



Helium Operators Familiarization Program

Unit 323 – Helium Compressors

Doha, 07/2012 | Audrey Schuller

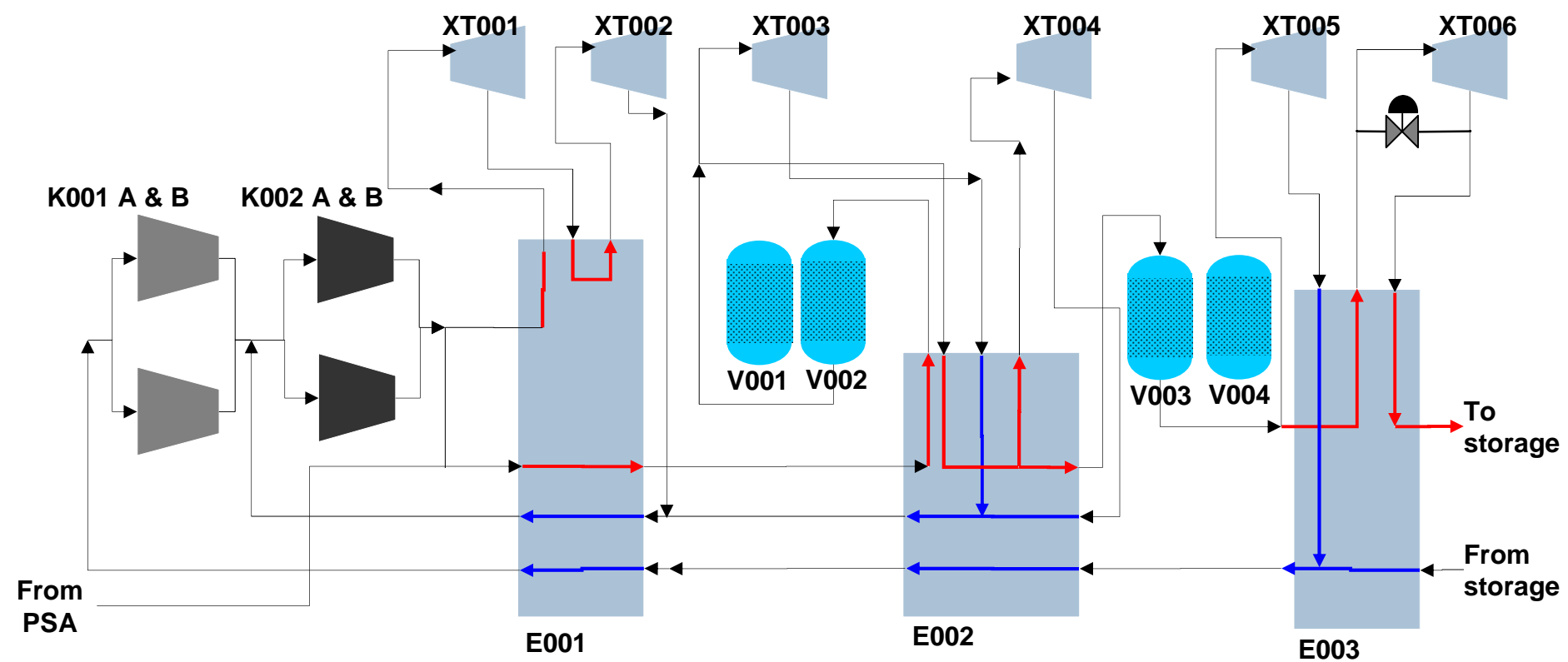
Course Agenda

■ Introduction

- Screw compressors
- Oil Removal Systems
- Process of the Helium Compression
- Process regulation

Introduction

- Helium Compressors are used in the helium cycle for Helium liquefaction
- Compressed Helium is expanded in 6 turbines to provide the cold duty needed for liquefaction



Course Agenda

- Introduction

- **Screw compressors**

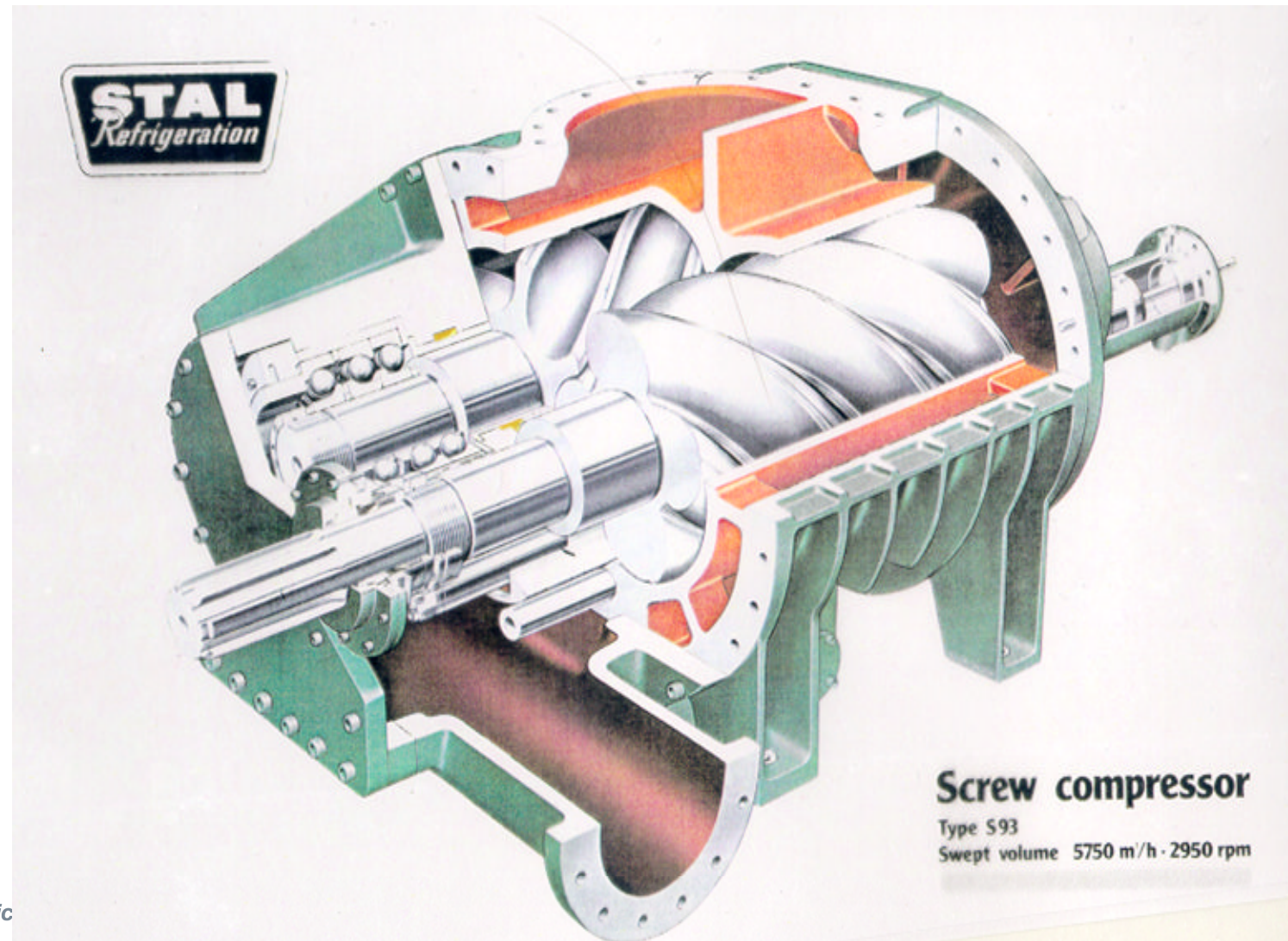
- ▣ Presentation of screw compressors
- ▣ Operation
- ▣ Control of the flow rate
- ▣ Functions of the oil
- ▣ Slide valves

