

Pilot freeze-drying systems Innovative technology



High performance and
high efficiency



Success from proof of principle to production launch!

Martin Christ Gefriertrocknungsanlagen GmbH is a leading global company that develops and manufactures freeze-drying systems, with over 70 years of experience.

Today we present what may be the most innovative area of endeavor within our company: the manufacture of pilot freeze-drying systems for process development and small-batch production.

The name Martin Christ stands for the highest level of customer satisfaction around the world. We develop and build to the highest quality standard for the best value for our customers. Our applications are the heart of our corporate identity.

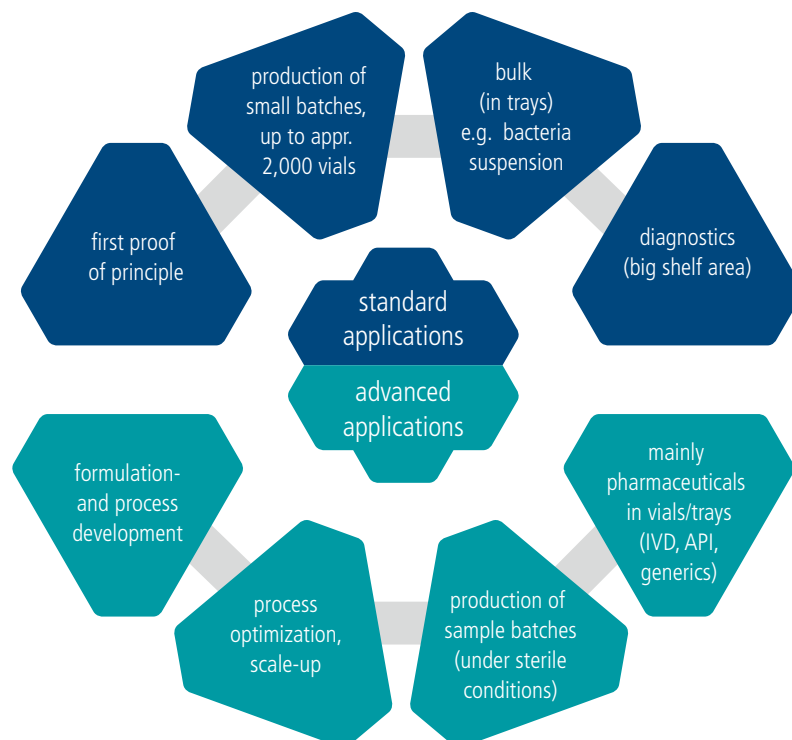
We see ourselves as a global innovation leader. We are continuously solidifying our outstanding position in the field of freeze-drying with technological innovations, such as the WTMplus (wireless product temperature measurement system), the LyoCoN (controlled nucleation) system for crystallization at the push of a button, or the LyoCam

for process-integrated camera monitoring. Dozens of corporate patents are undeniable proof of our pioneering approach.

Pilot freeze-drying systems from Martin Christ are ideally suited for research and development. They are also the perfect choice for series production. Users can choose among five models. Each provides the best possible results in freeze-drying solids or liquids in a wide variety of containers, such as Lyo-Vials, flasks, trays, glass bulbs, microtiter plates, and ampoules. With their geometric similarity, comparable temperature-control system, and identical operation, these systems are on a par with large production machines.

Of course, detailed but intuitive process controls are part of every model, as is the use of the best available process analytical technologies – especially important for development tasks.

We are at home in nearly every industry, with focal points in the pharma and biotech segments.



Optimal equipment for R&D and small-batch series production

The **Epsilon 1-4 LSCplus** and **Epsilon 2-4 LSCplus** freeze-dryers are the best choice for routine work. The single-chamber system has a 4 kg ice condenser integrated in the product chamber. A refrigerant cools the large shelf area directly. This results in a lower temperature for the shelf, and cooling and heating rates that are nearly twice as fast as indirectly cooled shelves.

Equipped with stainless steel shelf areas with synthetic heat transfer fluid, the larger **6 and 10 kg pilot systems** meet the highest standards of the pharma and biotech industries. These double-chamber systems with separate ice condenser integrate even more PAT functions for process optimisation and development. The LSCplus controller and LPCplus software make it easy for users to operate the pilot systems intuitively and document processes continuously. The proven SCADA system LPCplus is used for all types of units, from pilot freeze-dryers to complex production systems.



Epsilon 1-4 LSCplus
Epsilon 2-4 LSCplus

4 kg -55°C
-88°C ~ 430 x 2 ml
~ 30 x 100 ml



Epsilon 2-6D LSCplus

6 kg -88°C ~ 840 x 2 ml
~ 42 x 100 ml



Epsilon 2-10D LSCplus

10 kg -88°C ~ 3.065 x 2 ml
~ 98 x 100 ml

Pilot systems with larger capacities

– steam sterilizable for clinical samples –
are also available.

