Coatema Dryer

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Introduction

Drying,
curing &
crosslinking

Summary

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Drying, curing & crosslinking

Summary

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Overview

Quality
made in Germany

Innovations

Part of the ATH Holding

Working widths
from 100 mm
up to 5,400 mm

Coating

Printing

Laminating

Bespoke
equipment

Founded
1974

Printed electronics
Medicals
Membranes
Pharmaceutics
Renewables
Prepregs
Textiles

From lab 2 fab

R&D
projects & network

Worldwide
service

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Group of companies

ALTONAER TECHNOLOGIE HOLDING (ATH)

KROENERT

- ✓ Founded 1903
- ✓ Approx. 200 employees
- ✓ Located in Hamburg

DRYTEC

- ✓ Founded 1995
- ✓ Approx. 50 employees
- ✓ Located in Norderstedt

Coatema® Coating Machinery GmbH

- ✓ Founded 1974
- ✓ Approx. 50 employees
- ✓ Located in Dormagen

ZAE ANTRIEBSSYSTEME

- ✓ Founded 1919
- ✓ Approx. 140 employees
- ✓ Located in Hamburg

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Represented worldwide

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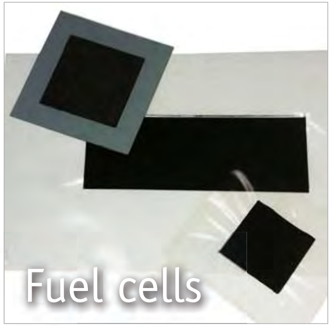
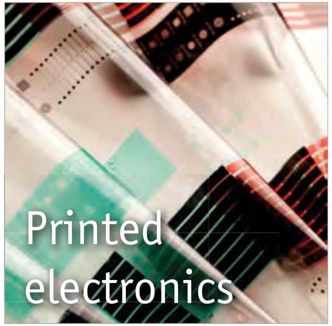
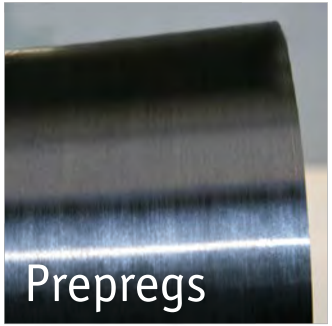
Our markets







and more

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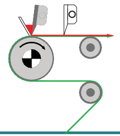
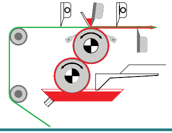
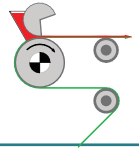
Coating systems



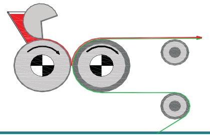
Knife system



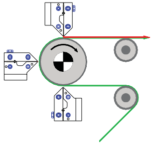
Double side system



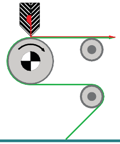
Commabar system



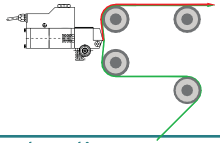
Reverse commabar system



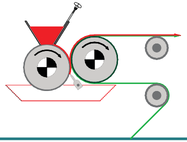
Slot die system



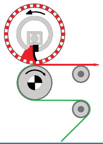
Curtain coating system



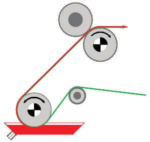
Hotmelt slot die system



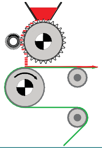
Case knife system



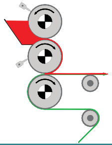
Rotary screen system



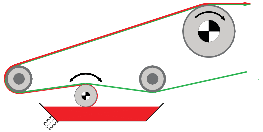
Dipping system (Foulard)



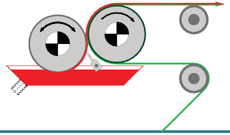
Powder scattering system



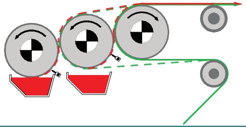
Reverse roll system



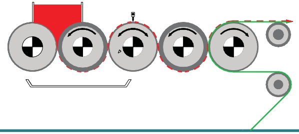
Micro roller system



2 Roller system



3 Roller combi system



5 Roller system

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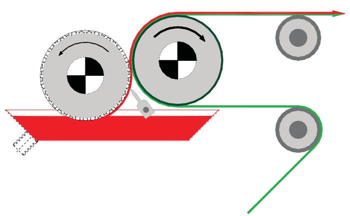
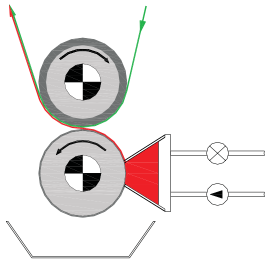
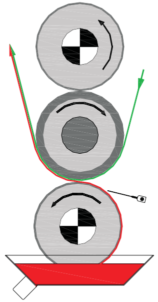
Printing systems



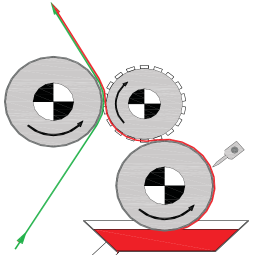
Engraved roller system



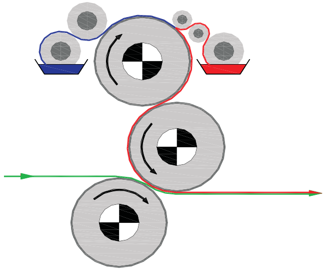
Gravure roller system



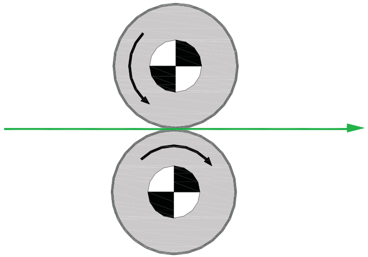
Gravure indirect system



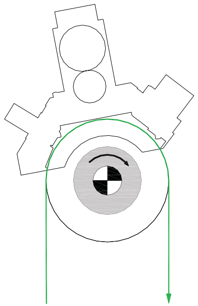
Flexography system



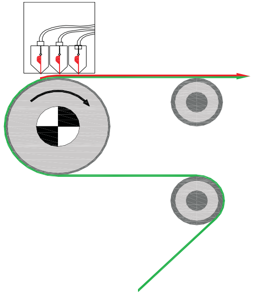
Offset lithography system



Hot embossing system



Nanoimprint system



Inkjet system

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Our work in associations – global networking

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3P InkJet Textiles
ionity

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Agency for Science, Technology and Research SINGAPORE

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UNSW SYDNEY

Queen Mary University of London

ARISTOTLE UNIVERSITY OF THESSALONIKI

TTRI Taiwan Textile Reasarch Institute

ITA Institut für Textiltechnik und Lehrstuhl für Textilmaschinenbau

RWTH AACHEN UNIVERSITY

NREL Transforming ENERGY

RUHR UNIVERSITÄT BOCHUM RUB

TECHNICAL UNIVERSITY OF LIBEREC www.tul.cz

hochschule hof University of Applied Sciences

Deutsches Textilforschungszentrum Nord-West
German Textile Research Centre North-West

cea

Fachhochschule Kiel Hochschule für Angewandte Wissenschaften

CENTI Centre for Nanotechnology and Smart Materials

FILK Forschungsinstitut Leder und Kunststoffbahnen

Hochschule Niederrhein University of Applied Sciences

Georgia Institute of Technology

UNIVERSITY OF CAMBRIDGE

Neue Materialien Fürth

JOANNEUM RESEARCH

HERIOT WATT UNIVERSITY

ZSW

DITF DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

JÜLICH FORSCHUNGSZENTRUM

NATIONAL UNIVERSITY of MONGOLIA

VTT

TNO innovation for life

eurecat Centre Tecnològic de Catalunya

Fraunhofer IMM

Fraunhofer LBF

KITECH Korea Institute of Industrial Technology

Holst Centre open innovation by imec & TNO

Hochschule Reutlingen Reutlingen University

Fraunhofer IAP

Fraunhofer IAF

Fraunhofer ILT

Fraunhofer IFAM

Fraunhofer ISC

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Fraunhofer ICT

Fraunhofer PYCO

Fraunhofer IPT

Fraunhofer IWM

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R&D projects overview 2020

PowderSizing

FLEX-G

GREEN SENSE

SUPERSMART

ENP

SOLID

Oled Solar

El-FIB
ELECTROLUMINESCENCE for FLAGS, INTERIOR and BANNERS

PEPcat

E-Nanoprint Pro

EffiLayers

REAL NANO

FLEX FUNCTION 2 SUSTAIN

SolGel PV

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Introduction

Drying, curing & crosslinking

Summary

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Drying, curing & crosslinking

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Coating parameters

Coating chemistry

- ✓ Rheology
- ✓ Viscosity
- ✓ Viscoelasticity
- ✓ Type of solvents
- ✓ Amount of solids
- ✓ Van der Waals force
- ✓ Sheer ratio
- ✓ Adhesion/Cohesion

Coating processes

- ✓ Coating systems
- ✓ Single or multilayer coatings
- ✓ Direct coatings
- ✓ Transfer (indirect) coatings
- ✓ Substrate speed
- ✓ Layer thickness
- ✓ Coating accuracy