- Oil Removal System

- Process of the Helium Compression

- Process regulation

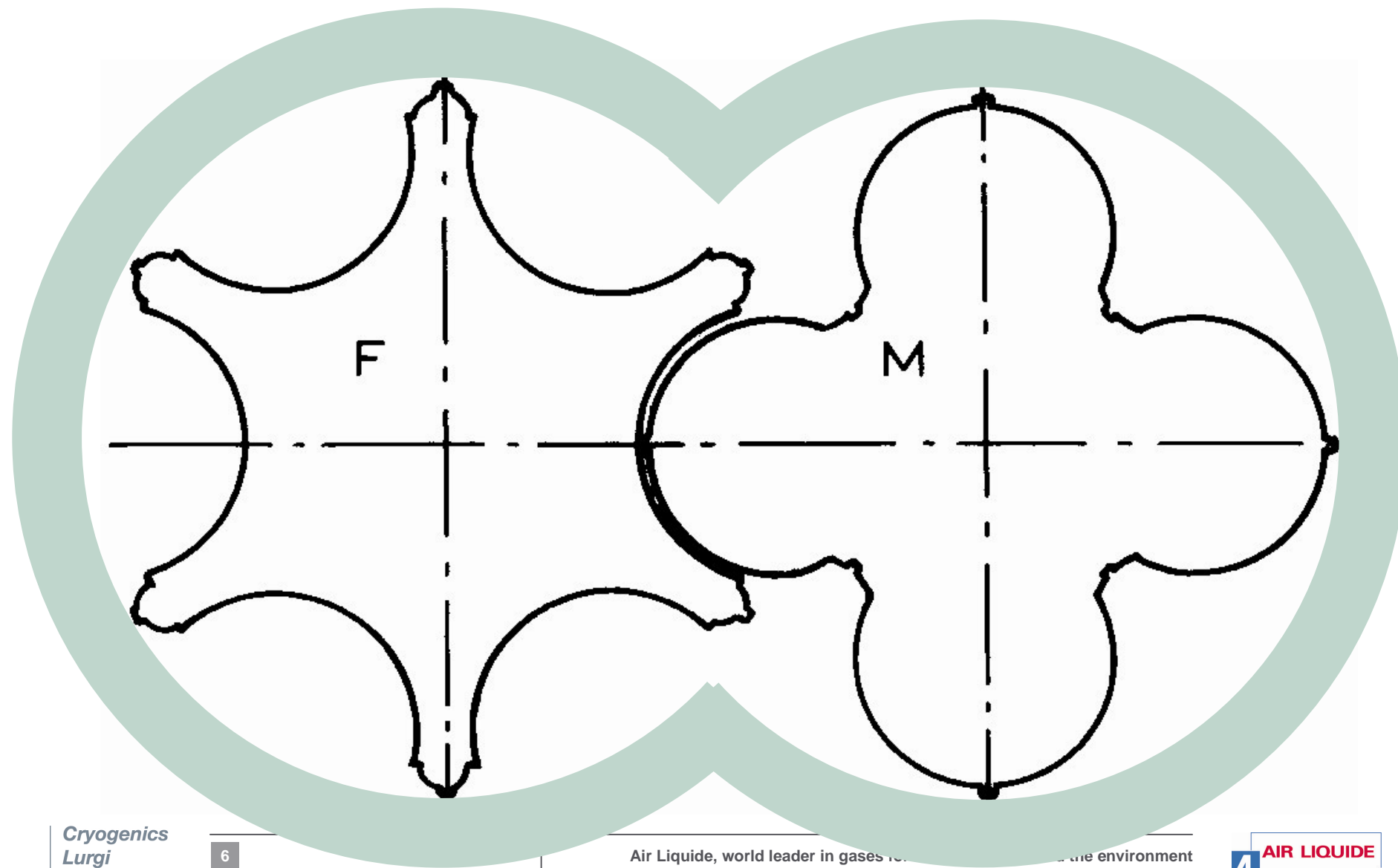
Screw compressor – Presentation



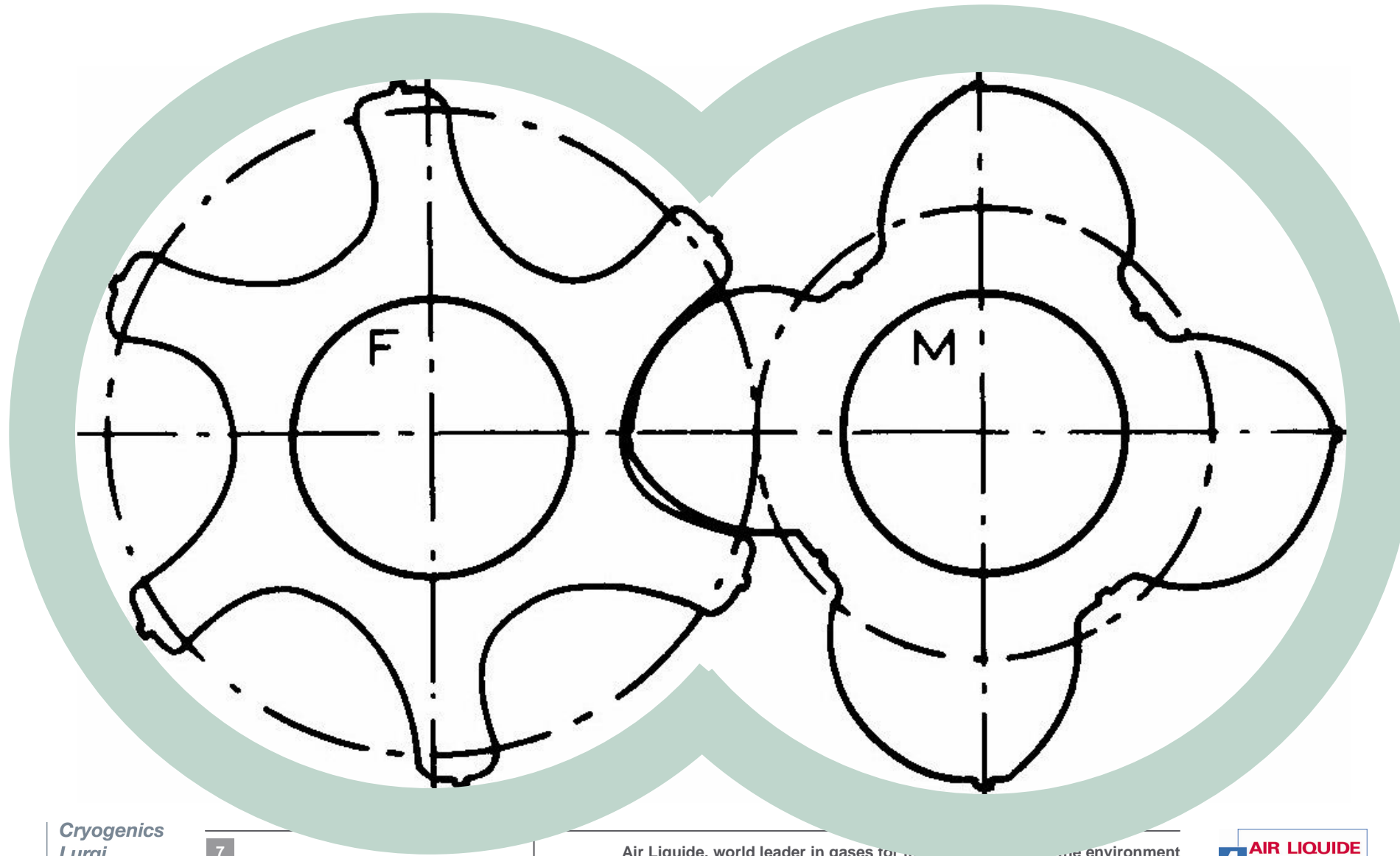
Cryogenic
Lurgi
Zimmer