Best for process optimisation and production of bulk and speciality products

Epsilon 2-12D LSCplus

 12 kg
  -80 °C
  ~ 4.100 x 2 ml
 ~ 180 x 100 ml



The higher-capacity pilot systems, with 12 and 16 kg ice capacity, are comparable in most ways to larger production machines. They are water-cooled systems with generously sized compressors in a massive steel frame.

Our customers like to use the **Epsilon 2-12D model** with LSCplus, or with a Siemens controller (for specialized functions) for developing recipes and for up scaling with the maximum number of PAT tools.

Optional features of the Epsilon 2-12D LSCplus:

- Single-plate closure (perform several tests in one run)
- Regulated ice condenser temperature (simulating the behavior of older systems)
- CIP-capable

Its big sister, the **Epsilon 2-16D**, has up to 1.2 m² of shelf area without compromising performance, using water cooling among other features. It was conceived especially for 24/7 production of tray goods (bulk), such as raw pharma materials, bacterial suspensions, and specialty formats such as MTPs or tall containers that do not require vial closures.

One favorite specialty application is the sublimation of solvents, such as ACN water from Zymark vials.

Equipment options for all machines:

- Automatic inertization with GN2
- VHP decontamination
- Freestanding design or wall installation
- Solvent-resistant
- ECO version with natural refrigerants

Epsilon 2-16D LSCplus

 16 kg
  -88 °C
  ~ 10 x 1.2 l bulk
 or numerous special formats



Advanced system technology

Freeze-dryers from Martin Christ are high-performance universal units for freeze-drying solid or liquid product in a wide variety of vials, trays, and other containers.

Our single and double-chamber systems provide numerous application possibilities:

- Freeze-drying of products using defined time, temperature, and pressure profiles. The shelf area temperature when freezing and in the initial phase of the sublimation process is a maximum of -75°C (depending on the model). This allows extremely sensitive pharmaceutical and biotechnical products, such as amorphous structures with a low glass transition point, to be safely freeze-dried.
- Final drying of products with preset time and temperature limits and high final vacuum, to remove water bound by capillary and adsorptive effects. The final vacuum is about 0.005 mbar (depending on the performance of the vacuum pump).

Shelf area temperature control

Powerful with active cooling & heating

Epsilon 1-4 & 2-4 LSCplus	
Main drying control range	-45°C (Epsilon 1-4 LSCplus) or -75°C to $+60^{\circ}\text{C}$ (Epsilon 2-4 LSCplus)
Accuracy of shelf area temperature	better than $\pm 2\text{ K}$ Can be optimized with the use of aluminum thermal blocks
Cooling/heating rate	> 2 K/min ($+20^{\circ}\text{C}$ to -40°C)
Ice condenser temperature	-55°C Epsilon 1-4 LSCplus or -88°C Epsilon 2-4 LSCplus

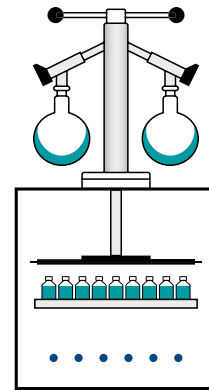
Shelf area temperature control

Powerful with active cooling & heating

Epsilon 2-6D, 2-10D, 2-12D & 2-16D LSCplus	
Main drying control range	-50°C or -60°C to $+60^{\circ}\text{C}$
Accuracy of shelf area temperature	$\pm 1\text{ K}$
Cooling/heating rate	> 1 K/min ($+20^{\circ}\text{C}$ to -40°C)
Ice condenser temperature	-85°C -80°C Epsilon 2-12D LSCplus

Single-chamber systems

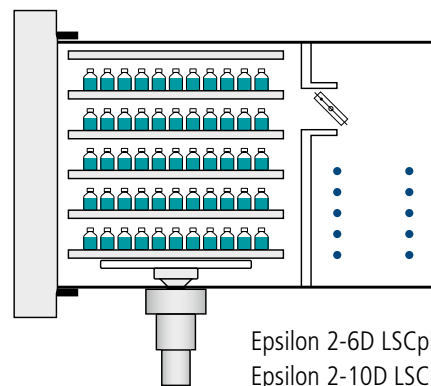
- **Most high-efficiency ice condenser design**
The ice condenser is directly inside the drying chamber, shortening drying time and avoiding vapor condensation in the vacuum pump.
- **Vial stoppering plus flask drying**
Multipurpose machine with a large shelf area at 0.11 m² and optional connections for up to four flasks. Controlled, reliable vial stoppering with manual operation (automatic as an option)



