving again to meet these challenges

Process automation & optimisation is one of the biggest focus areas for innovation by food manufacturers, with 73% of manufacturers investing in the area

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<tbody>
<tr>
<td>Mechanization, water power</td>
<td>Mass production, assembly line, electricity</td>
<td>Computer and automation</td>
<td>Cyber Physical Systems</td>
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How organizations are affected by the current challenges in the food and beverage industry

**STATUS QUO IS INSUFFICIENT**

to achieve production excellence in a rapidly changing market
due to the high degree of (manual) iteration in the innovation process across the food & beverage lifecycle

**DIGITAL TRANSFORMATION**
is required to achieve business objectives
Our mission for food & beverage

“Achieve production excellence for a sustainable future”

through the rapid configuration, calibration and deployment of science-based, data-calibrated digital twins
gPROMS – The Benefit of a Single Integrated Environment

Providing a unified approach to digital design and digital operations

Digital Design
Desktop and web tools for true digital design

Digital Operations
Model-based applications for real-time operations decision support

Accelerated innovation. Optimized process designs. Reduced experimentation.


R & D

Data analysis, experiment design

Conceptual process design

Catalyst design and analysis

Engineering Design

Front-end engineering design (FEED)

Detailed equipment design

Process optimization

CONTROL DESIGN

Virtual commissioning

Operating policy

Operator training

Operations decision support

Operations

Long-term health monitoring

Soft sensing

Real-time optimization

Run length prediction

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Designing crystallizer modifications resulting in a **25% increase in filtration capacity**

Siemens’ spray dryer optimizer enabled a **5% product moisture uplift** and **30% product variation reduction** above existing APC solution.

Significantly **reduced time and cost** required for experimentation and **minimised the risk** associated with **scale-up** of mills.

**Optimisation of the batch recipe** for pharma-grade lactose to **reduce time by 44%**

Delivering value to the F&B Industries

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Working towards our mission with the food & beverage industry
Siemens’ co-creation ecosystem

Food Centre of Excellence

Food Advisory Board: coordination, & industry adoption

SPSE experience in, and developments for, other industry sectors

Tools & Workflows

Collaborative R&D
Digital Twins for the Dairy Industry
Dairy Manufacturing Applications

- Troubleshooting
- Monitor operating envelope
- Predict product attributes
- Enable real-time optimisation

**MULTI-STAGE DRYING**
Maximise drying capacity & throughput
Reduce fouling due to stickiness

**CRYSTALLIZATION**
Meet product quality attributes
Reduce batch time

**MEMBRANE FILTRATION**
Reduce fouling & maximise throughput
Optimize configuration & control strategies

**HEAT TREATMENT**
Ensure product safety
Increase product quality

**FALLING FILM EVAPORATORS**
Avoid product fouling in evaporator tubes
Reduce energy consumption

**SEMI-HARD CHEESE MANUFACTURING**
Troubleshoot process interruptions
Maximise batch yields

**Dairy Manufacturing Applications**

- **Monitor operating envelope**
- **Predict product attributes**
- **Enable real-time optimisation**
Spray Drying Process Models – Overview

- The spray drying model library can be used for single-stage and multi-stage dryers with internal and/or external fluid beds
- Models for cyclones, bag filter units etc. are also available to complete flowsheets
- The models are frequently used in the dairy industry for troubleshooting and optimisation purposes:
  - For example, the model can capture particle drying and product stickiness, helping users identify optimal operating conditions to ensure product quality and desired drying capacity

- **Spray drying library features the following:**
  - Equilibrium based spray dryer
  - Kinetic based spray dryer
  - External fluid bed dryer
  - Cyclone, baghouse etc.
Drying – sorption isotherm