GLOBAL E&C SOLUTIONS
AIR LIQUIDE

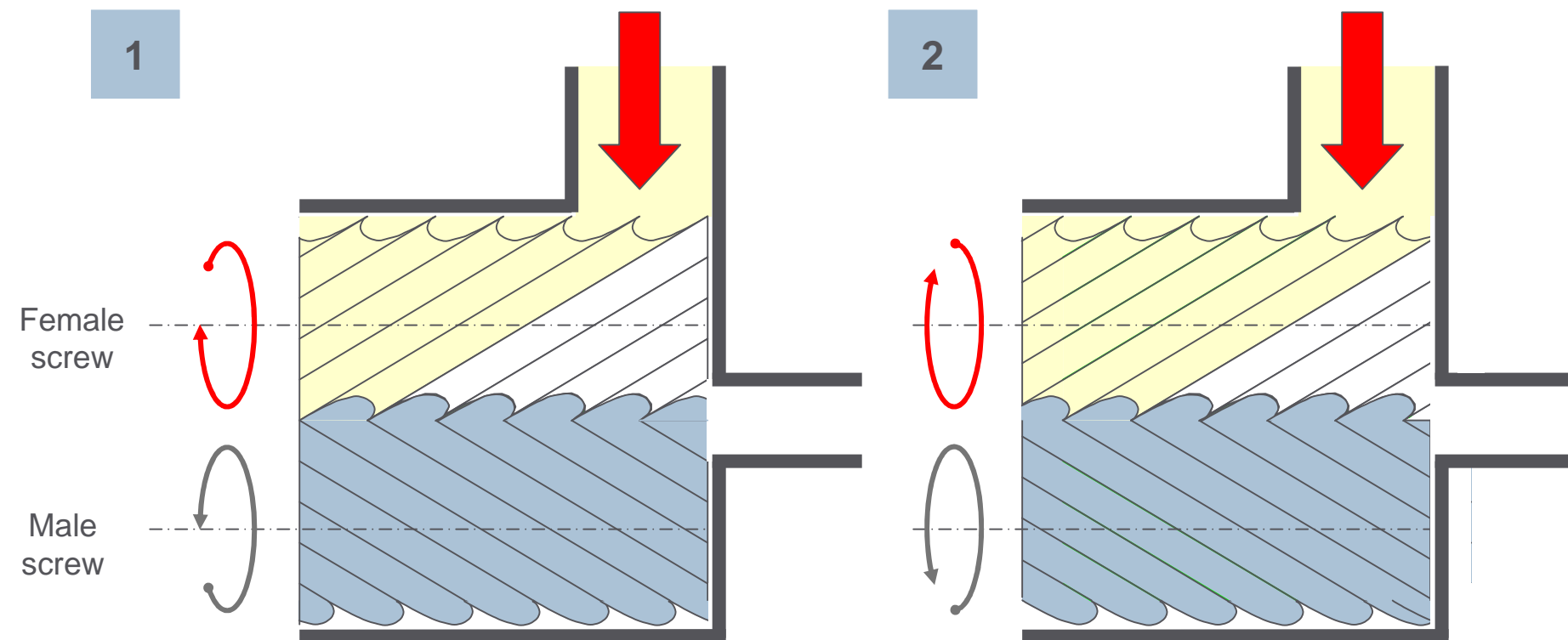
Screw compressor – Rotors – Symmetrical profiles



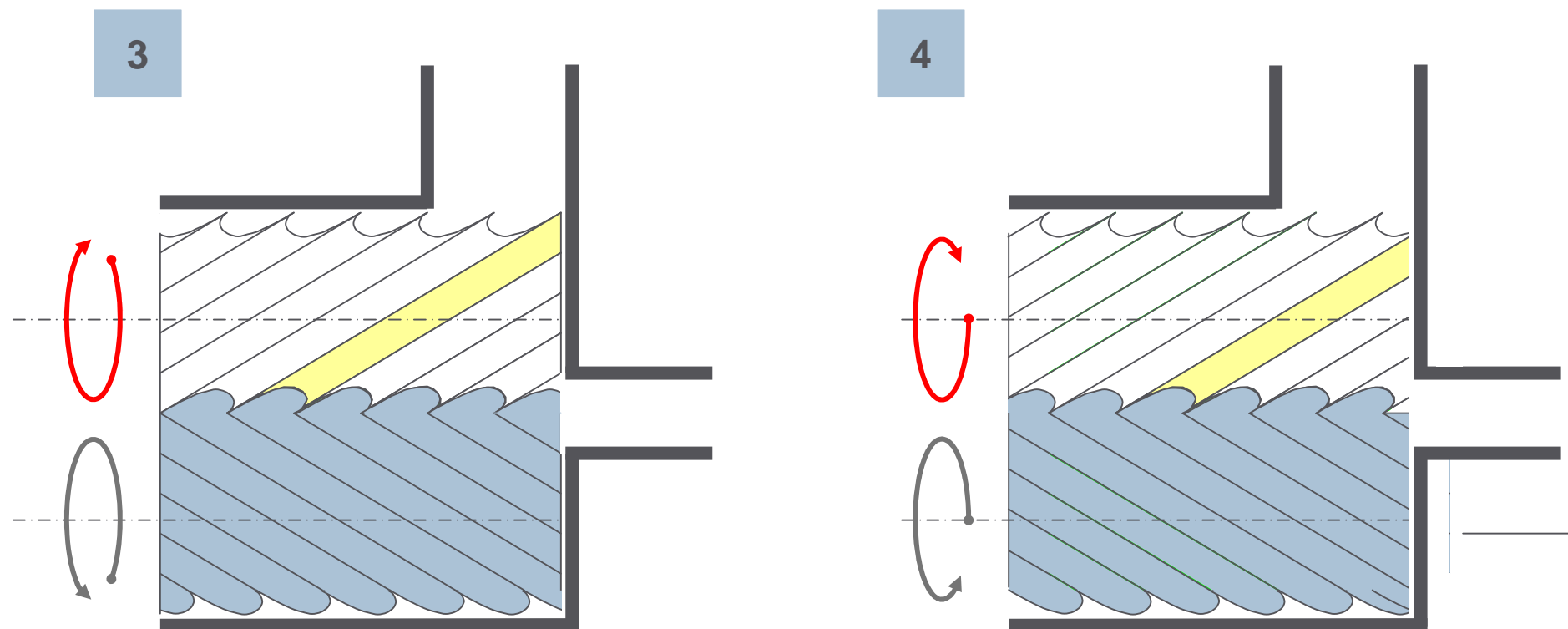
Screw compressor – Rotors – Asymmetrical profiles