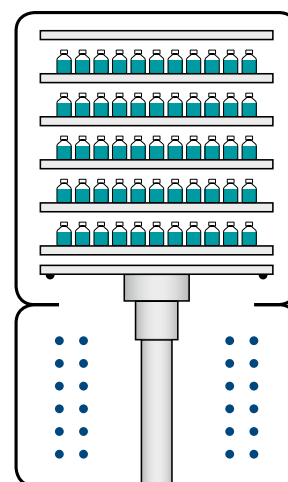
Epsilon 1-4 LSCplus
Epsilon 2-4 LSCplus

Double-chamber systems

- **Optimal vapor transport**
- **Ice condenser** directly **behind** or **beneath** the drying chamber
- **Large cross-section** between drying and ice condenser chambers
- Nearly **zero pressure drop** between the two chambers.
Excellent drying rates for sensitive materials and products with low eutectic points or low collapse temperatures
- **Intermediate valve** for determining the transition from primary to secondary drying phase
- Manual or hydraulic **vial stoppering**
- Connections for **flask drying** available as an option



Epsilon 2-6D LSCplus
Epsilon 2-10D LSCplus



Epsilon 2-12D LSCplus

Design features

Functionality without limitations

- **Minimal space requirements:** very compact design with highly efficient and economical operation.
- **Shelf temperature control:** high performance with active cooling and heating, up to > 2 K/min ($+20$ °C to -40 °C), depending on model.
- **Control processes – without compromise**
Extensive LSCplus user interface with intuitive controls. Can be combined with LyoLogplus software for documentation or LPCplus graphic process control interface – as desired.
- **Stoppering function for vials**
You choose: simple and secure manual stoppering, or time-saving automated operation. Optional “Ventilate-Close-Store” function
- **Defrosting without water**
Fast and efficient hot gas defrosting for the 6, 10, 12, and 16 kg units. For the 4 kg unit by irradiating the shelf area, or with hot gas (option).
- **Eco version** available, using environmentally friendly natural refrigerant.
- **User-defined configurations**
Would you like to run a special application? We have an extensive palette of proven solutions. They include freeze-drying substances containing solvents, preparing for coupling to a glove box or an isolator, and VHP decontamination with certificate.
- **System qualification**
(IQ/OQ) as an option.
- **Made in Germany**
Freeze-dryers from Martin Christ are 100% developed and produced in Germany, at our Osterode location. That includes an ISO 9001:2008 conforming QMS – certified since 1994.



Epsilon 2-6D LSCplus

Compact design with high-performance compressor and vacuum system



Example:

System for clean room integration with touchscreen controls



Widest range of custom solution

The extensive Epsilon pilot series from Martin Christ sets the standard for high-quality productive systems. We uniquely configure to our customers' requirements, supplying user-defined pilot systems to pharmaceutical companies and biotech start-ups all over the world. These freeze-dryers use the same working principle as their big brothers. They provide a high level of functionality for successful research and process development. They can use the following proven modifications:

- **Clean room integration**
- **Integration of isolator / glove box**
- **Process optimisation tools**
Process Analytical Technology (PAT)
 - LyoControl (freezing point determination)
 - LyoCam – Intelligent camera
 - LyoBalance – Scale system
 - Sample extraction system/manipulator
 - Comparative pressure measurement (Pirani/capacitive)
 - WTMplus – Wireless product temperature measurement
 - LyoCoN – Simultaneous freezing
- **H₂O₂ decontamination (VHP)**
- **LN₂ booster**
- **Special systems for solvents**
- **Inner film coating on the acrylic door:**
a transparent layer that protects against aggressive solvents and makes a stainless steel door redundant in many cases.
- **Radiation Shield:** transparent film coating (patent pending) reduces negative radiation effects through the transparent chamber door.
Both films enable continued full-surface product observation through the acrylic door.



Example:

Sample extraction system/manipulator with camera and additional LyoCam in the door for process documentation.



Example:

Integration with a glove box

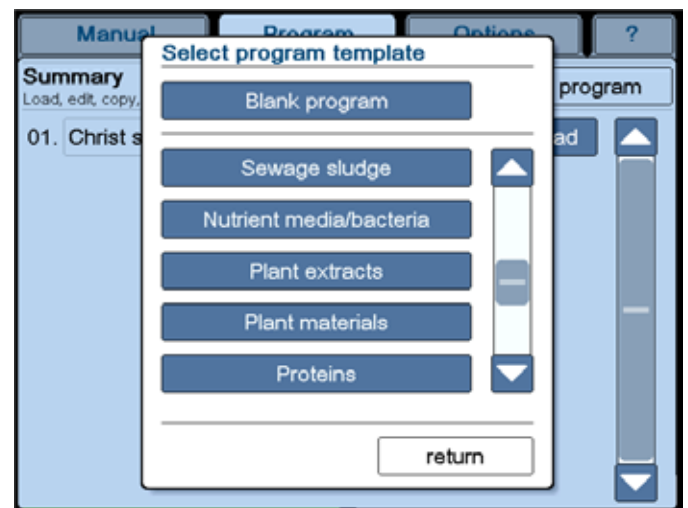
LSCplus controller

With its cutting-edge technologies, the LSCplus system offers an easy-to-use, intuitive user interface. All accessories are also integrated. With automated process sequences, reproducible results are ensured.

