THE NEED FOR ACCURATE MOISTURE MEASUREMENTS IN THE DRYING PROCES OF EXTRUDED FISH FEED

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- Industrial PhD Project
- Moisture measurements in fish feed
- A sensitivity analysis; accuracy of moisture measurements
- Modeling of the deep bed drying of extruded fish feed

Industrial PhD Project Group and collaborators

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WENGER®

ALLER AQUA

UNIVERSITY OF SOUTHERN DENMARK

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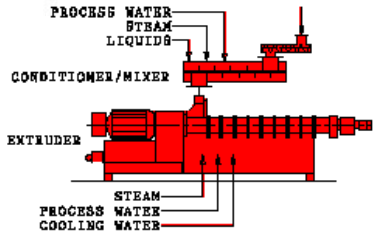
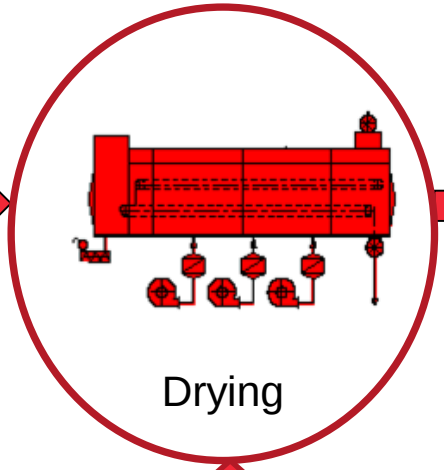
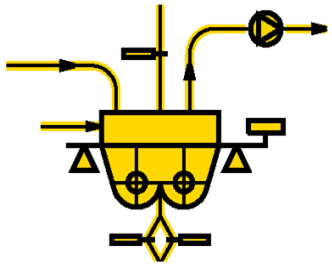
BACKGROUND



Extrusion

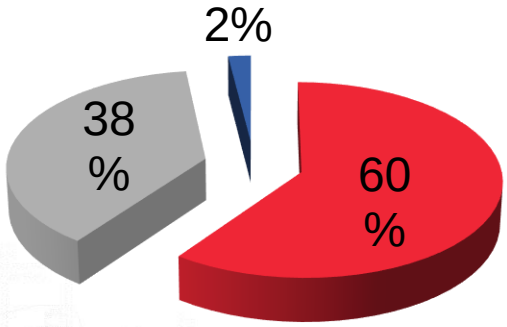


Drying



Coating

Thermal energy consumption



Technical Quality

- Density
- Mechanical durability
- Porosity
- Uniformity and surface

CONVENTIONAL DRYING EQUIPMENT

Horizontal belt dryers

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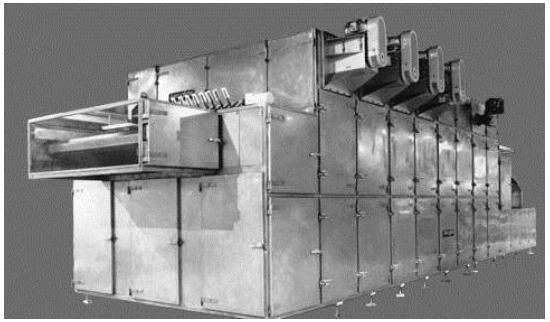
- **Several models with built-in heaters and fans**
- **2 – 4 stacked conveyor belts**
- **Perforated lamellas in SS or mild steel**

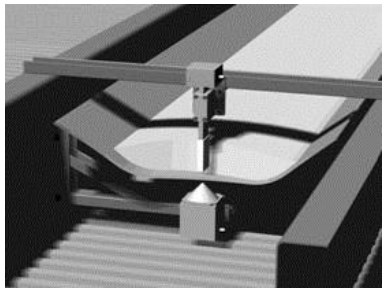


CONTROL EQUIPMENT
MEASURING PRODUCT MOISTURE

Measurements of water content in product

- Water content analyzer
  - Pros: Accuracy of equipment
  - Cons: inaccuracy on average moisture, sampling necessary

- NIR measurement
  - Pros: In line measurements, can also measure product composition and surface temperature
  - Cons: Expensive, calibration data needed, intense sample preparation