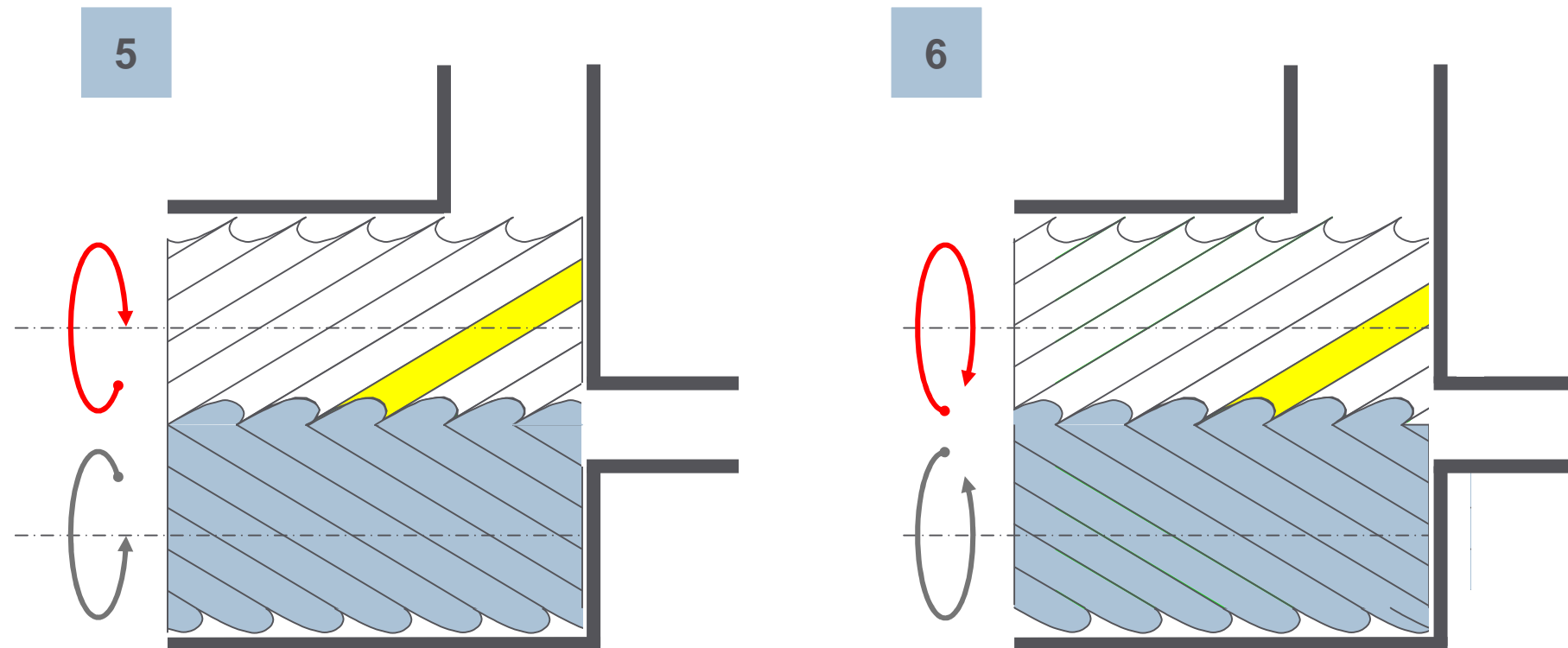
Screw compressor – Operation – Steps 1 and 2



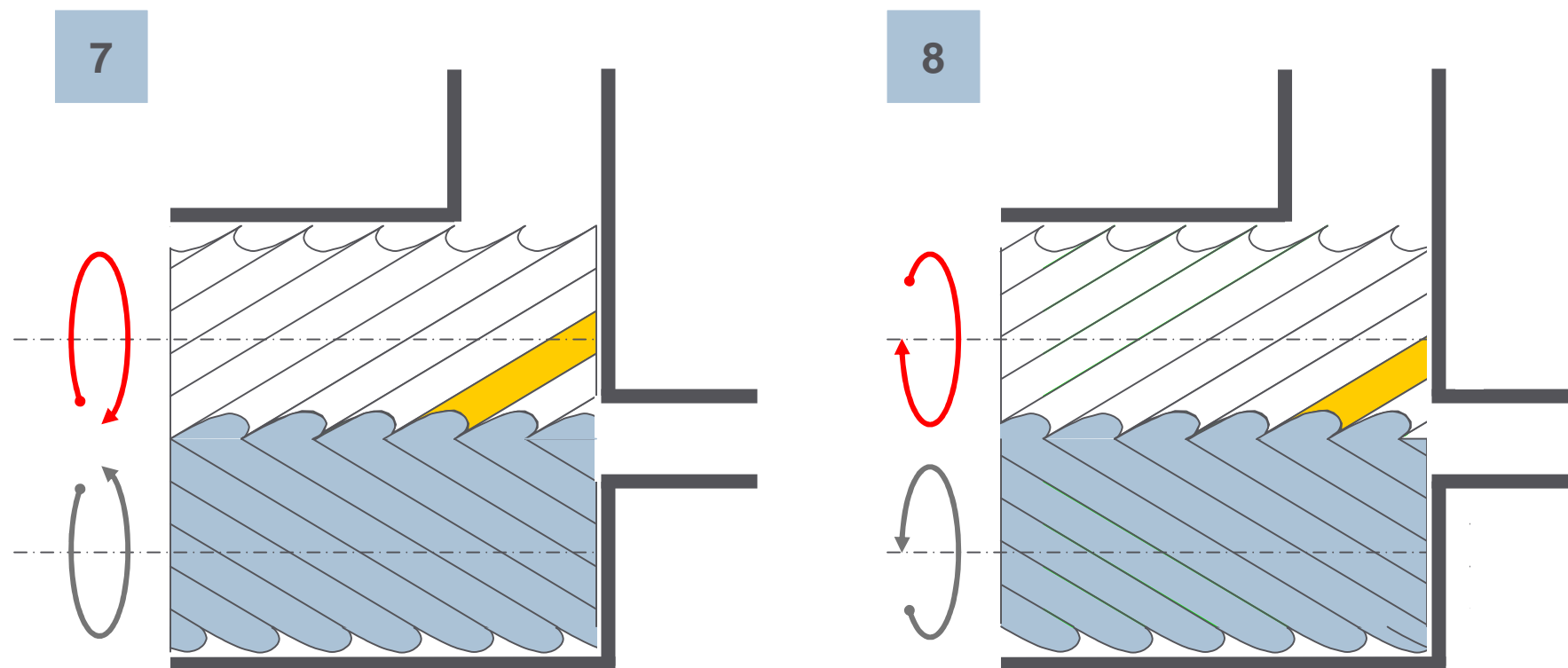
Screw compressor – Operation – Steps 3 and 4



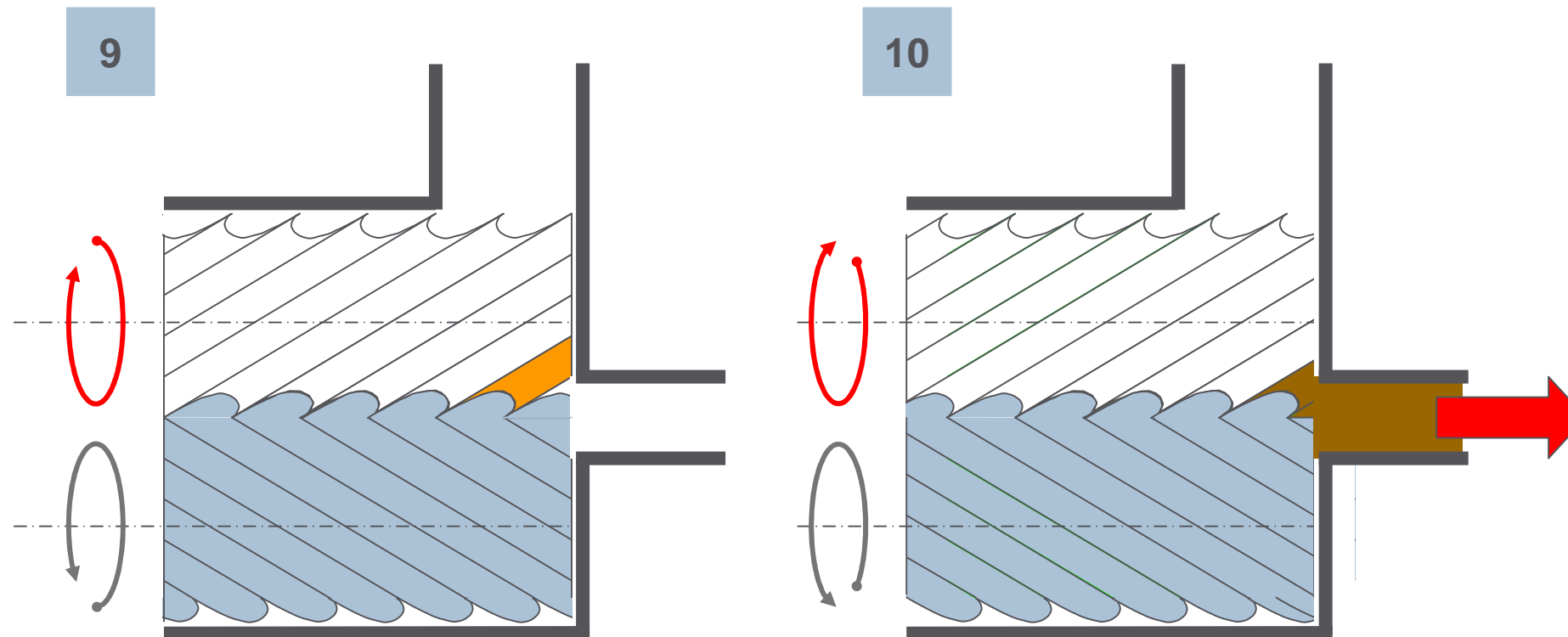
Screw compressor – Operation – Steps 5 and 6