- Color touchscreen with clear layout
- Automated or manual sequencing of freeze-drying processes
- Intuitive program entry, using various freeze-drying sequences and recipes
- Memory space for 32 user-defined programs
- Graphic display of the freeze-drying process sequence (target values)
- Selection of various connection options, depending on system configuration
- Extensive message texts and explanations
- Multiple language options
- Selectable units of measure for temperature (°C/°F) and pressure (mbar/hPa/Torr)
- Optional password protection
- Process data acquisition and option for data exchange, via USB or Ethernet



LSCplus color touchscreen



Sample programs for a wide range of applications

LSCplus:
Unique system controller
 Convenient and intuitive

Process monitoring and documentation

Our experience shows that processes must be precisely monitored and documented. This is the only way to achieve precise analysis of a wide range of applications – regardless of the drying recipe and batch size.

Documentation and archiving of all process data is possible with LyoLogplus software, which can be installed on a separate PC. Data can be transferred directly to the PC from the freeze-drying system via USB medium or Ethernet. LyoLogplus enables continuous documentation and subsequent analysis of processes with an intuitive user interface.

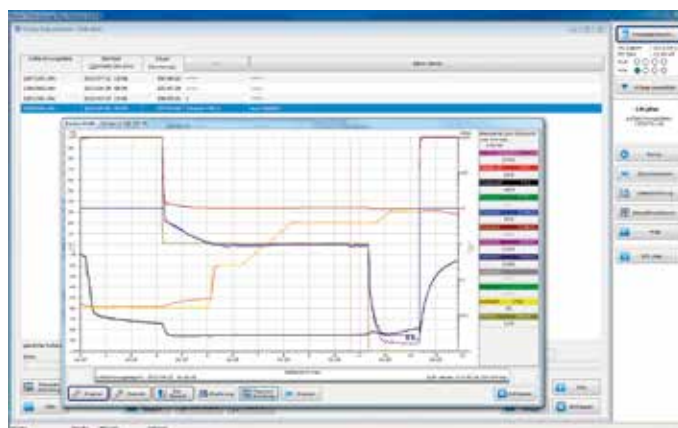
LPCplus is another option. With LPCplus, programs for freeze-drying can be developed and process data observed in real time in a graphic format. LPCplus also offers the same capabilities as LyoLogplus. Operation is consistent and uniform across all unit sizes, as LPCplus is used with larger production freeze-drying systems as well.

Are you planning to scale up?

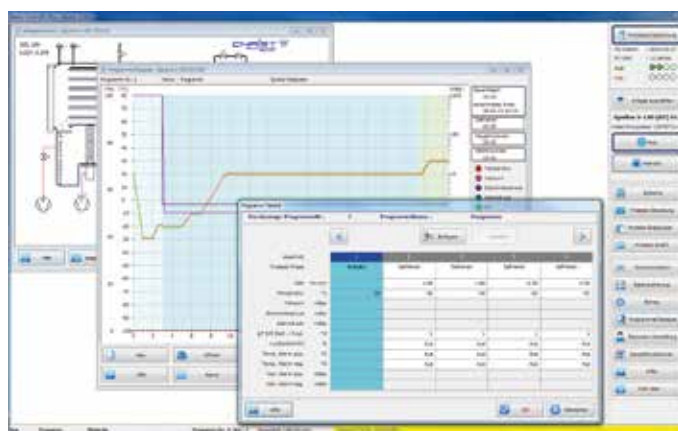
Use simple platform migration from pilot to production scale, with a uniform user interface and identical software solutions.

- Data recording on USB drive
- Simple process documentation with LyoLogplus
- LPCplus for process control and documentation
- Process monitoring with the LyoRx sensor to avoid undesired defrosting effects
- Automatic determination of the freezing point with LyoControl for reliable process control
- Wireless product temperature measurement WTMplus for easy operation, with improved sensor technology
- LyoLogplus and LPCplus with multilingual interface

The system concept for our freeze-drying systems is based on cGMP/GLP guidelines. The LPCplus software is compliant with current GAMP guidelines.



LyoLogplus software for process documentation



LPCplus software for process control and documentation

To the
video for
LPCplus.

Link:

www.martinchrist.de/LPCplus



Process optimization

The LSCplus controller offers numerous options for optimizing your freeze-drying processes. Practical for any user: automatic determination of critical product data.

AutoLyo saves time and money

Use predefined programs and recipes with intelligent interactions for product-related parameters. For example:

- Product temperature
- Ice condensation temperature
- LyoRx (electrical resistance)
- Pressure data (test, comparison between Pirani and capacitive sensors)

Using the values obtained, a self-optimized AutoLyo process can be defined.

Your production is faster and less expensive. Tests for cycle development and transition to production are reduced by about half in comparison with conventional freeze-dryers.