- Microwave
  - Pros: Penetrate product (up to ~4 in), non-destructive, in line measurements, non-product specific calibration, average moisture over large sensing areas
  - Cons: Average moisture over large sensing areas, expensive

http://www.grecon-us.com
http://www.microradar.com
http://www.ndcinfrared.com

SENSITIVITY ANALYSIS
IMPACT OF INLET MOISTURE CONTENT

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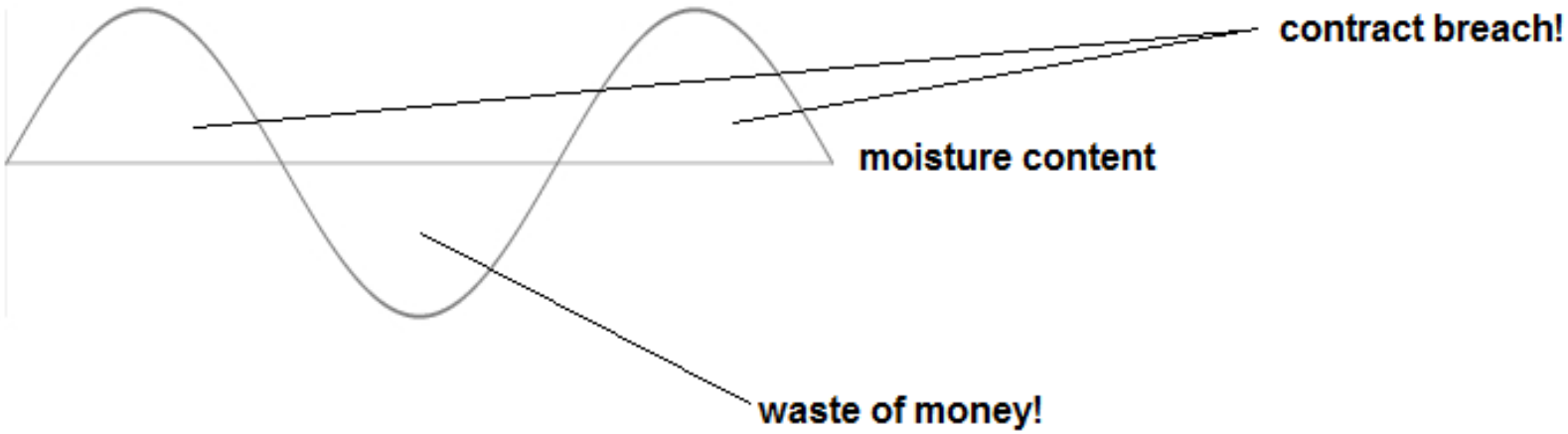
Precision ~ accuracy !

- **Apparatus <u>offset / precision</u>**
  - Outlet moisture is measured too <u>high</u> - > <u>low</u> actual moisture content -> evaporation of product AND excess dryer load
  - Vice versa… -> feed safety compromized

- **Accuracy / uncertainty achieved from process control and moisture measurement strategy**



SENSITIVITY ANALYSIS
THE IMPORTANCE OF MOISTURE MEASUREMENTS

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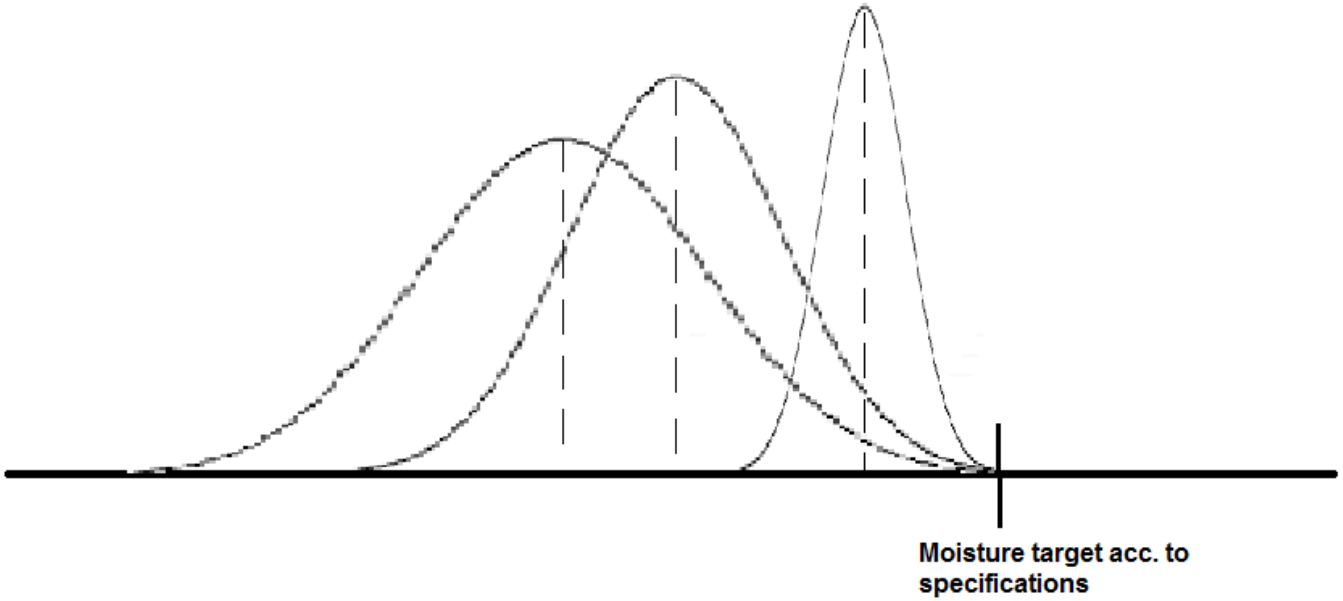