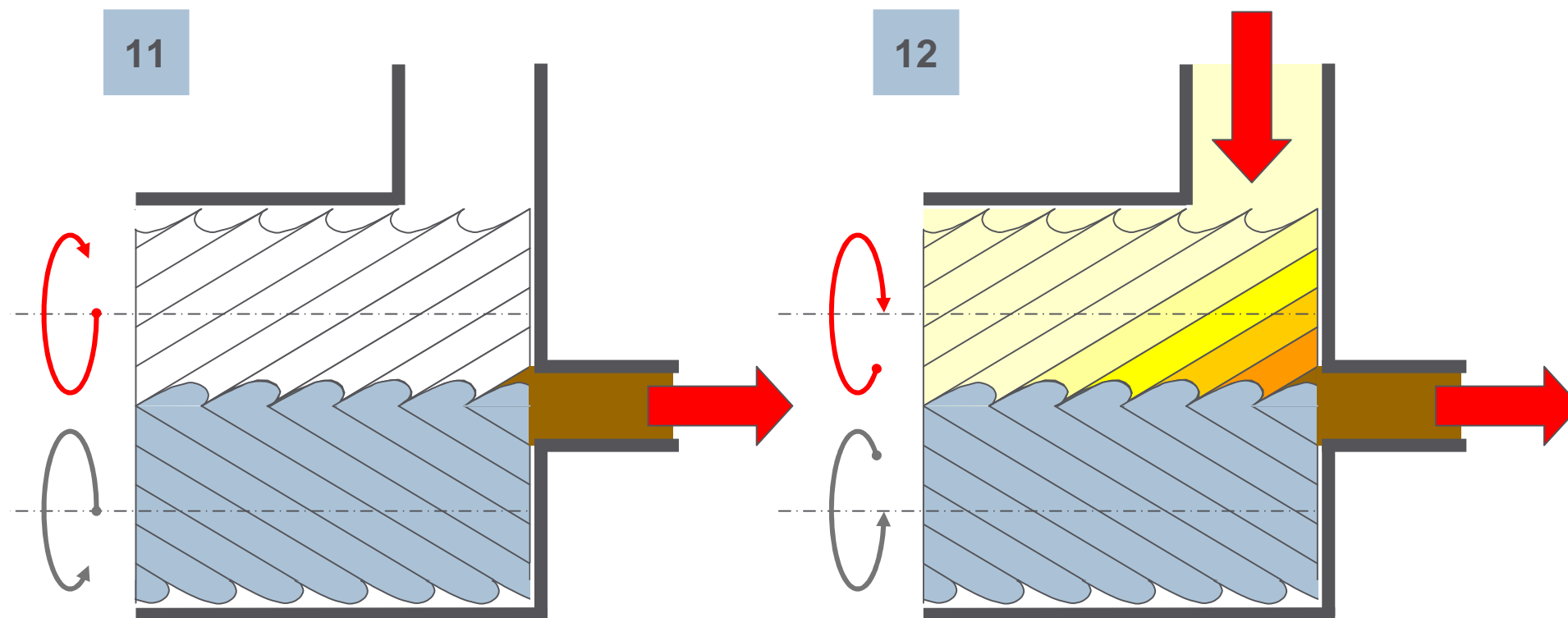
Screw compressor – Operation – Steps 7 and 8



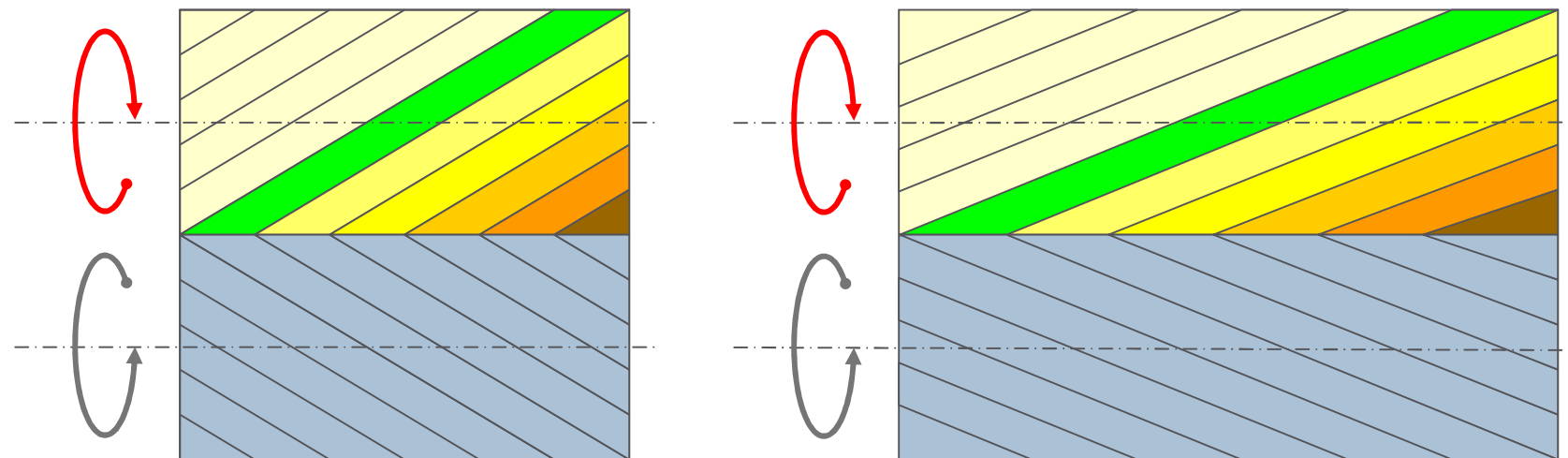
Screw compressor – Operation – Steps 9 and 10