Process control

- ✓ Process layout
- ✓ Tension control system
- ✓ Material guiding system
- ✓ Inline parameter control
- ✓ Quality control

Drying

- ✓ Convection drying
- ✓ Contact drying
- ✓ Infrared drying
- ✓ Sintering
- ✓ NIR
- ✓ High frequency
- ✓ UV crosslinking systems

Substrate

- ✓ Surface tension
- ✓ Dimension stability
- ✓ Surface structure
- ✓ Contact angle

Pretreatment

- ✓ Corona
- ✓ Plasma
- ✓ Cleaning

Environment

- ✓ Humidity
- ✓ Temperature
- ✓ Inert conditions

Finishing

- ✓ Calendaring
- ✓ Embossing
- ✓ Slitting

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Classification of drying procedures

Drying		
Chemical drying	**Physical drying**	
	Mechanical drying	Thermal drying
Reactions (oxidation of innitiators, cross linking reactions)	Centrifugal Pressing / squeezing	Convectional drying Contact drying Condensation drying Vacuum drying Flash drying Molsieve Silicagel IR/NIR Radiation drying

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Information needed to properly select and size a drying system

Information about the substrate

- ✓ Web weight – weight per unit area
- ✓ Web material
- ✓ Specific heat of web
- ✓ Temperature limitations
- ✓ Operating web tension – tension sensitivity
- ✓ Special characteristics

Soucre: Drytec

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Information needed to properly select and design drying system

Information about the environment

Details on the ambient conditions:
- ✓ Climatic conditions
  (ambient temperature, air moisture, etc.)
- ✓ Local conditions (geodetic height, size of the work hall)
- ✓ National guide lines (EN 1539, NFPA, etc.)

Details on peripherical systems:
- ✓ Air treatment facilities
- ✓ Energy supply (gas, steam, electrical energy)
- ✓ Compressed air supply
- ✓ Energy recovery facilities

Soucre: Drytec

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Dryer heating sources

- ✓ Gas
- ✓ Thermal oil
- ✓ Steam
- ✓ Electrical energy

Soucre: Drytec

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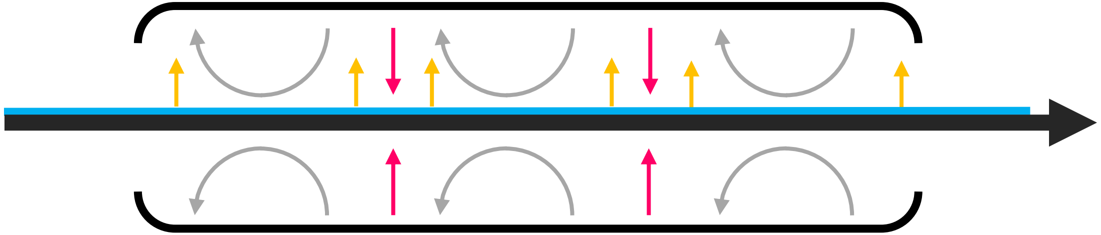
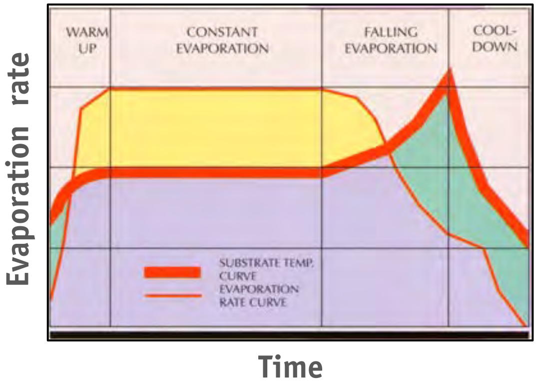
Motivation – general tasks of drying



Substrate
Coating
Heat transfer
Vapor removal
Evaporating solvent



Relevant parameters:

- ✓ Solid heat capacity
- ✓ Solvent heat capacity
- ✓ Solvent evaporation energy
- ✓ Solvent evaporation speed

→ Seems to be trivial, but dryer technologies differ exactly in handling these tasks

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Solvent

Solvent	Molar mass (g/mol)	Boiling point (°C)	Vapor pressure at 20°C (mbar)	Vapor pressure at 50°C (mbar)	Evaporation energy (kJ/kg)	Heat capacity (kJ/kg*K)	Surface energy at 20°C (mN/m=dyn/cm)
Water	18	100	23	123	2256	4.2	71.9
Methanol	32	65	129	535	1100	2.5	22.5
Ethanol	46	78	59	280	840	2.4	21.6
1-Proponol	60	97	20	112	750	2.8	23.0
2-Proponol	60	82	43	225	650	2.7	21.0
Acetone	58	56	246	830	525	2.2	22.8
MEK	72	80	105	373	447	2.2	24.6
NMP	99	203	0.3	2.9	511	2.1	40.9
Ethylacetate	88	77	98	380	362	1.9	23.0
Toluene	92	111	29	124	414	1.7	28.5

no guaranty

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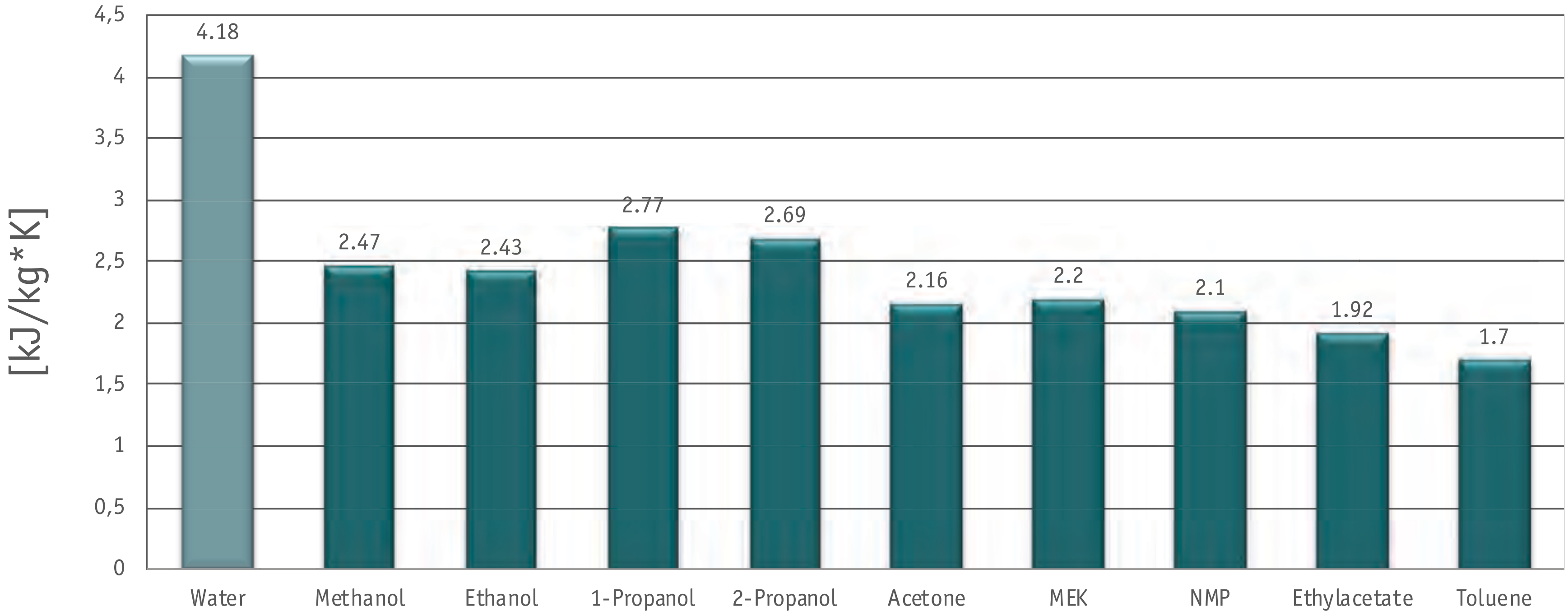
Heat capacity