Dryer outlet:

8 % ± 0,5-3%
T=75 °C
Capacity =8500 t/h

Dryer S/P
T_{air}=120°C
Y_{air}=60 g/kg
Vair=0,5 m/s
depth=25 cm

SENSITIVITY ANALYSIS
IMPACT OF INLET MOISTURE CONTENT

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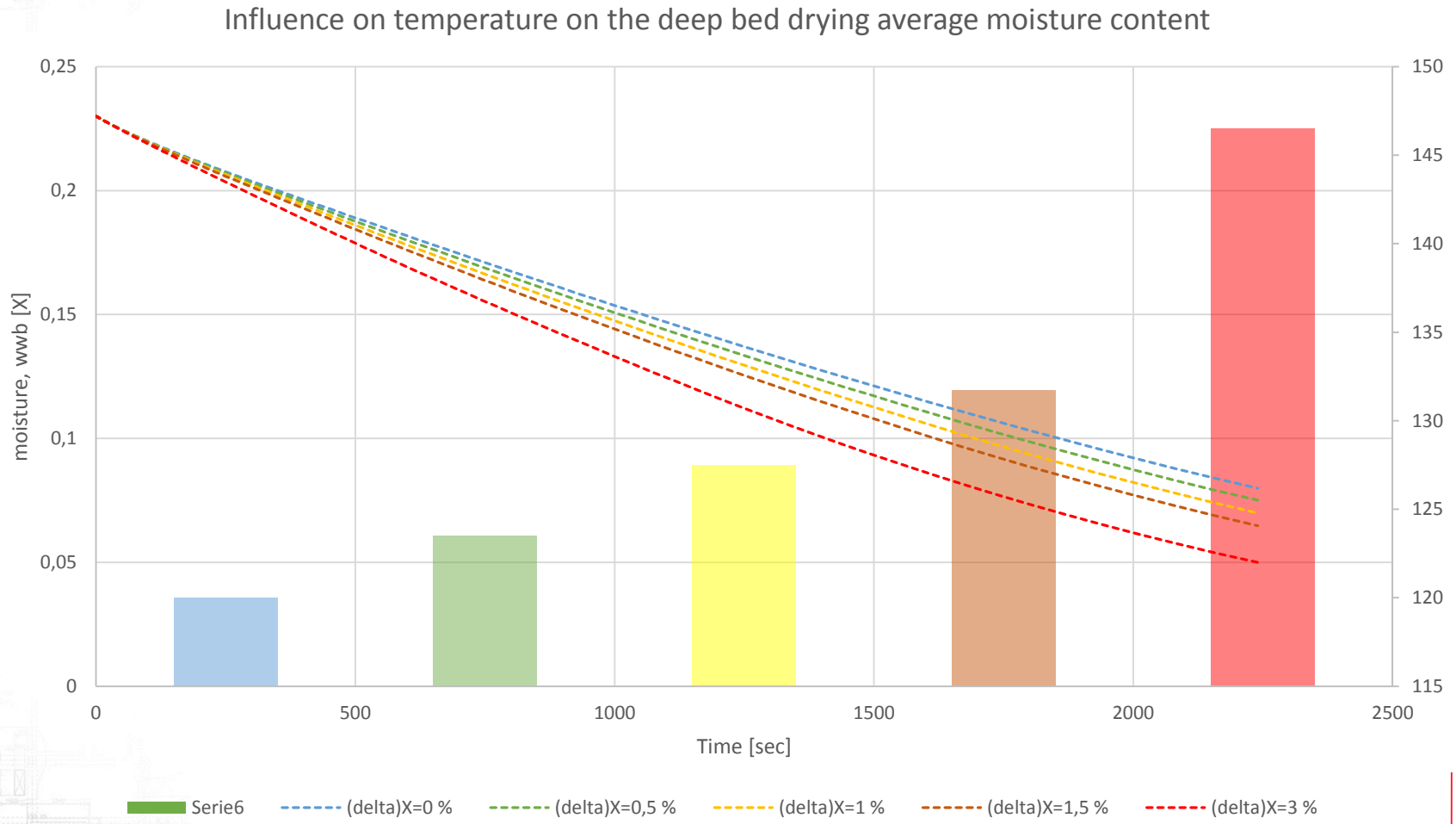