Freezing point

Our LyoRx sensor monitors the electrical resistance and product temperature. From the curves of both data points, you can automatically determine the freezing point of your product. Our LyoControl software makes this possible. Critical product temperatures during the main drying phase can be reliably estimated, thus preventing the product from melting.

Product resistance

The LyoRx sensor allows automated control of the energy supply to the shelf areas during the main drying phase. This limits potential defrosting effects of the product.

Product temperature

Each shelf area can be equipped with WTMPlus and/or a PT100 sensor to measure the product temperature.

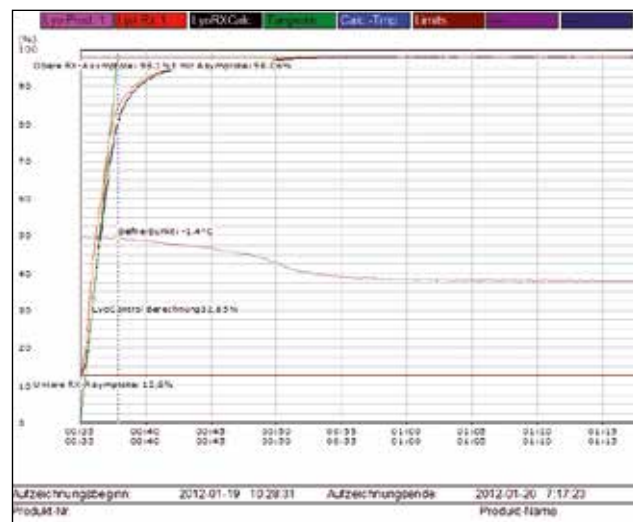
These measurements are displayed in the LSCplus system controls.

Pressure rise test (double-chamber systems)

The transition between main drying and final drying can be determined using the pressure rise test. Valves are placed between the product space and the ice condenser for this purpose. They are closed briefly during the main drying phase. If the pressure rise in the product chamber with the intermediate valves closed remains below a certain threshold, then there is no more sublimating water left in the product and final drying can be started automatically.

Comparative pressure measurement

By using two different vacuum measurement probes (using the Pirani and capacitive measurement principles), the end of the main drying phase can be derived. When the difference between the pressure measurements falls below a preselected threshold, final drying is started automatically.



LyoControl: Determining the freezing point with LyoLogplus

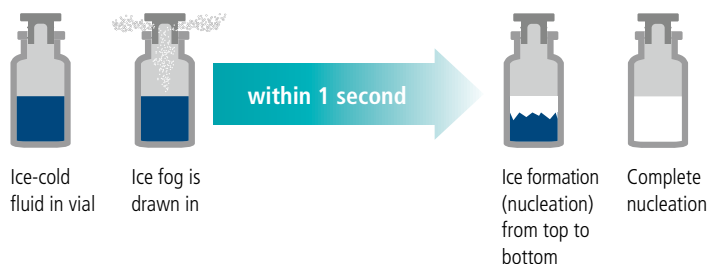
Innovative functions

LyoCoN – simultaneous freezing at the push of a button

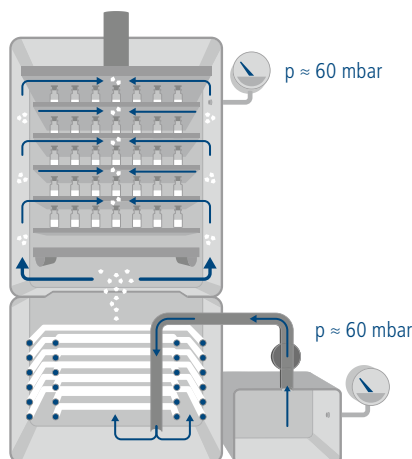
Due to thermodynamic constraints, freezing the same product in many vials is not a parallel process, but a stochastic one. The differences in the length of time for subcooling lead to difference in crystal structures, and ultimately to inhomogeneity of the drying results (e.g. residual moisture, appearance). The ice-fog principle that we use initiates solidification abruptly by simultaneously seeding each vial with an ice crystal. The special feature of LyoCoN is that the ice fog is not generated externally, but instead comes from prior controlled evaporation out of the product itself ("self-feeding"). The ice crystals that have frozen on the cold ice condenser of the freeze-dryer in the meantime are "shot back" as an ultrafine ice fog into each individual vial under vacuum.

The unique features in summary:

- Ice fog is generated from the product itself; no external media such as WFI or LN₂ are needed. cGMP compliant!
- Surprisingly simple principle – vacuum is already available
- Design does not need to handle overpressure, so it is ideal for smaller pilot systems
- No blow-off of gases from the chamber (which could contain product)
- Simple upgrade to existing systems
- LyoCoN can also be cleanly integrated in CIP/SIP and VHP processes
- Few additional components required – inexpensive



Functional principle of LyoCoN from Martin Christ



Principle sketch of the ice fog flow in the product chamber.