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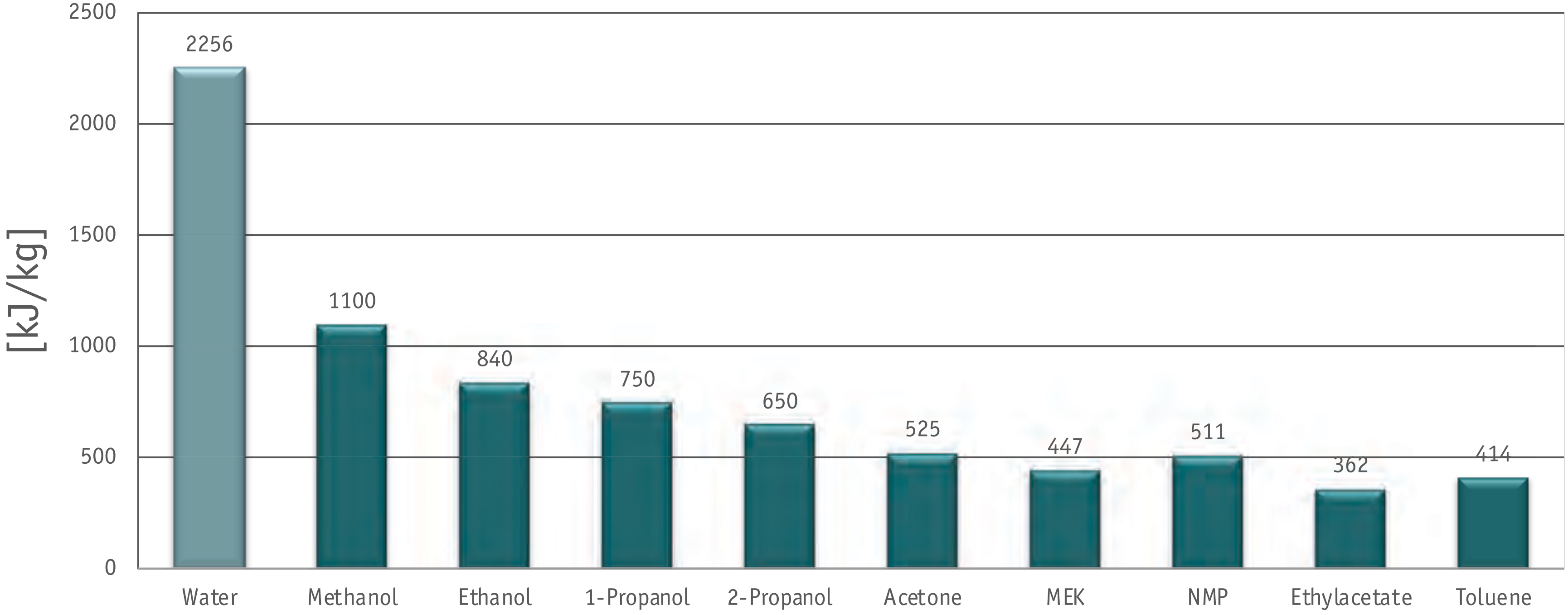
Evaporation energy



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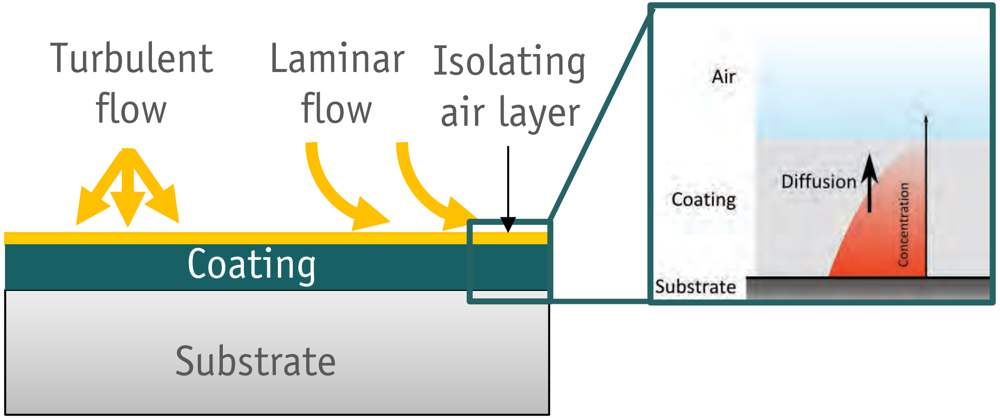
Drying time

An isolating air layer forms just on top of the coating layer.

- ✓ This layer is hardly moving and thereby hinders the heat transfer as well as the solvent evaporation.
- ✓ It has to be broken by sufficient air flow without sacrificing the coating surface.



Usually there is a trade-off:

effective fast heat transfer
or
gentle mild slow drying

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Drying time: heat transfer coefficient

- ✓ The heat transfer coefficient α describes energy transfer from hot air to liquid
- ✓ Energy transfer $\dot{Q}$ can be calculated in fair approximation from Reynolds number R_e , Prandtl numer P_R and Nusselt number N_U

✓ $\propto = \frac{\dot{Q}}{A\,(TD - TO)}$ $\quad R_e = \frac{wD}{v}$ $\quad P_r = \frac{v}{a}$ $\quad N_u = f\,(Re, Pr)$

- ✓ An empirical function Nu = f (Re, Pr) is given in the literature for single slot nozzle and slot nozzle arrays
- ✓ From $N_u = \alpha \cdot \frac{D}{\lambda}$ then derive α and $\dot{Q}$

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Drying time

- ✓ Drying time depends on the solvent evaporation rate at demanded temperature (sufficient energy transfer to achieve this temperature may be presupposed).
- ✓ A decisive factor for evaporation rate is vapor pressure. If drying is allowed near the solvent boiling temperature, there is no difference in vapor pressure for all solvents.
- ✓ But if by other reasons the drying temperature is limited, there are huge differences in vapor pressure.
- ✓ So the issue is to find the vapor pressure and evaporation rate for the given solvent at demanded temperature.

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Vapor pressure

- ✓ Vapor pressure can be calculated for any solvent at any temperature, if 2 pairs of pressure and temperature are known:

  Clausius-Clapeyron: $\log p = K_1 + \frac{K_2}{T}$

- ✓ Such pairs of p and T are available in the literature for any solvent e.g. p (20°C) and T (1013 hPa).

- ✓ Online excel-sheets are available to calculated the vapor pressure for any solvent at any temperature from two pairs (p/T).

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Drying time, calculation of evaporation rate

- ✓ Vapor pressure is one factor of evaporation rate, but not the only one.
- ✓ Other than for vapor pressure there is no simple way to calculate the evaporation rate for any solvent at the demanded temperature.
- ✓ Based on a modified Hertz-Knudsen approach, the evaporation rate of any solvent at any temperature can be estimated (Coatema IP).
- ✓ $Z \sim (P_s - Pp) \cdot \sqrt{\frac{M_r}{T}}$
- ✓ But still there are other influencing factors unknown (like the matrix of solids). Such factors have to be determined experimentally.

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Calculation example

This is a practical example of a real calculation of dryer length for a 900 µm wet coating based on solvent xylene at drying temperature 120°C.

Sufficient energy transfer is supposed.

The result was verified by trial.

Coating data:	
Coating thickness wet	900 µm
Solvent xylene	65%
Pure solvent thickness wet	585 µm
Specific weight xylene	0.88 g/cm³
Solvent grammage	514.8 g/m²
Web speed	0.13 m/min
Evaporation data:	
Vapor pressure xylene at 20°C	880 Pa
Boiling temperature xylene	140°C
Vapor pressure at 120°C	56180 Pa
Relative molar mass xylene	106.17
Evaporation rate (according to Coatema method)	1.64 g/m²s
Result (from web speed, grammage, evaporation rate):	
Dryer length	0.68 m

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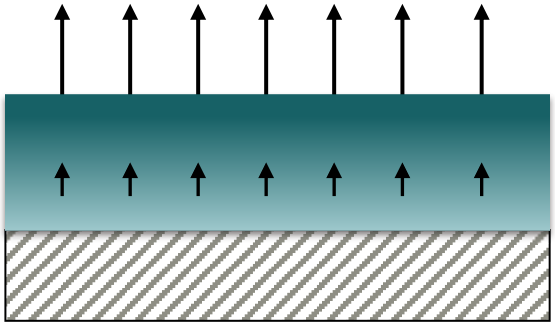
Diffusion limit and skinning

- ✓ Drying is limited by diffusion
  (at least in the final state of low residual solvent content).
- ✓ If the internal diffusion is slower than the evaporation from the surface, then a skin may be created.
- ✓ The skin acts as a barrier. The remaining diffusion through the skin may be slower than the wet diffusion by many orders of magnitude.



So the initial evaporation must be reduced by low temperature and/or by partially saturated atmosphere. Despite reduced evaporation the total drying time then may be shorter than at full initial evaporation.

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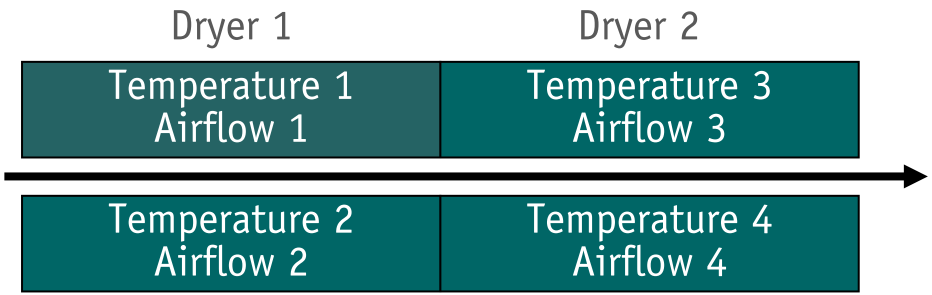
Dryer design

- ✓ Downweb temperature profiles can be realized by partitioning the dryer in different zones with different drying parameters.
- ✓ But temperature uniformity is difficult.
  Possible cause: Mixing of hot and cool air at unintended leakages by Venturi effect.
- ✓ Experience shows, that there is always a compromise:
  Good temperature uniformity requires low homogeneous air flow. High air flow results in less temperature uniformity.