DESIGN EXECUTE INSTALL MAINTAIN

SENSITIVITY ANALYSIS
IMPACT OF INLET MOISTURE CONTENT

- Corrective action -> change T_{air} when moisture inaccuracies

Std. dev. in X [%]	0 %	+ 0,5 %	+ 1 %	+ 1,5 %	+ 3 %
Act. X after corr.	8 %	7,5 %	7 %	6,5 %	5 %
T_{air}	120	123,5	127,5	131,7	146,5
Q_{drier} [kW]	1900	1977	2060	2147	2415
Q_{drier} [%]	0,00 %	4,0 %	8,4 %	13,0 %	27,1 %
Product loss [%]	0,00%	-0,54%	-1,08%	-1,60%	-3,16%
net product loss [DKK/year/ton]	kr. 0,00	kr. 211.516	kr. 420.757	kr. 627.760,99	kr. 1.235.698
net energy loss [DKK/year/ton]	kr. 0,00	kr. 10.164	kr. 21.120	kr. 32.604	kr. 67.980

- **Continious moisture readings should be used as input to a mathematical model for automatic control of the drying proces and to minimize std. Deviation!**

SENSITIVITY ANALYSIS
CHALLENGES WITH INLET MOISTURE CONTENT
(root-causes and feed-forward control)

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Extruder outlet:

23 % ± 1,5%
T=84 °C
Capacity =10 t/h

Dryer S/P
T_{air}=120°C
Y_{air}=60 g/kg
Vair=0,5 m/s
depth=25 cm

- Inlet moisture typically fluctuates. Ideally, drier control software should make use of this!
- Inlet moistrue almost impossible to measure accurately in the industry!
- Early and intermediate moisture readings could greatly reduce the moisture accuracy
- On line moisture readings could eliminate ‘false dryer control decisions’ by obtaining a ‘floating’ average bed moisture content.

ENSURING TECHNICAL QUALITY OF EXTRUDED FISH FEED IN THE ENERGY EFFICIENT HOT AIR DRYING PROCES

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I II

IV

OBJECTIVE

Tecnical Quality

Characteri-zation and investigation

Predict influence from drying

complete model

IIIA IIIB+C

Energy efficiency

Proces level

Pellet level + Drier/bed level

Prediction of technical quality

Optimize energy efficiency

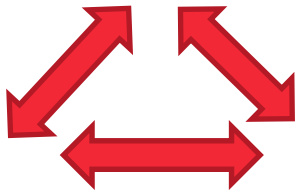
Design & debottle-necking

MATHEMATICAL MODELLING OF THE DRYING PROCESS

$Moisture_{in}$
$Temperature_{in}$
Capacity
…

$Moisture_{out}$
$Temperature_{out}$
Efficiency
…

BED LEVEL



PELLET LEVEL

PROCES LEVEL

- Heat and mass balance
- Good for mapping energy consumption
- Not suitable for exploring feasible drying conditions