- Sorption isotherm is **key** to a successful drying model
  - It defines the equilibrium moisture that can be achieved at the conditions
  - Typically measured using DVS (Dynamic Vapour Sorption)
    - Chamber with controlled environment, set humidity, measure change in mass
    - Typically want the ‘desorption’ curve
  - Experimental data can be fit to GAB isotherm
  - Does temperature matter?
    - Yes, they can be temperature dependent
      - But typically measured at 25°C
    - Isotherms at multiple temperatures can be entered
Near equilibrium calculation

\[ X_{po} = X_{ao} + \Delta X \]

- At equilibrium, \( \Delta X = 0 \)
- Equilibrium is not always reached due to atomization and residence time effects, hence near equilibrium can be considered
- For a given product and a given spray dryer, the difference from equilibrium is a function of dry solid content of feed, as this influences the atomization behaviour

\[ \Delta X = A_x \left( D S_c - D S_{c,ref} \right) + B_x \]

\( X_{po} \) – equilibrium moisture content of outlet dry air (kg/kg)
\( X_{ao} \) – moisture content of outlet dry air (kg/kg)
\( \Delta X \) – difference from equilibrium (kg/kg)

\( A_x, B_x \) – product and dryer dependent parameters
\( D S_c \) – dry solids content of feed (kg/kg)
\( D S_{c,ref} \) – reference dry solids content of feed (kg/kg)
Internal fluid bed

- Internal fluid bed (IFB) can have an additional inlet air flow that passes through the bed and is mixed with the air in spray drying chamber.

- The overall model is flexible and can be configured to include the IFB as a separate compartment.

- Alternatively, the IFB compartment can be excluded for either:
  - Non-IFB spray dryer installations
  - Model simplification
Material characterisation – glass transition temperature, $T_g$

- **What is a glass?**
  - Mechanical properties of a solid but structural arrangement of a liquid
  - Meta-stable amorphous solid
  - Contains water that may be exchanged with the surroundings and acts as a matrix plasticiser
- **Glass transition**
  - Temperature at which material goes from a solid glass to a visco-elastic rubber
  - Can be described using Gordon-Taylor or other expression
  - Indicator of stickiness, leading to several operational problems such as fouling and unwanted agglomeration
  - Therefore, it is important to operate below the stickiness temperature curve particularly in dairy industry as feeds that are high in lactose are prone to sticking

G. Vuataz, *The phase diagram of milk: a new tool for optimising the drying process*, *Lait* 82 (2002), 485-500, Fig. 12
Spray Dryer Digital Twin Use Case
Spray drying is a method of producing a dry powder from a liquid or slurry by rapidly drying with a hot air.
Spray Drying
Why is it important?

Is it the correct decision to change the parameter?

How can I overcome the rapidly changing market requirements?

How can I save our resources?
Spray drying in dairy today
Why is it important?

Increase Productivity
Support operator decisions

More Flexibility
Overcome rapidly changing market requirements

Reduce Cost
Save our resources
Key questions in spray drying

How can I increase the moisture content in the powder?
By reducing variability in the process and operating at conditions that bring the powder moisture closer to the upper limit.

How can I avoid downtime due to caking?
By reducing variability in the process and operating in a safe region where the powder does not become sticky.

How can factory trials be reduced?
By capturing deep process knowledge to accelerate determination of optimal operating parameters for new product introductions.

How can the throughput be increased?
By operating under the best conditions possible, subject to product and process constraints.

How can I save energy?
By running the spray dryer closer to the powder moisture specification, typically the drying temperature can be reduced and therefore energy savings can be achieved.
Example pain points and loss

- **Over drying of product beyond upper limit**
  - 0.5 wt.%
  - €650 k per annum operating loss

- **Inefficient energy usage (over drying etc.)**
  - up to 10% total usage
  - €50 k per annum operating loss

- **Lost throughput opportunity during peak milk**
  - up to 10% additional for 2 – 3 months
  - €200 k per annum lost revenue

- **Variations in product moisture**
  - +/-20 – 30%

- **Additional factory trials to introduce new products**
  - 1 – 2 per annum
  - €100 k per annum operating loss

- **Unplanned stoppages (blockage etc.)**
  - 2 days per annum
  - €100 k per annum operating loss

**EXAMPLE**
7.5 te/h product multi-stage dryer producing dairy products operated **without** support of process digital twins (e.g., APC, operator decision support etc.)