LyoCoN vessel and connected pilot system Epsilon 2-10D LSCplus.

To the video
for LyoCoN.

Link:

www.martinchrist.de/LyoCoN



Innovative functions

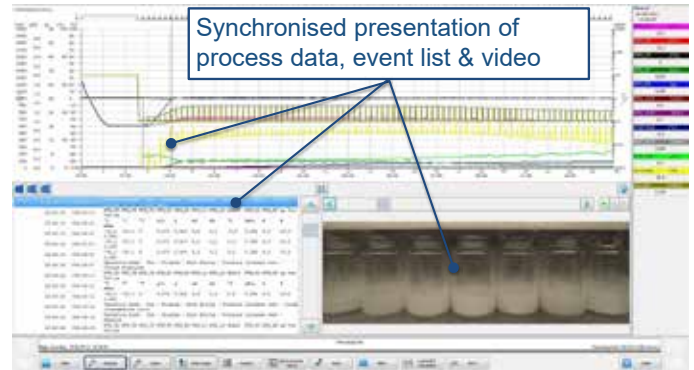
LyoCam – greater transparency in freeze-drying

Because process times run to several hours, observation of drying is nearly impossible in practice. And yet, process incidents that last only seconds or minutes can result in anything from a loss of “pharmaceutical elegance” to product collapse and the loss of the batch. This is where the LyoCam from Martin Christ comes in. A full HD industrial camera continually records the product at intervals preselected for each program step. When using LyoCoN controlled nucleation, for example, the freezing process is documented every second. The behavior of the ice condenser (allocation) can also be documented. The decisive feature, however, is coupling the image to the LPCplus SCADA system of the freeze-dryer.

To put it simply: using a slider on the process control screen, the images can be viewed in perfect synchronization with the recorded data. The same goes for process segments in the event list. A perfect tool for process optimisation and quality control!

The unique features in summary:

- Monitoring and analysis of freeze-drying processes
- Fully linked to the LPCplus graphic process interface
- Identical timestamp as the other recorded process parameters
- Intelligent image storage, that is, image frequency linked to segment changes and special process events (e.g. alarms)
- Cold-light LED lamps to avoid energy input
- Up to four cameras are possible with LPCplus



Synchronous images to the process graph and event list shown in LPCplus



LyoCam in the housing.

To the video
for LyoCam.

Link:
www.martinchrist.de/LyoCam



WTMplus in pilot freeze-dryers from Martin Christ

The WTMplus wireless temperature measurement system with up to 16 product sensors is available as an option. With special functions like:

- Fully integrated in the LSCplus system controller
- No separate modules required for monitoring and graphic interface
- Antennas inside the drying chamber for maximum coverage of all vial positions
- Improved sensor technology, compact and robust design
- High precision ± 0.5 K (max. ± 1 K)
- No falsification of measured values due to heat input to the samples, as with wired sensors
- Excellent value for the price



LyoBalance – precisely determine the drying rate

LyoBalance provides the ultimate direct measurement of drying progress. Integration of operations in the LSCplus system controller, with data monitoring via LyoLogplus or LPCplus software, is entirely innovative.

This means that no additional software is required for recording mass loss. The drying rate (g/h) is also documented. Comparative tests can be directly evaluated by the user and cycles can be optimized based on real data.





**Future-proof
with Martin
Christ**

We supply applications expertise

We offer holistic solutions.

This includes performing test drying and process optimisation with customer products in our applications lab. We also test new detailed solutions available on the market, such as in the field of packaging materials or PAT.

Machines with various levels of performance and equipment are available in our in-house test lab.

If needed, we incorporate qualified specialists from the relevant subject areas, such as pharmaceuticals or biotech.

Holding scientific seminars is a tradition at Martin Christ. We invite outside speakers from a wide range of specialties to share the latest state-of-the-art technology with participants.

Recently we have added hands-on practice seminars, where participants train to work with and on the machines. Qualification and calibration procedures are also practiced.

On request we will also hold in-house seminars at your facility. Challenge us!