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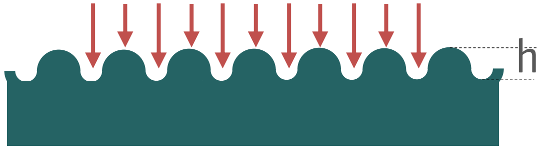
Dryer design: surface deterioration

- ✓ Air flow removing the evaporating solvent may be laminar or turbulent.
  Fluctuations of the flow may deteriorate the surface of a low viscous liquid causing wavy or stochastic structures.
- ✓ For rough estimation it may be assumed, that 10% fluctuations of the dynamic (impact) pressure of the air flow compensate the hydrostatic pressure difference caused by surface structures of the low viscous liquid:

$$10\rho_{liquid} \cdot g \cdot h = 1/2 \cdot \rho_{air} \cdot v_{max}{}^2 \qquad v_{max} = \sqrt{20\left(\frac{\rho_{liquid}}{\rho_{air}}\right) g \cdot h}$$

→ Result: orange skin of 1 µm deterioration depth would be created by an air flow of 0.5 m/sec with superimposed fluctuations of 10%.

Nonuniform air flow with 10% fluctuations



Coating with orange skin surface (exaggerated)

Dynamic effects being influenced by viscosity are not calculated. So the estimation holds for very low viscous liquids only.

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Dryer design

Practical example: measured air speed in different dryers

Dryer	Setting	v_{air} at slot exit [m/s]	v_{air} at web surface [m/s]	Remarks
SC 12 30 cm wide mini hot air dryer with slots from above	100%	4.7	0.8	7 slots 260 x 7 mm² Slot length = web width Only from top values measure at first slot
CC 08 50 cm wide hot air dryer with slots from above and below	100%	4.6	1.6	48 slots 83 x 5 mm² 24 from top 24 from bottom
SM 21 50 cm wide hot air floating dryer with 180°-shifted air cusion nozzles from above and below	100%	25		8 nozzles from top 8 nozzles from bottom 3 slots for each nozzle Center 800 x 7 mm² Sides 800 x 4 mm²

From the 100% setting the air speed can be reduced to any intended value by changing the ventilator settings and/or reducing the slot width. Surface deterioration thus can be avoided.

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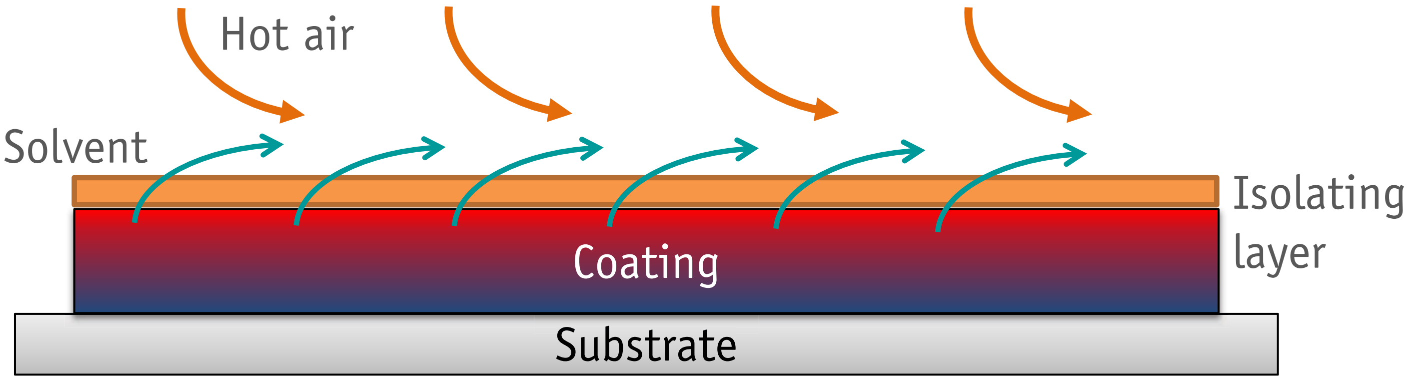
Dryer design: hot air

- ✓ Heating and vapor transport combined
- ✓ Bulk heating by thermal conductivity from surface
- ✓ Isolating layer to be overcome by air flow
- ✓ High air flow deteriorates surface
- ✓ Temperature easy to limit
- ✓ Slow



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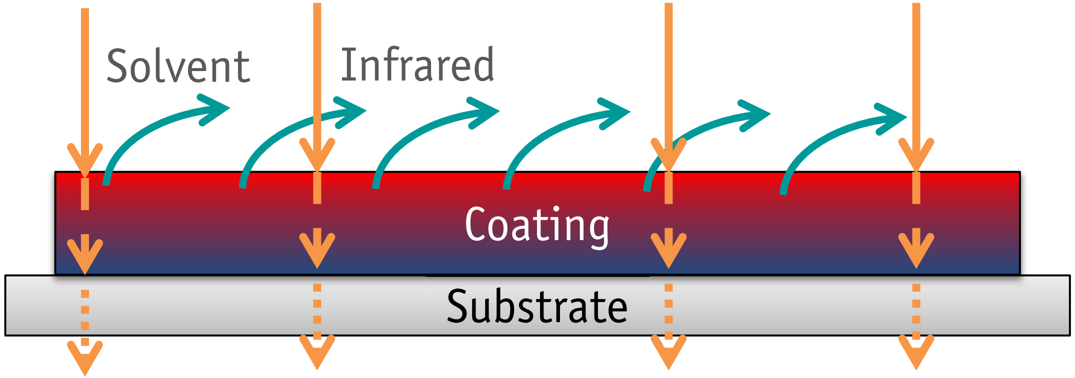
Dryer design: near-infrared (NIR)

- ✓ Heating and vapor transport separated
- ✓ Selective bulk heating by absorption
- ✓ Absorption dependent on λ
- ✓ Overheating and uniformity to be controlled
- ✓ Fast, if applicable
- ✓ Wavelength range 780 nm – 3 µm



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Dryer design

Wing shaped slot dryer

Wing shaped nozzle dryer with different nozzles

Simple slot dryer

- ✓ Combined functions of heating and vapor transport
- ✓ Bulk heating by heat transfer from the surface
- ✓ Overheating easily avoided by limited air temperature

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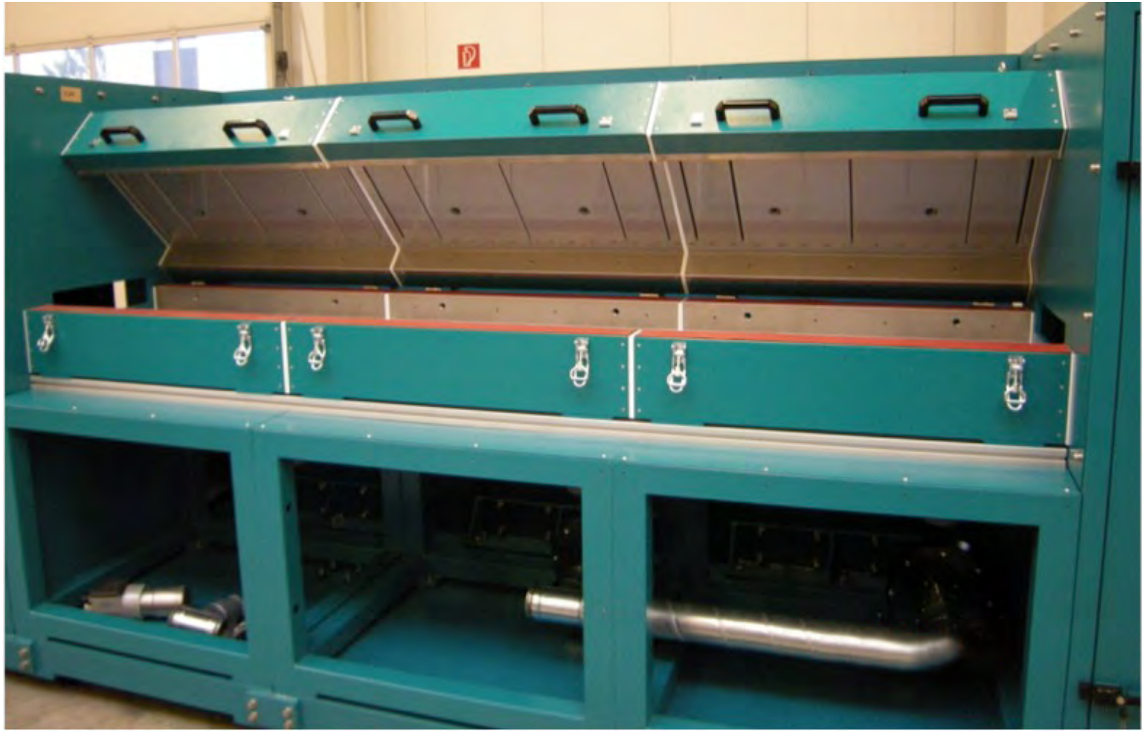
Dryer design