MATHEMATICAL MODELLING OF THE DRYING PROCESS

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Input

$Temp_{in}$
$Moisture_{in}$

Time

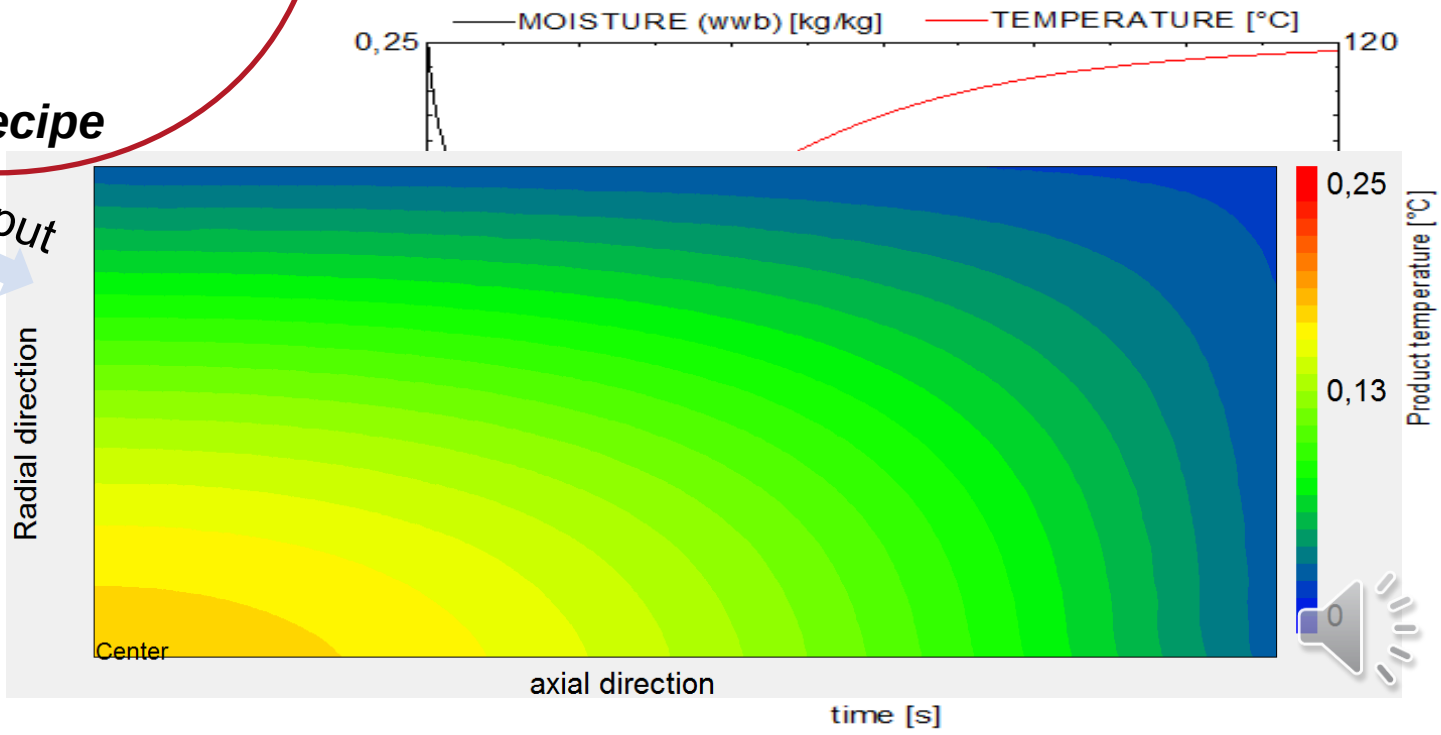
Size & recipe

Output

BED LEVEL

PELLET LEVEL

PROCES LEVEL



MATHEMATICAL MODELLING OF THE DRYING PROCESS

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Input

$Temp_{in}$
$Moisture_{in}$