Lab worker extracting samples while the GT process is running



User training in the applications lab



Freeze-drying seminar at Martin Christ

Technical data

Specifications	Epsilon 1-4 LSCplus	Epsilon 2-4 LSCplus
Ice condenser <ul style="list-style-type: none"> • Max. Capacity • Performance • Temperature (approx.) • Chamber volume (approx.) 	Single-chamber system 4 kg 3 kg/24 h -55 °C 41 l	Single-chamber system 4 kg 3 kg/24 h -88 °C 41 l
Shelf area system: <ul style="list-style-type: none"> • Dimensions (W x D) • Temperature range (approx.) • Temperature precision 	270 mm x 400 mm -45 °C to +60 °C <±2 K	270 mm x 400 mm -75 °C to +60 °C <±2 K
Chiller	1x 0.51 kW	2x 0.51 kW
Dimensions (W x H x D) with stoppering device (mm)	780 x 975 x 550	780 x 975 x 550
Weight (approx.)	110 kg	140 kg
Electrical supply (other voltages on request)	230 V / 50 Hz 230 V / 60 Hz 208 V / 60 Hz	230 V / 50 Hz 230 V / 60 Hz 208 V / 60 Hz
Cooling water	○	○
Noise level per DIN 46535 (approx.)	54 db(A)	51 db(A)
Defrost function	Shelf radiation (hot gas optional)	Shelf radiation (hot gas optional)
Vial stoppering <ul style="list-style-type: none"> • Manual • Hydraulic • Automatic "ventilation – stoppering – shelf" function 	● ○ ○	● ○ ○
Process control and safety functions: <ul style="list-style-type: none"> • LyoCoN controlled nucleation • Pressure rise test • Safety pressure • Safe value to prevent defrosting (R_x) • Target/actual comparison $T_{product}$ and $T_{shelf\ area}$ 	– – ● ● ●	– – ● ● ●
PAT tools: <ul style="list-style-type: none"> • LyoControl (determining freezing point, product resistance) • Product temperature measurement • WTMplus wireless temperature measurement • Capacitive pressure measurement • Comparative pressure measurement • LyoBalance Scale system • LyoCam camera system 	● ● ○ ○ ○ ○ ○	● ● ○ ○ ○ ○ ○
Programming module for up to 32 recipes, 64 segments	●	●
Ethernet interface	●	●
USB	○	○
LyoLogplus software for process documentation	○	○
LPCplus software for process control and documentation	○	○

● = Standard ○ = Option – = not available

Subject to technical modifications.

Capacities and shelf dimensions

Epsilon 1-4 LSCplus & Epsilon 2-4 LSCplus

Shelf area dimensions (W x D x H): 270 mm x 400 mm x 20 mm								
Vial volume (total)			2 ml	6 ml	10 ml	20 ml	50 ml	100 ml
Number of shelves	Area (m ²)	Spacing (mm)	Max. number of vials ^a					
1	0,108	140	430	225	180	120	50	30

Epsilon 2-6D LSCplus

Shelf area dimensions (W x D x H): 225 mm x 300 mm x 15 mm									
Vial volume (total)			2 ml	6 ml	10 ml	20 ml	50 ml	100 ml	
Number of shelves	Area (m ²)	Spacing (mm)	Max. number of vials ^a						
1	0.07	250	280	130	115	72	36	21	
2	0.14	117	560	260	230	144	72	42	
3	0.21	73	840	390	345	216			
4	0.27	51	For trays, MTP/deep well plates, etc.						
5	0.34	40							
6	0.40	31							

Epsilon 2-10D LSCplus

Shelf area dimensions (W x D x H): 350 mm x 400 mm x 15 mm									
Vial volume (total)			2 ml	6 ml	10 ml	20 ml	50 ml	100 ml	
Number of shelves	Area (m ²)	Spacing (mm)	Max. number of vials ^a						
1	0.14	354	613	326	266	165	83	49	
2	0.28	170	1226	652	532	330	166	98	
3	0.42	108	1839	978	798	495	249		
4	0.56	77	2452	1304	1064	660			
5	0.70	59	3065	1630					
6	0.84	47	For trays, MTP/deep well plates, etc.						
7	0.98	38							

^{a)} Data for maximum load; when using trays or frames reduce by 10 %

Standard configuration

Epsilon 2-12D LSCplus

Shelf area dimensions (W x D x H): 350 mm x 450 mm x 15 mm								
Vial volume (total)			2 ml	6 ml	10 ml	20 ml	50 ml	100 ml
Number of shelves	Area (m ²)	Spacing (mm)	Max. number of vials ^a					
1	0.16	381	688	357	294	189	96	60
2	0.32	183	1376	714	588	378	192	120
3	0.47	117	2064	1071	882	567	288	180
4	0.63	84	2752	1428	1176	756	756	
5	0.79	64	3440	1785	1470			
6	0.95	51	4128					

Epsilon 2-16D LSCplus

Shelf area dimensions (W x D x H): 300 mm x 400 mm x 14,5 mm		
Number of shelves	Area (m ²)	Spacing (mm)
1	0.12	963
2	0.24	474
3	0.36	311
4	0.48	230
5	0.60	181
6	0.72	148
7	0.84	125
8	0.96	107
9	1.08	94
10	1.20	83
11	1.32	74
12	1.44	67

Chiefly used with trays and other formats, vials can also be lyophilized, but not automatically closed.