Slot dryers with adjustable slots easy to clean

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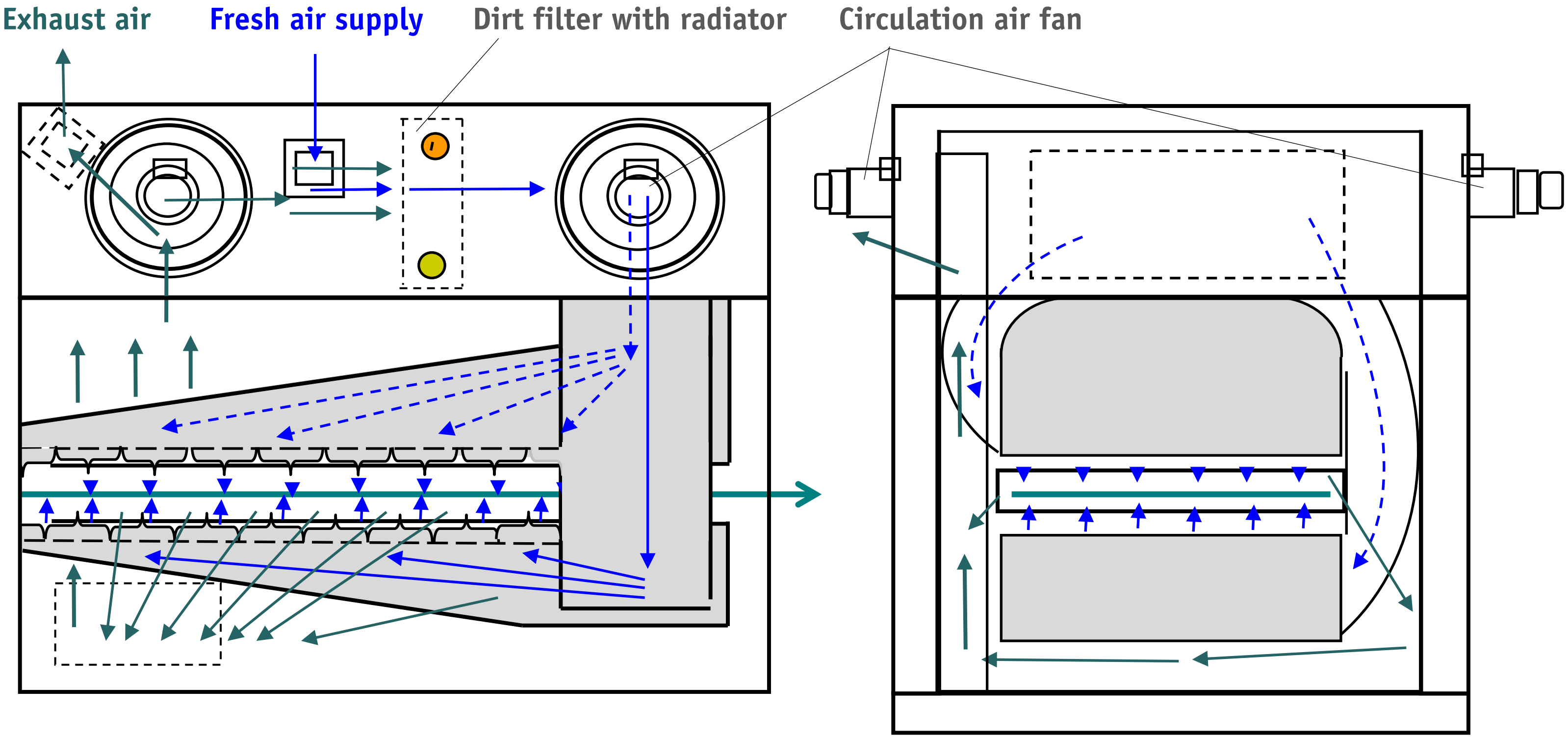
Drying topics – drying technologies



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Hot air technology

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Hot air technology

Nozzle dryers modul
Dry with shifted nozzles and wing shaped blow boxes

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Operation modes for drying systems

1. **„IN – OUT" mode** -> Operation where the drying air / gas will not be recirculated
   - ✓ Small machines and R&D lines
   - ✓ or high requirements to the drying air / gas (e.g. purity)

2. **Recirculating mode** -> Operation where the drying air / gas will be recirculated and only a necessary part of drying fluid will be purged
   - ✓ The ratio of exhaust / circulated volume shall be < 0.5
   - ✓ Coating / converting machines
   - ✓ Paper machines etc.

3. **„OVER PRESSURE" mode** -> Operation where the drying air / gas will be recirculated and a surplus fresh air / gas occur
   - ✓ Inert drying systems (at the inlet and outlet area of the drying system)

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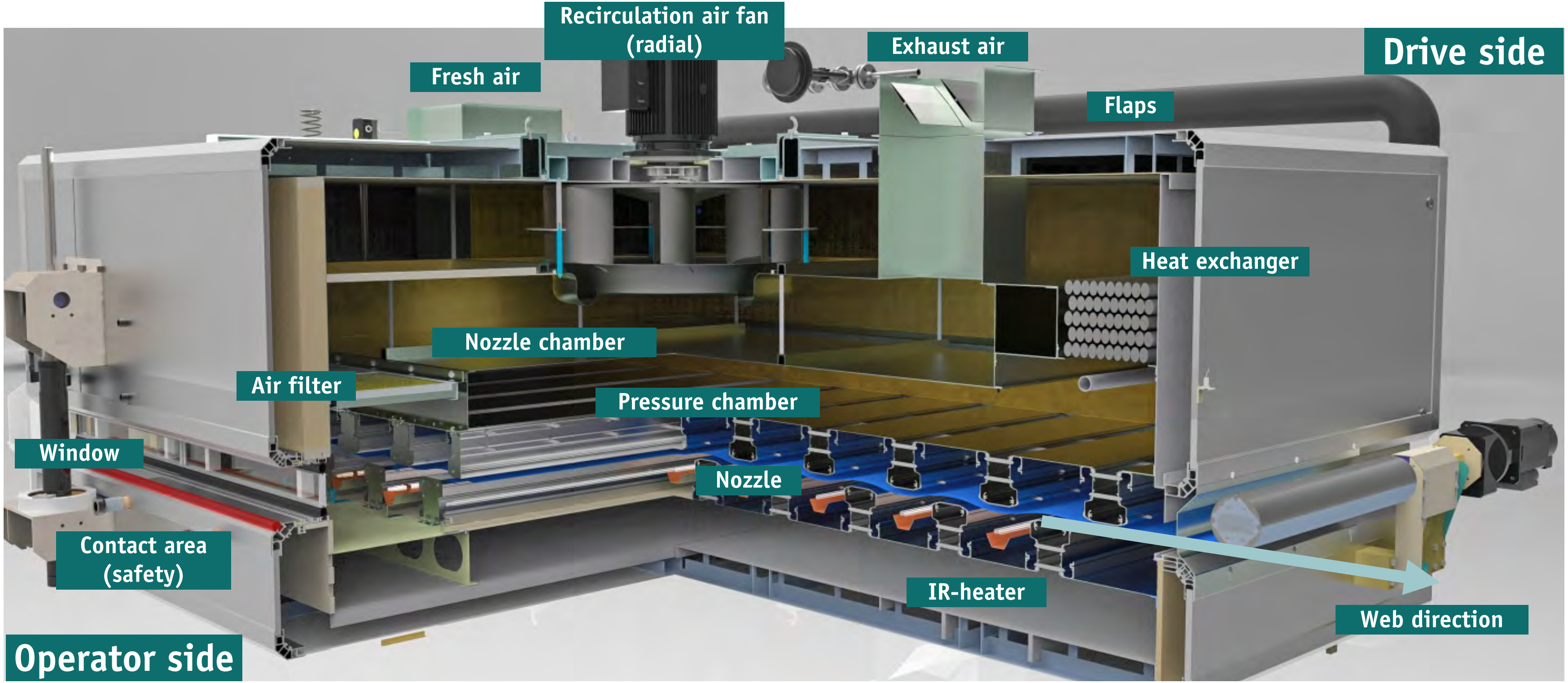
Drying topics – drying technologies: HighDry HD500

DRYTEC



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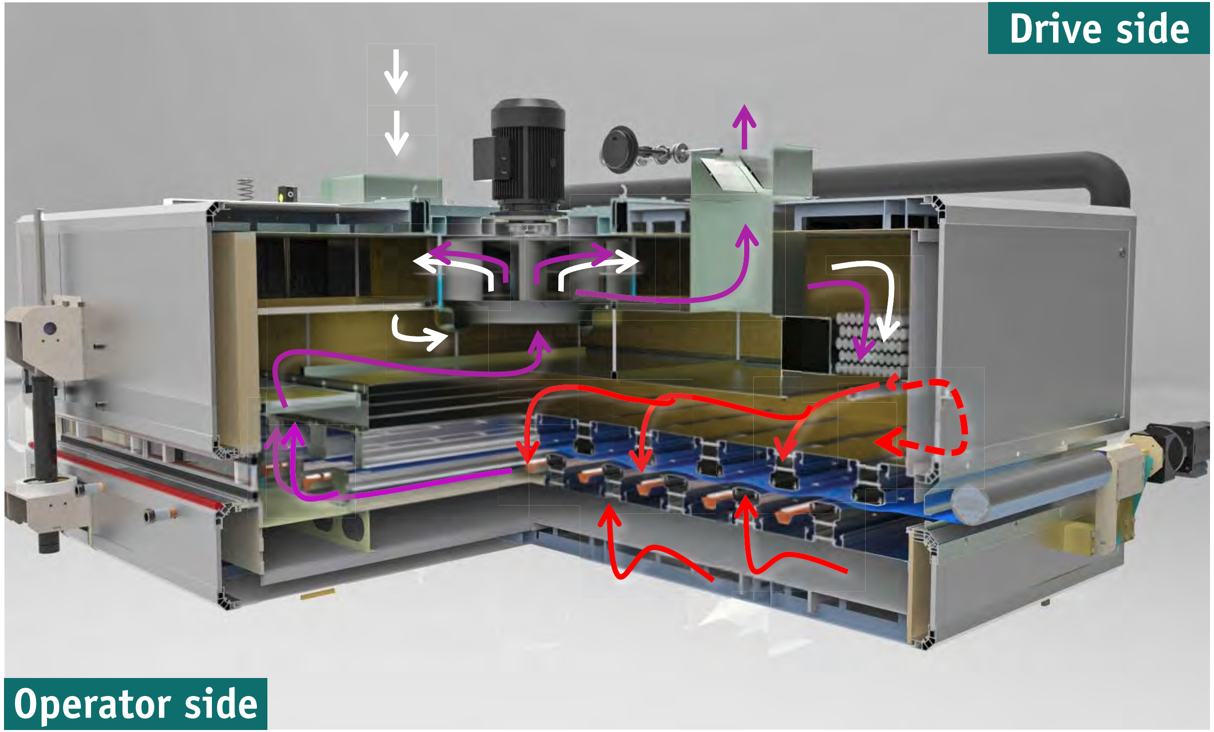
Drying topics – drying technologies: HighDry HD500