**In summary**
Over €1 m untapped productivity bonus per annum on a typical dairy spray dryer*

* Numbers based on following parameters: Product value 2500 EUR / te; Spray dryer throughput: 7.5te/h powder; Operating profit margin: 10%; 80% spray dryer utilization annually; 0.03 EUR / kWh gas cost
Our solution
Siemens Spray Dryer Optimizer

Increasing productivity bonus through increased integration

Operator process training
Operator decision support
Monitoring
Real-time optimization
Advanced Process Control

Siemens Spray Dryer Optimizer

Internet browser-based Independent of spray dryer
Integrated with DCS or SCADA/PLC with operator dashboard for monitoring

Underpinned by the same process digital twin for your spray dryer
Digital Process Twins
At the heart of spray dryer operation …

**CAPTURE DATA...**

**APPLY PHYSICAL SCIENCE-BASED MODEL**

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**Simulation**

**Optimization**

**Model calibration**

Performed offline with historical plant data to ensure accuracy

**Optimize**

Calculate optimal conditions to run the plant

**Soft sense**

Predict current values of unmeasured KPIs
Spray dryer optimization – How it works

**Challenges**
- Environmental parameters like humidity, air temperature, product parameters can influence product moisture content and therefore also the product quality

**Solution**
- Calculation of ideal process parameters in all situations
- Closed-loop implementation to continuously optimize production

**Benefits**
- Consistent product quality by maintaining ideal moisture content and output rate

**Improve Quality**

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### Challenges
- Environmental parameters like humidity, air temperature, product parameters can influence product moisture content and therefore also the product quality

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### Benefits
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Why physical science-based vs. data-driven or AI? – A customer perspective

We did look at data-driven modelling approaches, but the data scientists found it difficult to generate robust models as they were missing what happens inside the spray dryer. Whenever an existing product moved beyond the calibration boundary, or a new product was introduced, the model was not accurate anymore.

I think the benefit of the physical science-based model is that we calculate the mass and energy balances within the spray dryer and can properly predict the unit operation behavior.
The next generation of APC
Reducing variability and increasing performance

Siemens Spray Dryer Optimizer

Benefits compared to traditional APC systems:
- Reduces variability in powder moisture content
- Uplifts moisture (wt.%) closer towards the limit
- Prevents decay of performance over time as the models can better capture the complexity of spray drying

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<tr>
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<th>3.0% – Limit</th>
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<tbody>
<tr>
<td>Manual operation</td>
<td>2.8% – Average, Siemens’ optimizer</td>
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<tr>
<td>Traditional APC</td>
<td>2.6% – Average, Traditional APC</td>
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<tr>
<td>Siemens’ optimizer</td>
<td>2.3% – Average, Manual operation</td>
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Siemens spray dryer optimizer: A Danone case study

Customer Challenges
- Improve operating margins for infant formula manufacture:
  - Uplift product moisture
  - Reduce energy usage
- Achieve improvements for a large, evolving product portfolio

Our Solution
- Configure and calibrate physical science-based digital twin of spray drying process
- Deploy digital twin as a soft sensor on a plant within APC system
- Use for real time optimization and control

Customer Benefits
- 5% increase in product moisture content*
- 30% reduction in product moisture variability*
- Reduction in energy usage due to moisture uplift

ROI < 6 months

*Compared to previously employed data-driven APC at the factory
The next level of dryer improvement is determined by data and the ability to utilize software more effectively for its analysis.

**Extended spray dryer functionality**

with new advanced functionality for machine-related data collection, processing, storage & visualization for e.g., condition monitoring, alarm management.

**Remote Software and optimization Management**

Reduced time to market for spray dryer software during operations with centralized device-, application- & security management.

**IT-Integration**

Flexibility to integrate machine data into cloud and IT-systems of any kind for advanced analysis and optimization.
Thank You

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