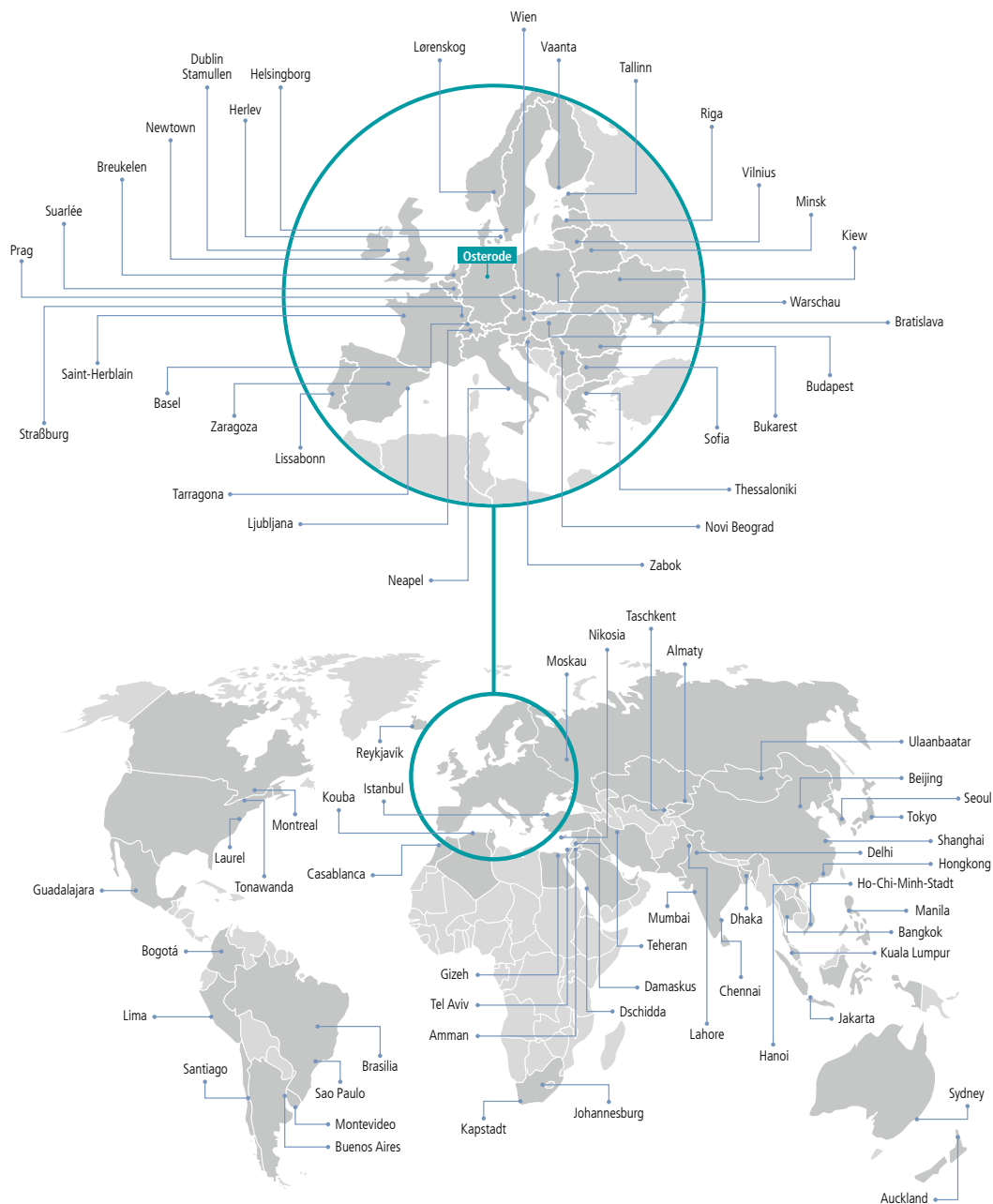


Vial size overview

Total vial volume	2 ml	6 ml	10 ml	20 ml	50 ml	100 ml
Vial type	2R	6R	10R	20R	50H	100H
‡ mm Vial only	35	40	45	55	73	95
‡ mm with Lyo-plug	45	50	55	65	83	105
∅ mm	16	22	24	30	43	52
Net fill volume at 1 cm fill height (ml)	16	22	24	30	43	52

Global service for local production reliability

Our systems are operating successfully in over 70 countries around the world. An international network of partners is available for service and qualification work. Our specialists can also be engaged quickly around the world, either remotely or on-site in person.



Selected locations of our representatives.

An overview of all representatives with detailed contact information can be found at www.martinchrist.de

Our product range

With a unique, broadly classified program of machines and accessories, we provide freeze-drying systems and vacuum concentrators for any application. Challenge us!



- 1 Freeze-drying systems for industrial production, with ice-condensing capacity from 20 to 500 kg, individual system project planning incl. loading and unloading systems.
- 2 Pilot freeze-drying systems for process development and optimisation, with ice condenser capacities from 4 to 16 kg.
- 3 Freeze-drying systems for routine applications, research and development, with ice condensing capacities from 2 to 24 kg.
- 4 Rotary vacuum concentrators for routine applications up to evaporation at the high end of pharma research.



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