Air flow air inlet (cold)

Air flow heated air (hot)

Air flow reverse

Clear arrows

Click „Air distribution“ to show air flow direction

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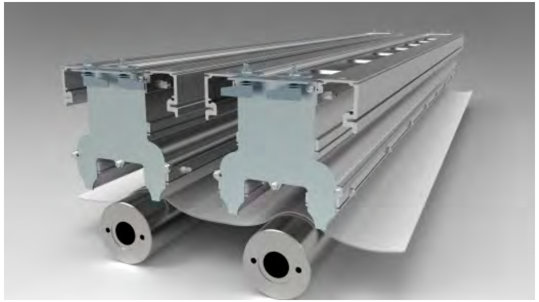
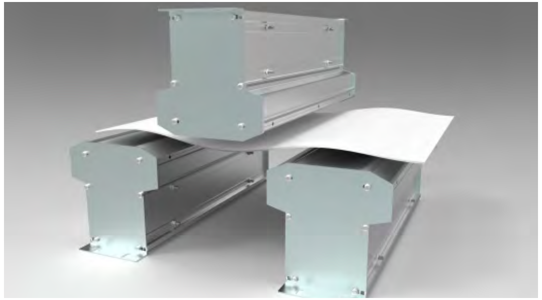
Hot air technology

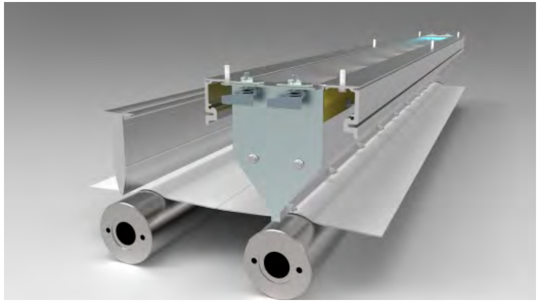


Impingement nozzles with two jets

Flotation nozzles with adjustable air direction



Flotation nozzles



Impingement nozzles with one jet

Flotation nozzles with Contec 3 roller nozzle

*) Contec 3 – Nozzles are placed directly above each other. The top nozzles have to be directly above the rollers which are placed in nozzles.

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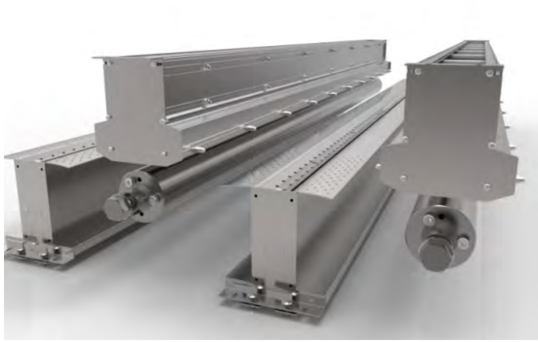
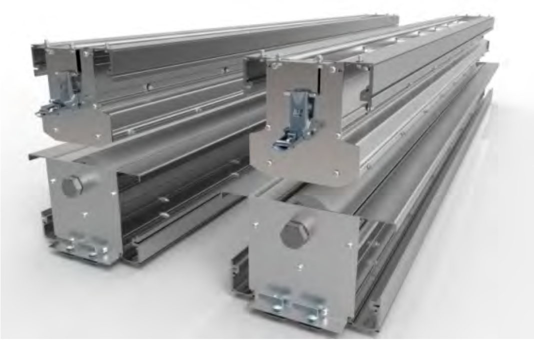
Hot air technology

Flotation nozzles with contec 1 roller nozzle



Flotation nozzles with contec 2 roller nozzle



Flotation nozzles with contec 3 roller nozzle

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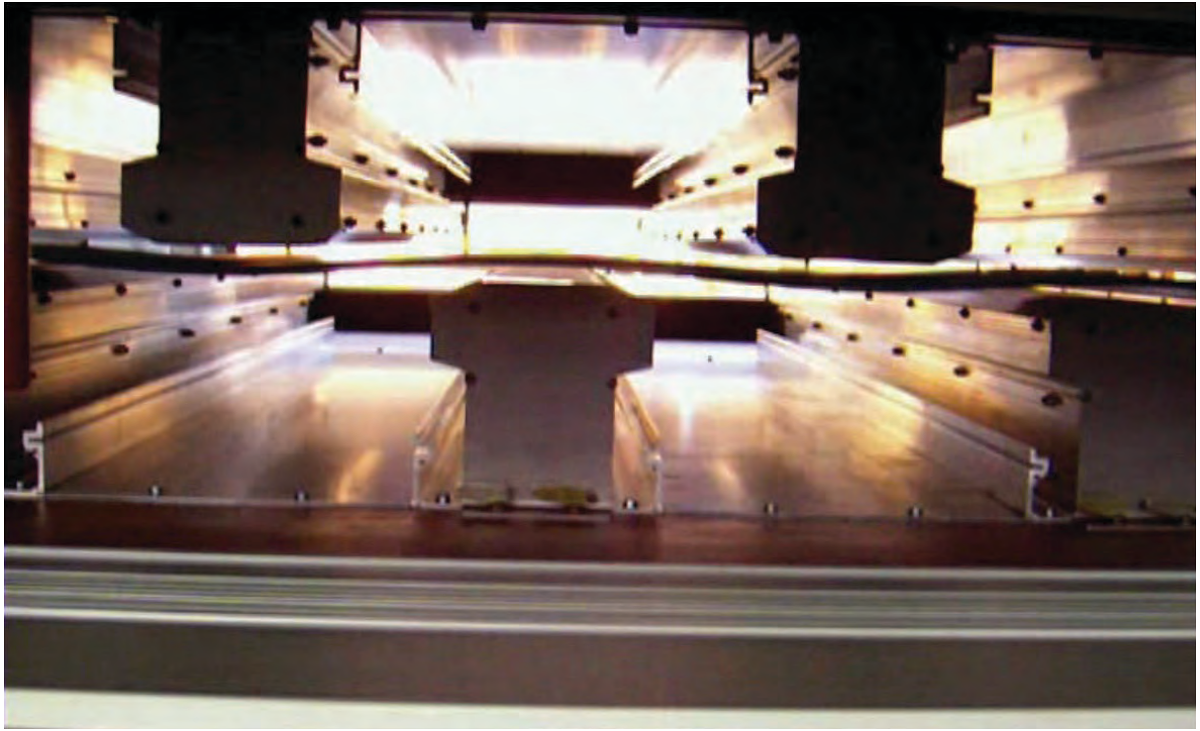
Dryer operation



Web behaviour in a floatation dryer

Click on the picture to show the video

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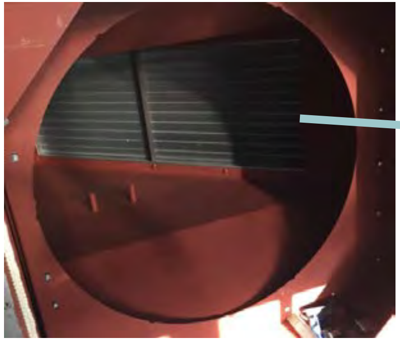
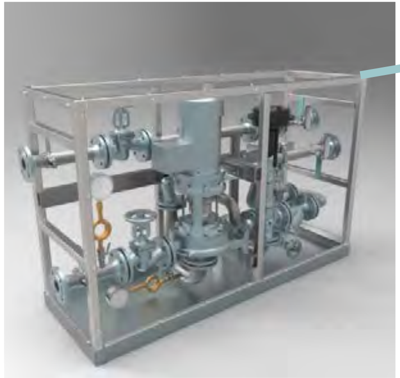
Heat exchanger – HIGHDRY 250 and thermal oil circulation system