Screw compressor – Operation – Steps 11 and 12



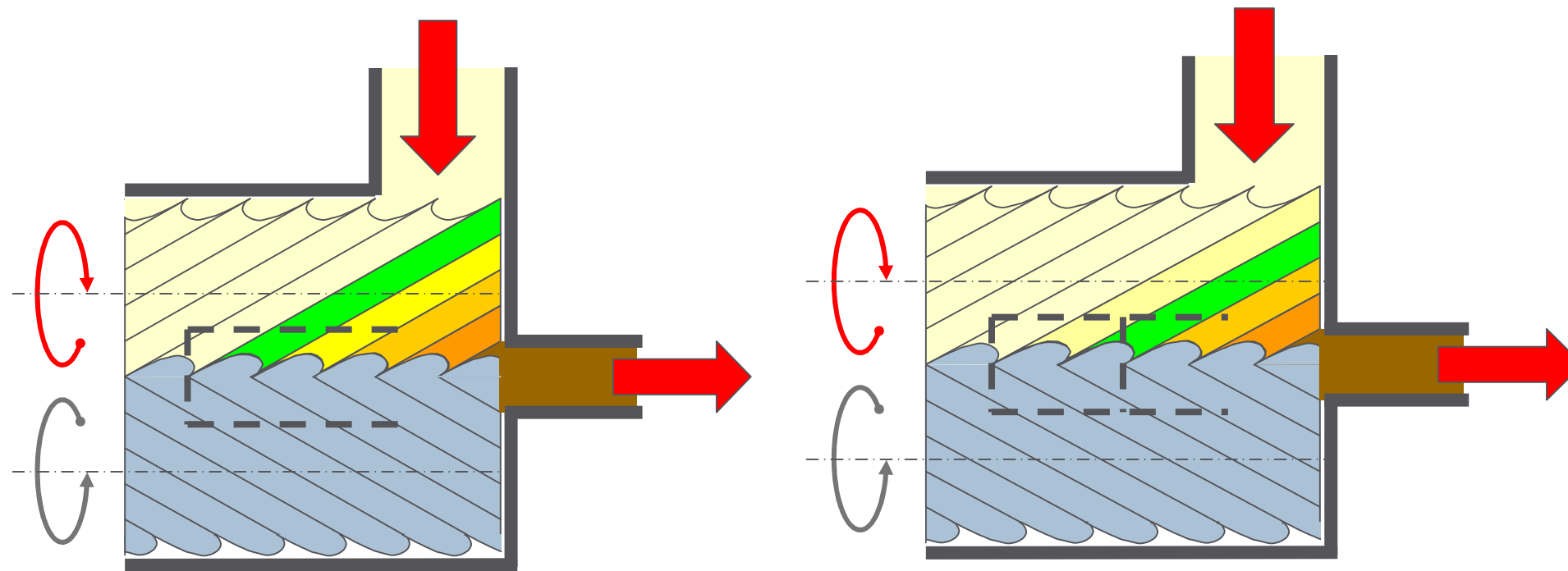
Screw compressor – Volume flow



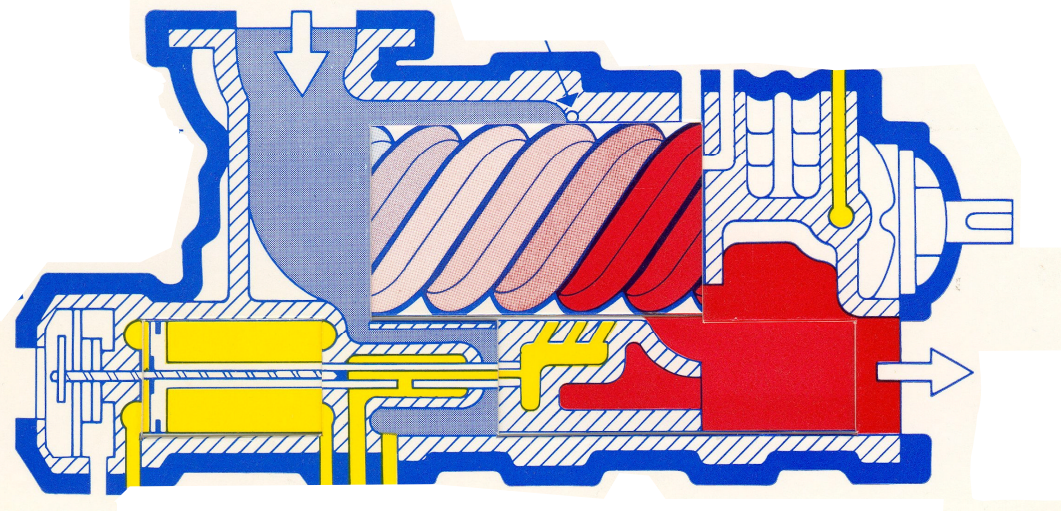
The volume flow of a screw compressor changes:

- With the **length** of the screw,
- With the **diameter** of the screw.

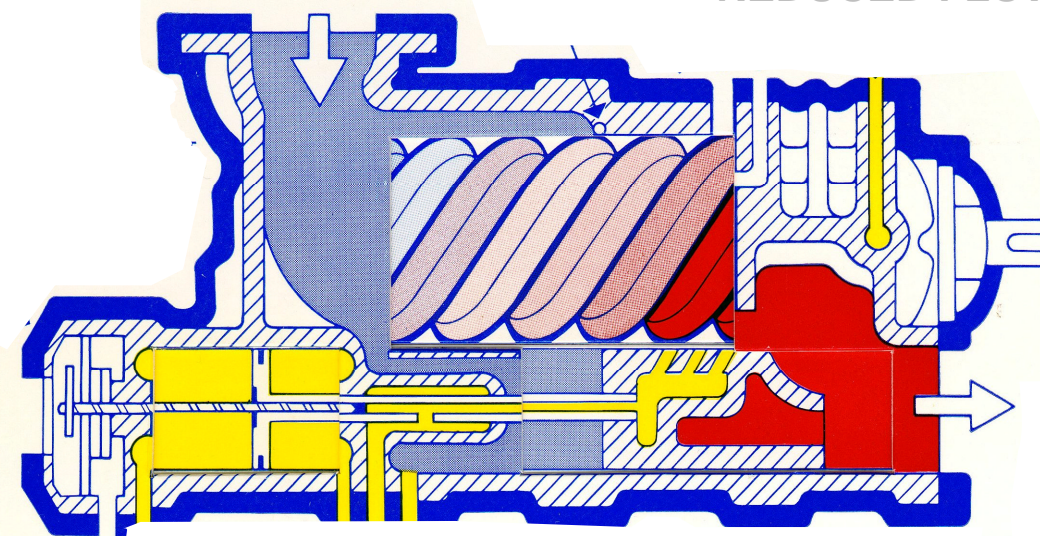
Screw compressor – Control of the flow rate