Capacity

BED LEVEL

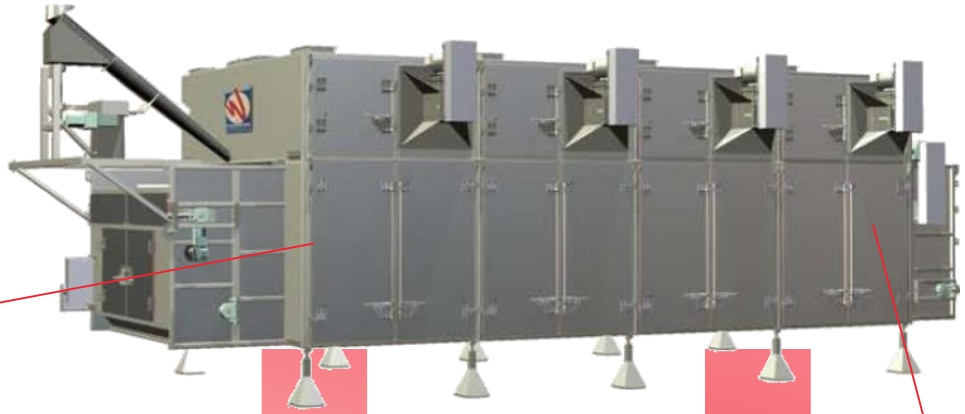
PELLET LEVEL

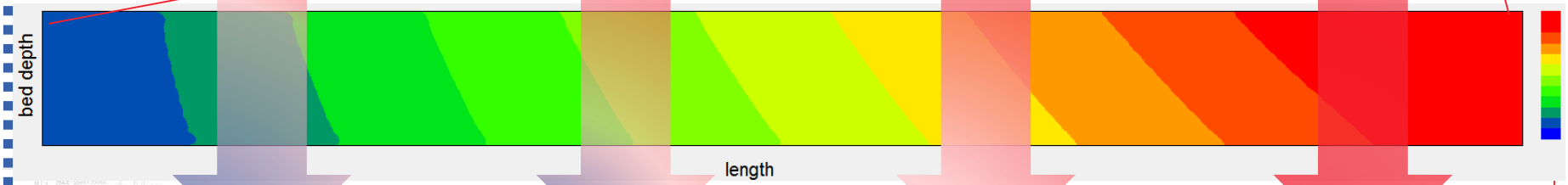
PROCES LEVEL

Time

Bed depth

Size & recipe

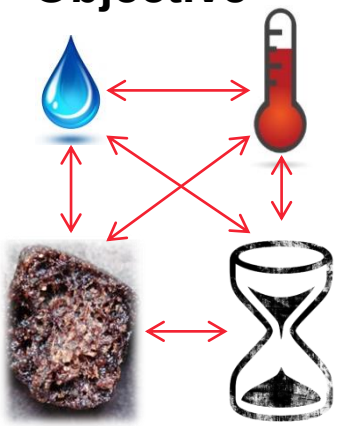


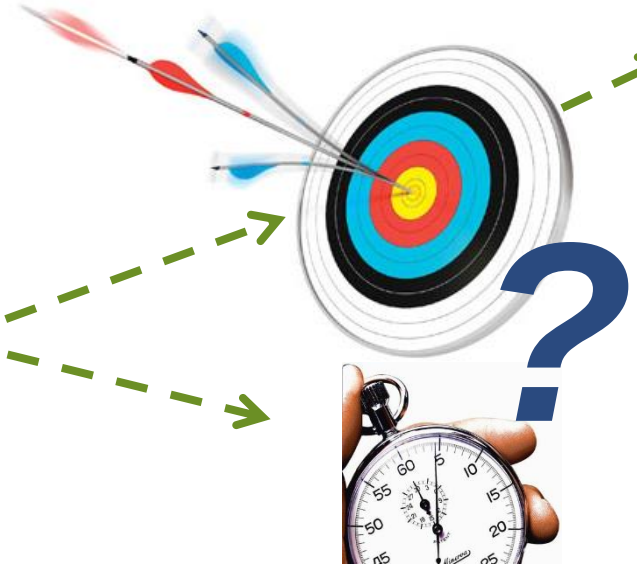


Air conditions

MATHEMATICAL MODEL
Composition

Objective

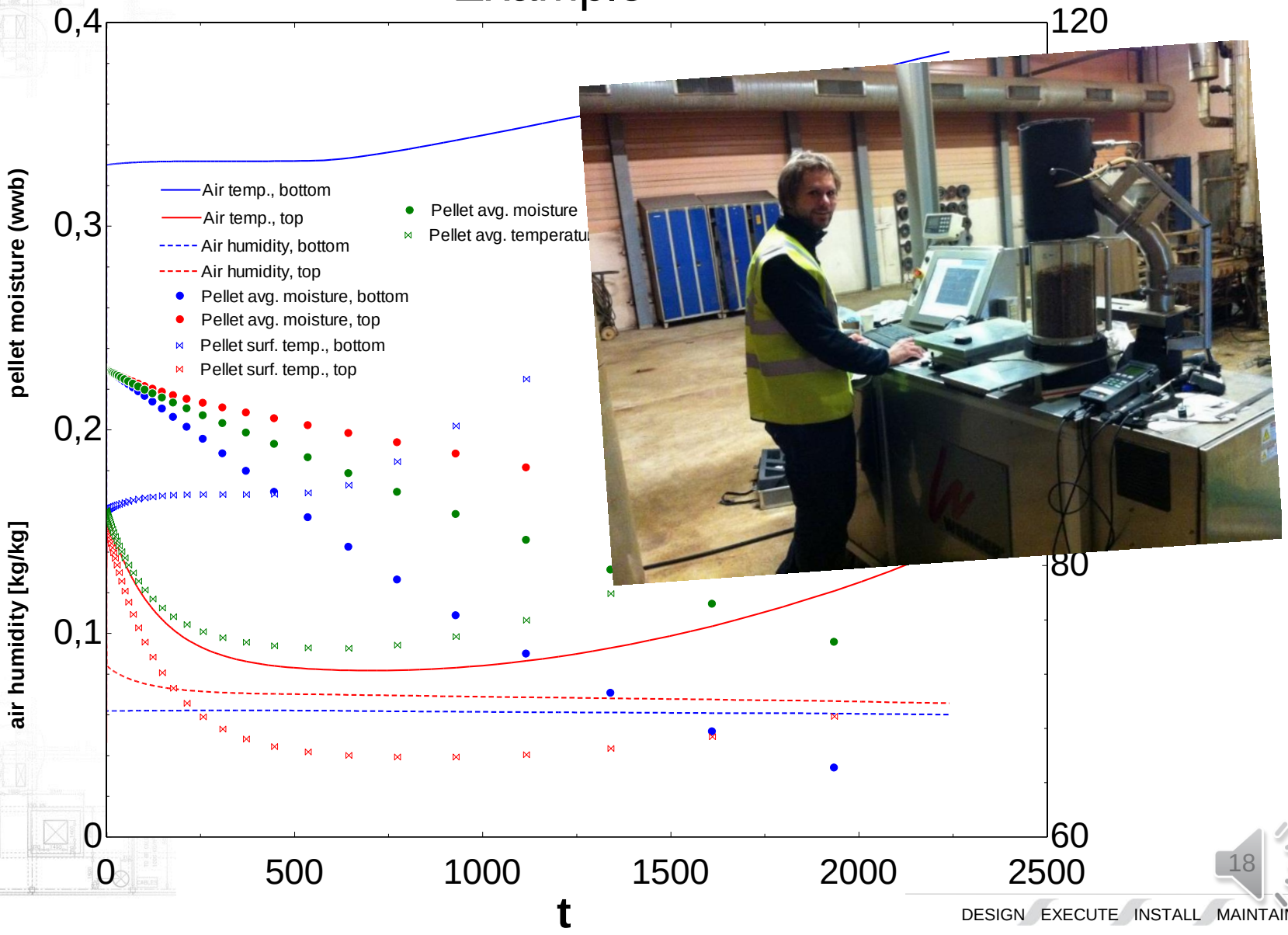




Inclusions…

Simplifications…