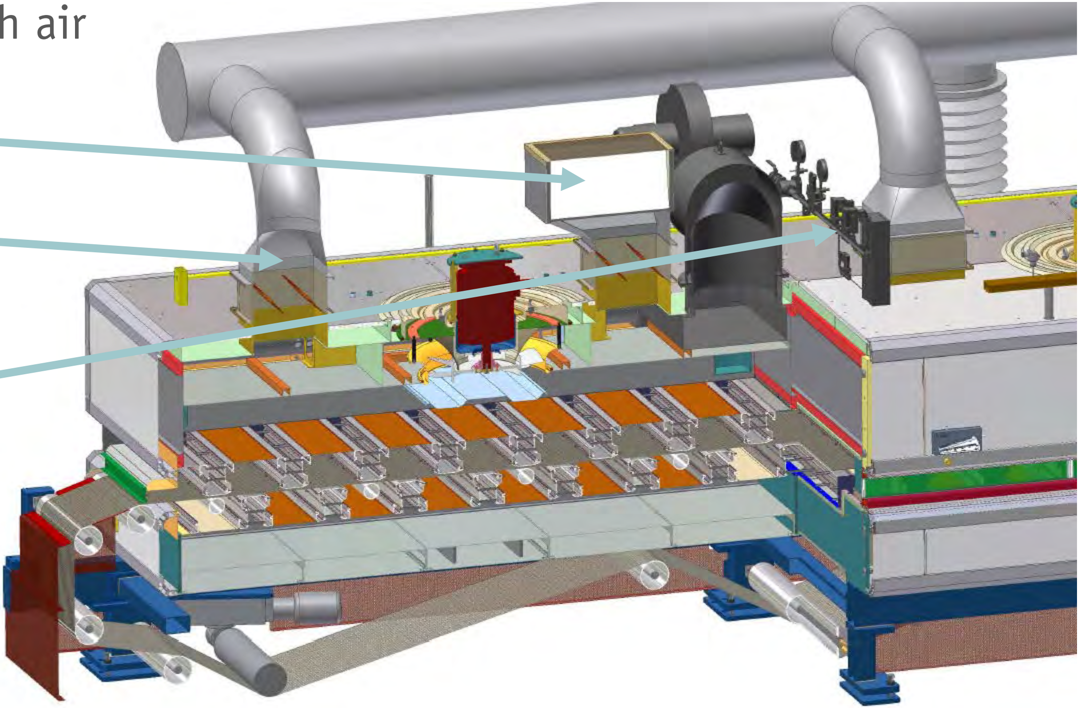


Filter for fresh air

Valves for exhaust air



Thermal oil heat circulation unit



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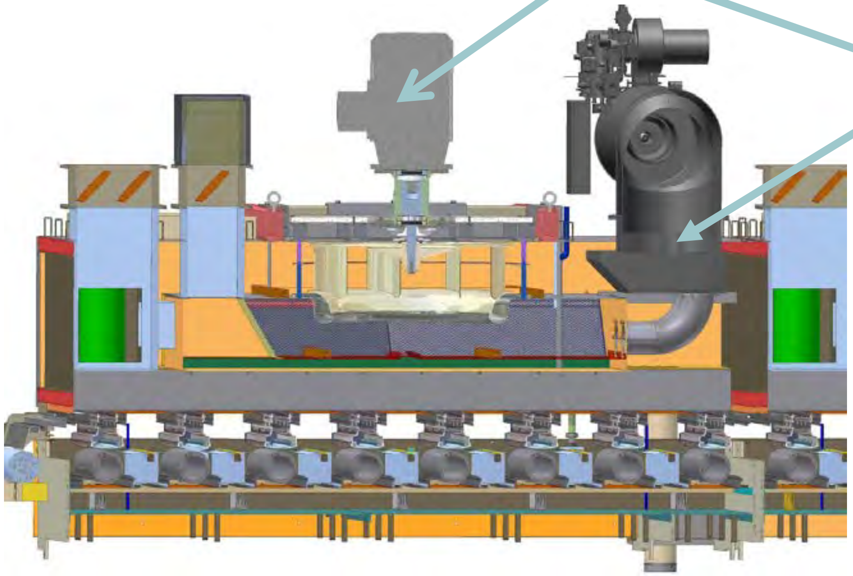
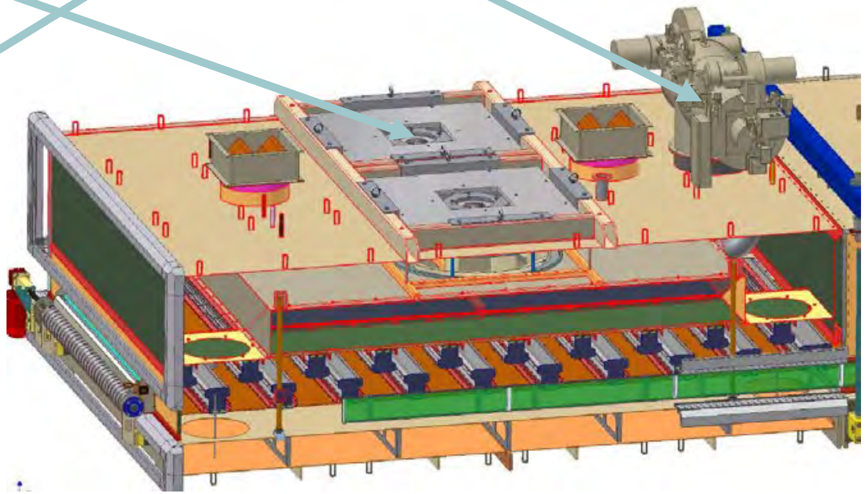
Direct gas heating

Ventilation for circulation air

Gas burner



Contact roller dryer



Flotation dryer

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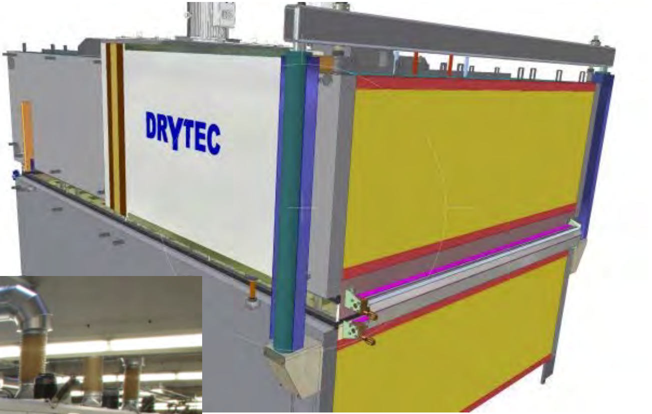
Dryer design – hydraulic lifting device



Dryer open with safety system

Dryer closed

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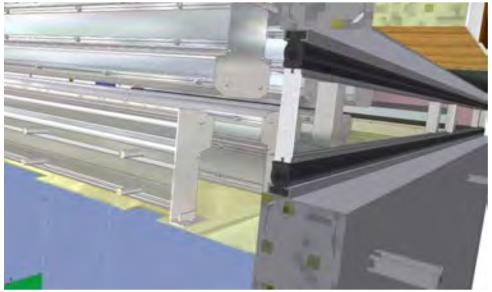
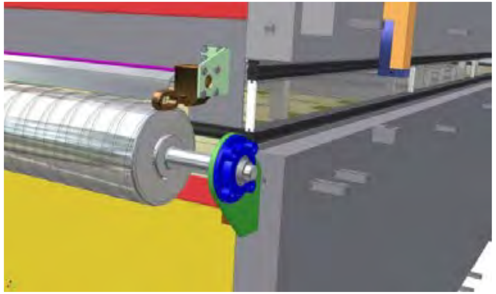
Dryer design – double glass windows

DRYTEC



Along both sides of the dryer for the observation of the web



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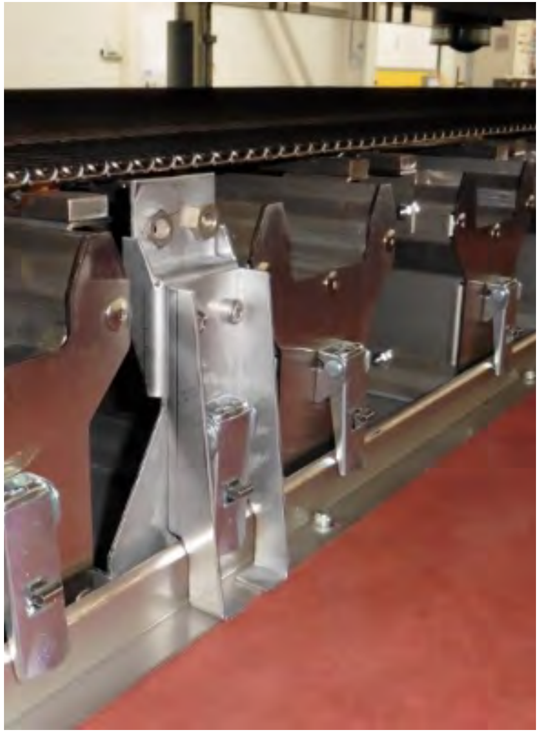
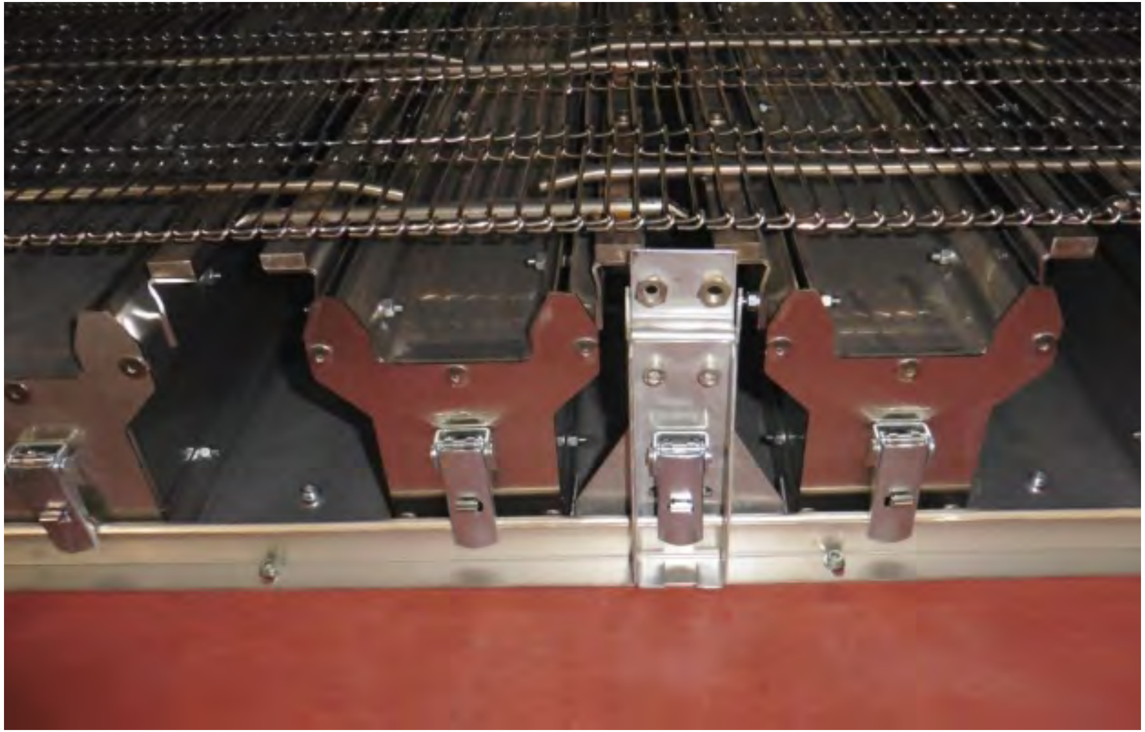
Dryer design with transport system – metal grid