Screw compressor – Control of the flow rate

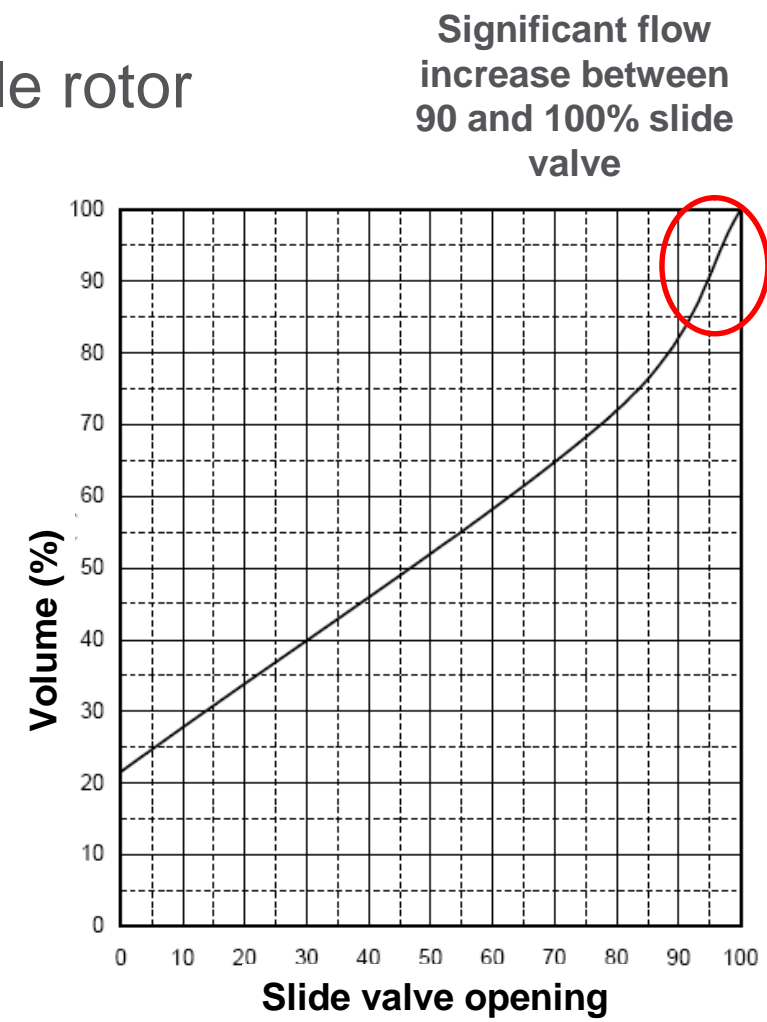
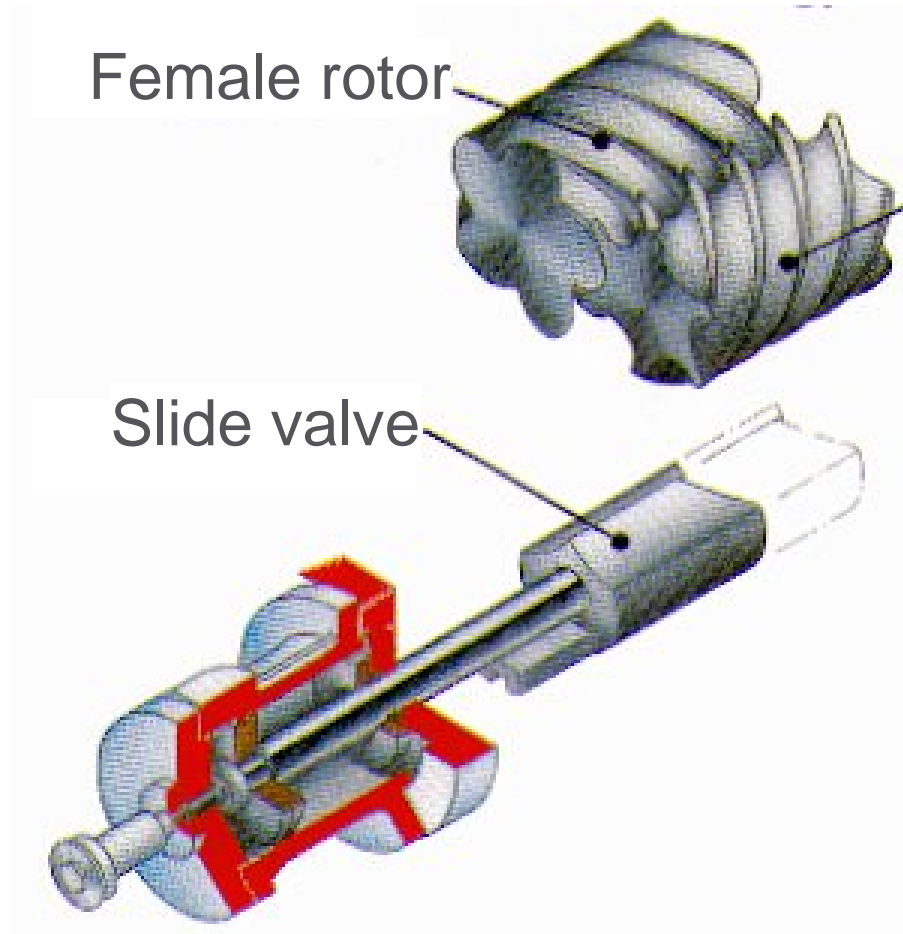


FULL FLOW



REDUCED FLOW

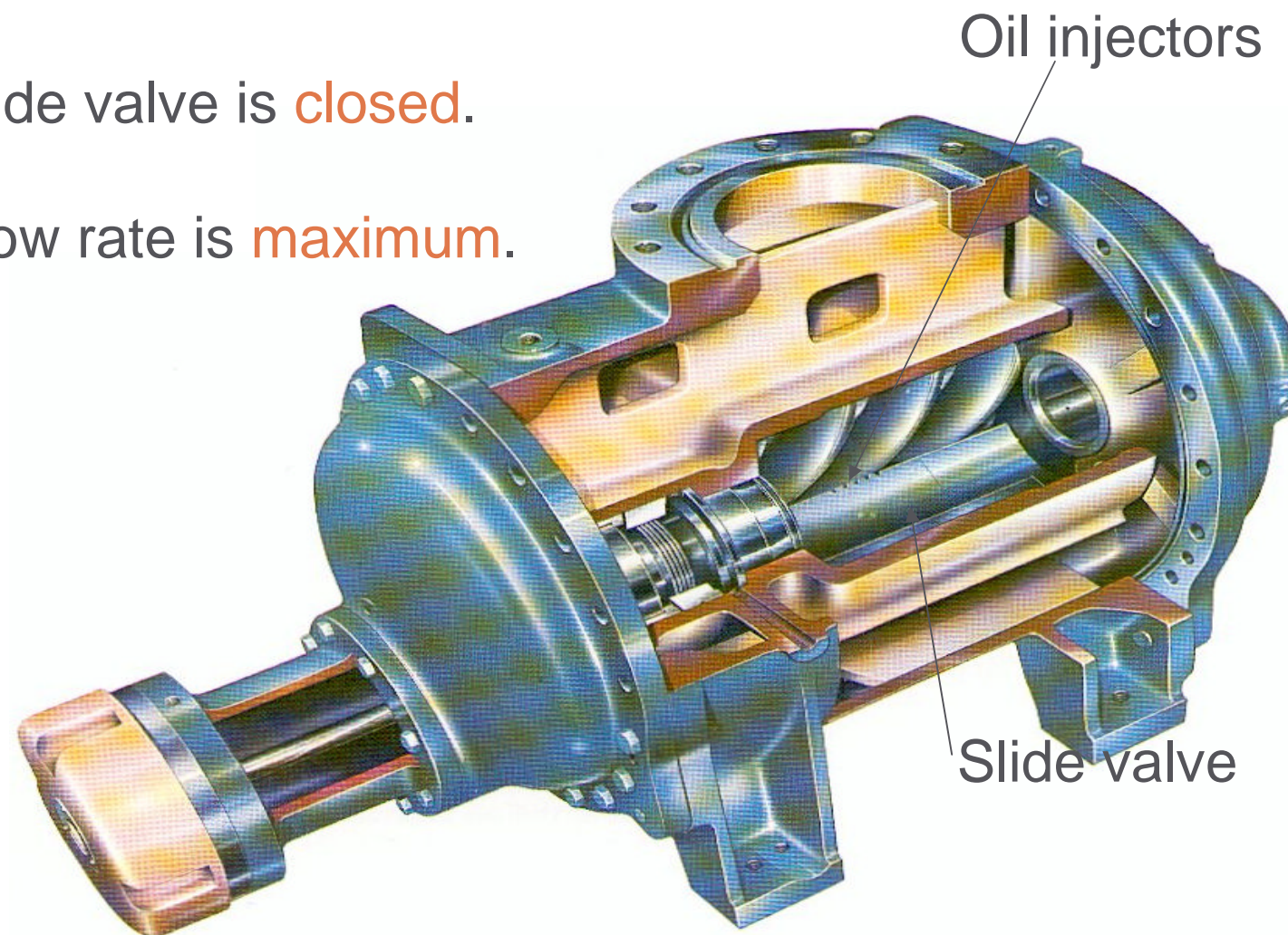
Screw compressor – Control of the flow rate



Screw compressor – Control of the flow rate

Slide valve is **closed**.