MATHEMATICAL MODEL
Example



MATHEMATICAL MODEL
Example

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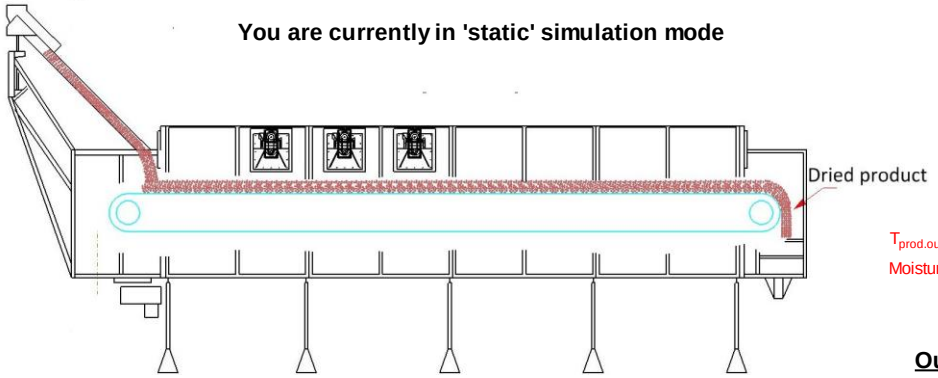
BED LEVEL

PELLET LEVEL

PROCES LEVEL



Product specifications

Product.in = 5000 [kg/h]

$T_{prod.in}$ = 84 [C]

$Moisture.content_{in}$ = 19,15 [%]

oil.prod.in = 6 [%]

$T_{prod.out}$ = 60,2 [C]

$Moisture.content_{out}$ = 10,15 [%]