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Dryer design with transport system – transport belt

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Typical position of the dryer in the second level of a coating line

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RECO drying equipment

DRYTEC

- ✓ Opening with parallel lifting
- ✓ Thermal oil heat exchanger
- ✓ Flexible design of nozzles

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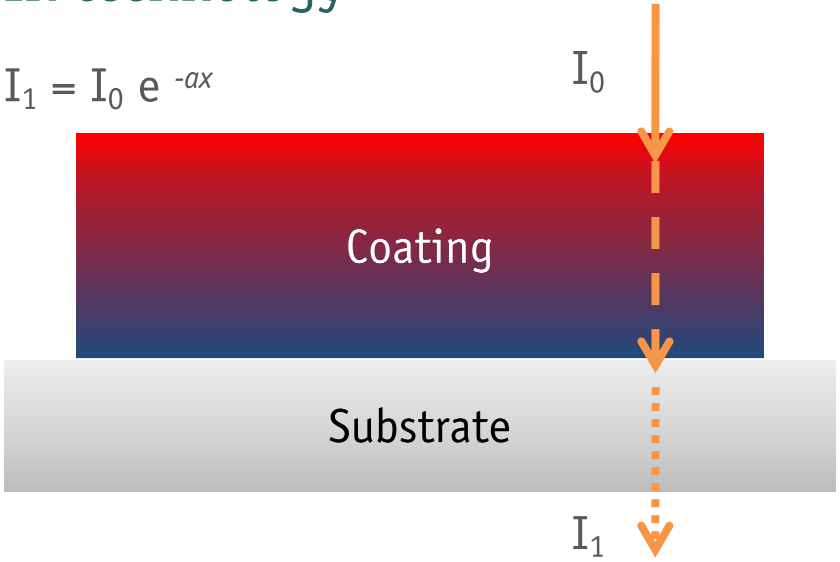
IR technology

$I_1 = I_0 \, e^{-ax}$



I_0 Intensity in
I_1 Intensity out
a Absorption coefficient
x Layer thickness

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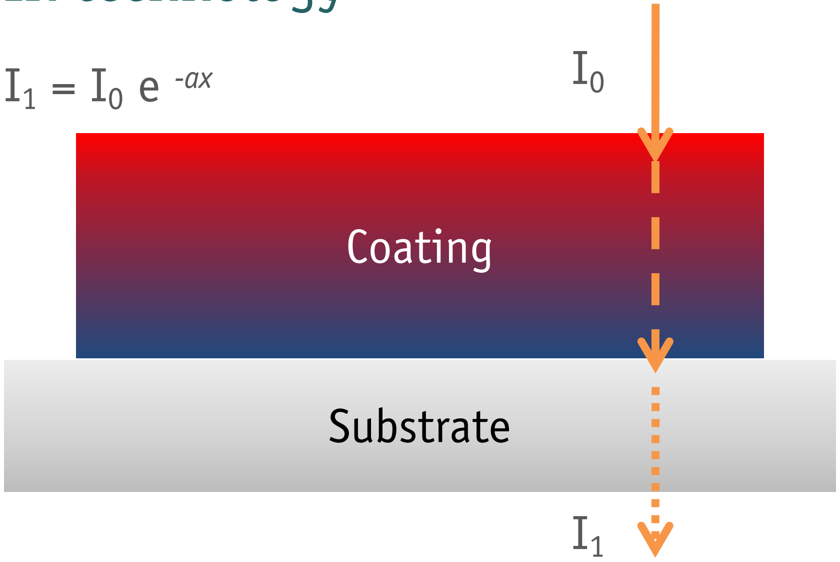
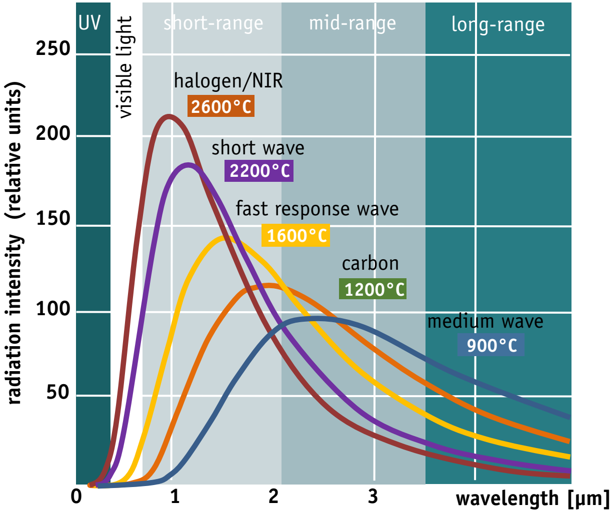
IR technology

$I_1 = I_0 e^{-ax}$



I_0 Intensity in
I_1 Intensity out
a Absorption coefficient
x Layer thickness

High absorption | Optimum absorption | Low absorption



Relative intensity of radiators at different wavelengths

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IR technology – combined hot air / IR dryer

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Dryer design: microwave technology

- ✓ Same pros and cons as IR, but even exaggerated
- ✓ Penetration depth approximately 2 cm,
  low absorption in thin layers (low absorption coefficient),
  resonator required for multiple passage
- ✓ Complex system
- ✓ Advantages for very thick layers only (e.g. foam blocks)

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Introduction

Drying,
curing &
crosslinking

Summary

Summary

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Comparison

Short wave NIR can be of great advantage, but only if applicable.

Applicability depends on coating liquid and substrate.

(The table focusses on applicable cases)

	Hot air dryer	Heated drum-based dryer	Infrared dryer	NIR drying technology	UV/EB curing
Drying time of physical drying	> 1.0–20.0 s	Depending on substrate thickness ~> 1.0 s	0.3–10.0 s	0.02–1.5 s	Not applied
Curing time of cross-linking section	5.0–30.0 s	3.0–15.0 s	1.0–10.0 s	0.1–2.0 s	0.1–2.0 s
Dynamic capability	Preheating and standby operation while web stop required	Preheating and standby operation while web stop required	Mostly no preheating required	Fully instantaneous start/stop capability	Depending on system, extreme dynamic, often preheating required
Max. possible production speed	Mostly only up to 600 m/min (1969 fpm)	Mostly <100 m/min (328 fpm)	Max. up to <1000 m/min (3281 fpm)	At present no limit up to >2000 m/min (6562 fpm)	Mostly only up to 600 m/min (1969 fpm)
Risk regarding thermal damage	High, depending on air temperature especially at fast web stop	High, depending on drum temperature	Lower, but given depending on heat due to mass of dryer design	Low, due to working principle and dryer design	Low, due to working principle
Applied for thermal sensitive substrates	Limited to low air temperature (<80 °C/ 176 °F) results in strong reduced drying performance	Limited to low drum temperature (<80 °C/ 176 °F) results in strong reduced drying performance	Limited to low drying power due to resulting thermal stress	Possible up to high production speed due to working principle and dryer design	Possible up to high production speed due to working principle an dryer design
Risk regarding penetration of the coating materials in open substrates	Cannot be avoided due to long drying time required	Cannot be avoided due to long drying time required	Can be reduced slightly, but not completely avoided	Can be avoided, due to extreme short drying time and high energy density	Can be avoided, due to extreme short drying time and high energy density
Consumption of consumable material	High, especially due to penetration in the substrate	High, especially due to penetration in the substrate	Lower, because of low penetration	Lower, because of mostly avoided penetration in the substrate	Lower, because of mostly avoided penetration in the substrate

courtesy Adphos

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