Output values

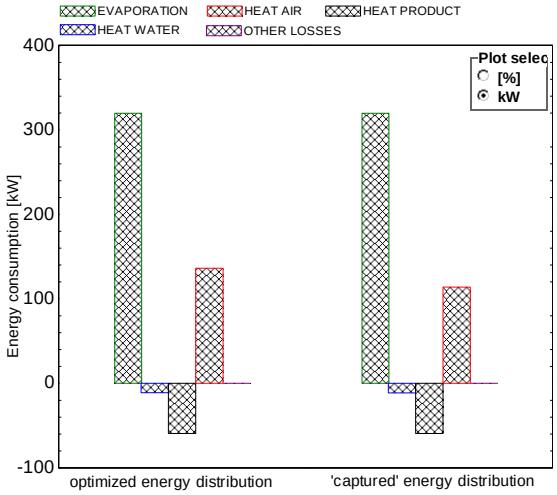
Product.out = 4499 [kg/h]

Evaporated = 500,8 [kg/h]

$Dryer_{effect}$ = 394,2 [kW]

$Dryer_{efficiency}$ = 81,11 [%]

☐ Capture energy chart



Air flow specifications

Mass balance object:
Exhaust abs. humidity

Energy balance object:
Exhaust temperature

Select non-ideality:
Recycle = 5,985

$T_{ambient}$ = 21,8 [C]

$w_{ambient}$ = 40,3 [%]

$\dot{M}_{make.up}$ = 12106 [kg/h]

$\dot{V}_{make.up}$ = 10221 [m^3/h]

$X_{make.up}$ = 0,006531 [kg/kg]

☐ investigate weather

$\dot{M}_{false.air.pre.bed}$ = 0 [kg/h]
(ambient cond.)
☐ false air not amb. cond.

$w_{from.heater}$ = 19,87 [%]
$X_{from.heater}$ = 0,04054 [kg/kg]
$\dot{V}_{from.heater}$ = 90656 [m^3/h]
$\dot{M}_{from.heater}$ = 87554 [kg/h]
T.drier.sp = 70 [C]
☐ investigate T_db

Heater

$\dot{M}_{to.heater}$ = 87554 [kg/h]
$\dot{V}_{to.heater}$ = 86703 [m^3/h]
$T_{to.heater}$ = 55,03 [C]
$w_{to.heater}$ = 39,28 [%]
$X_{to.heater}$ = 0,04054 [kg/kg]

$T_{dryer.inlet}$ = 70 [C]
$w_{dryer.inlet}$ = 19,87 [%]
$X_{dryer.inlet}$ = 0,04054 [kg/kg]
$\dot{M}_{dryer}$ = 87554 [kg/h]
$\dot{V}_{dryer}$ = 90656 [m^3/h]

Product on dryer bed

$T_{after.bed}$ = 60 [C]
$w_{after.bed}$ = 34,99 [%]
$X_{after.bed}$ = 0,046 [kg/kg]
$\dot{M}_{after.bed}$ = 88055 [kg/h]
$\dot{V}_{after.bed}$ = 89247 [m^3/h]

$\dot{M}_{false.air.post.bed}$ = 0 [kg/h]
$T_{false.air.post.bed}$ = 21 [C]
$Rh_{false.air.post.bed}$ = 50 [%]
☒ false air not ambient cond.

$\dot{M}_{recycle}$ = 75449 [kg/h]
$\dot{V}_{recycle}$ = 76470 [m^3/h]

5,985

recirculation air flow / exhaust air flow

☐ investigate

$\dot{M}_{exhaust}$ = 12606 [kg/h]

$\dot{V}_{exhaust}$ = 12777 [m^3/h]

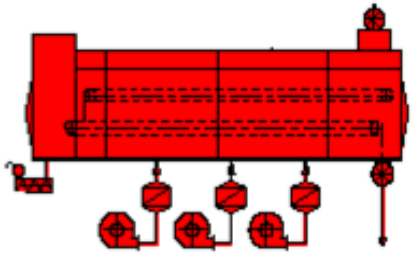
$T_{dryer,exhaust}$ = 60 [C]

$w_{dryer,exhaust}$ = 34,99 [%]

$X_{dryer,exhaust}$ = 0,046 [kg/kg]

EXPECTED OUTCOME

Accurate in-line moisture readings



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PRIORITY BASED
SIMULATION TOOL

Prediction of technical quality

Optimize energy efficiency

Design & debottlenecking

Thank you for your attention!