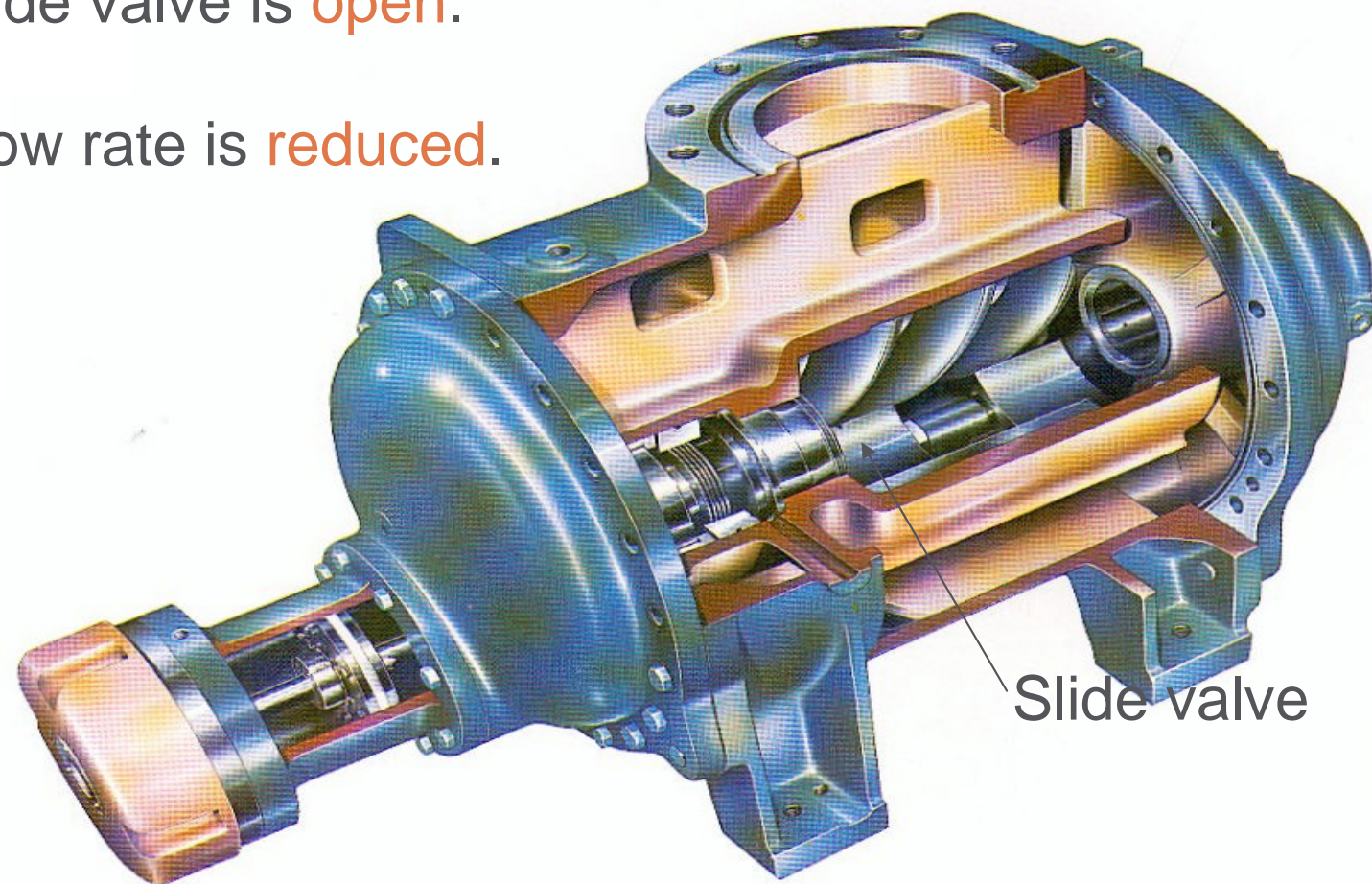
Flow rate is **maximum**.



Screw compressor – Control of the flow rate

Slide valve is **open**.

Flow rate is **reduced**.



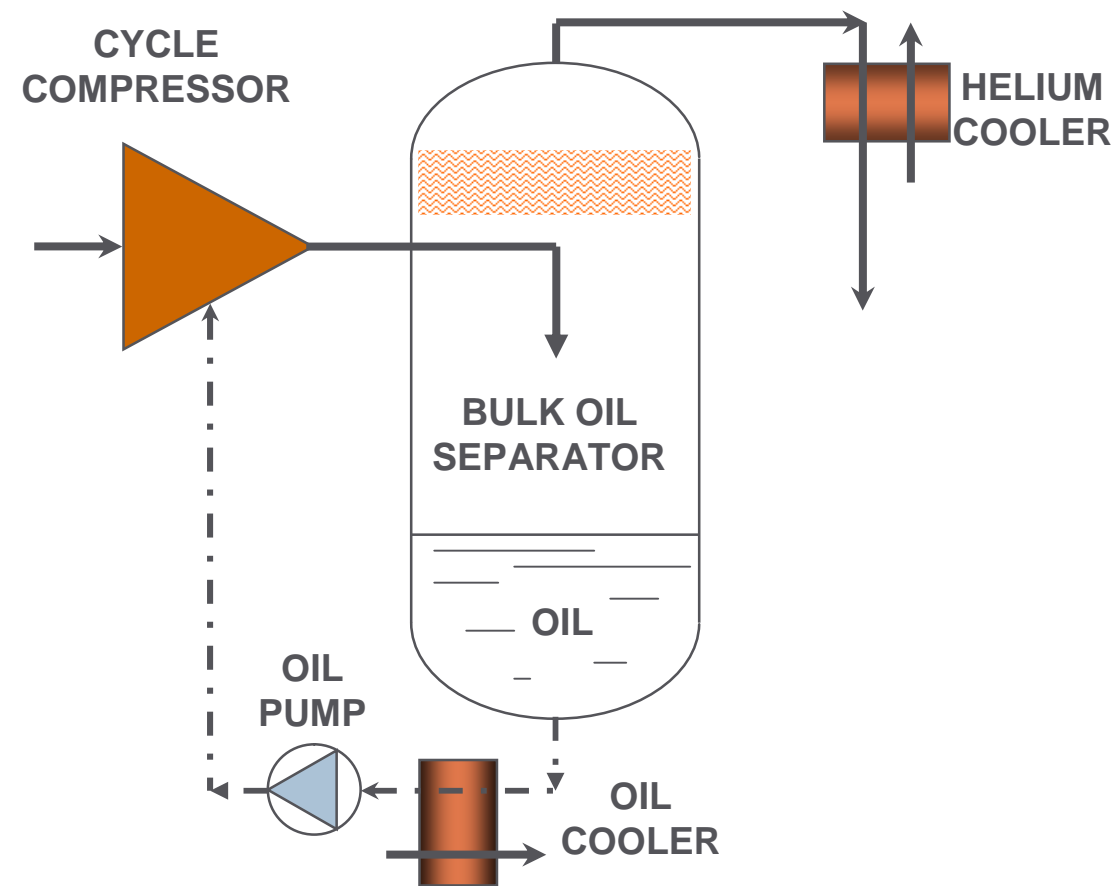
Screw compressor – Functions of oil

- Oil is injected during the compression phase,
- It is finely dispersed
- Its contact with Helium is very large
- It absorbs the major part of the compression heat
- It improves the leak tightness between the rotors
- It lubricates the compressor.

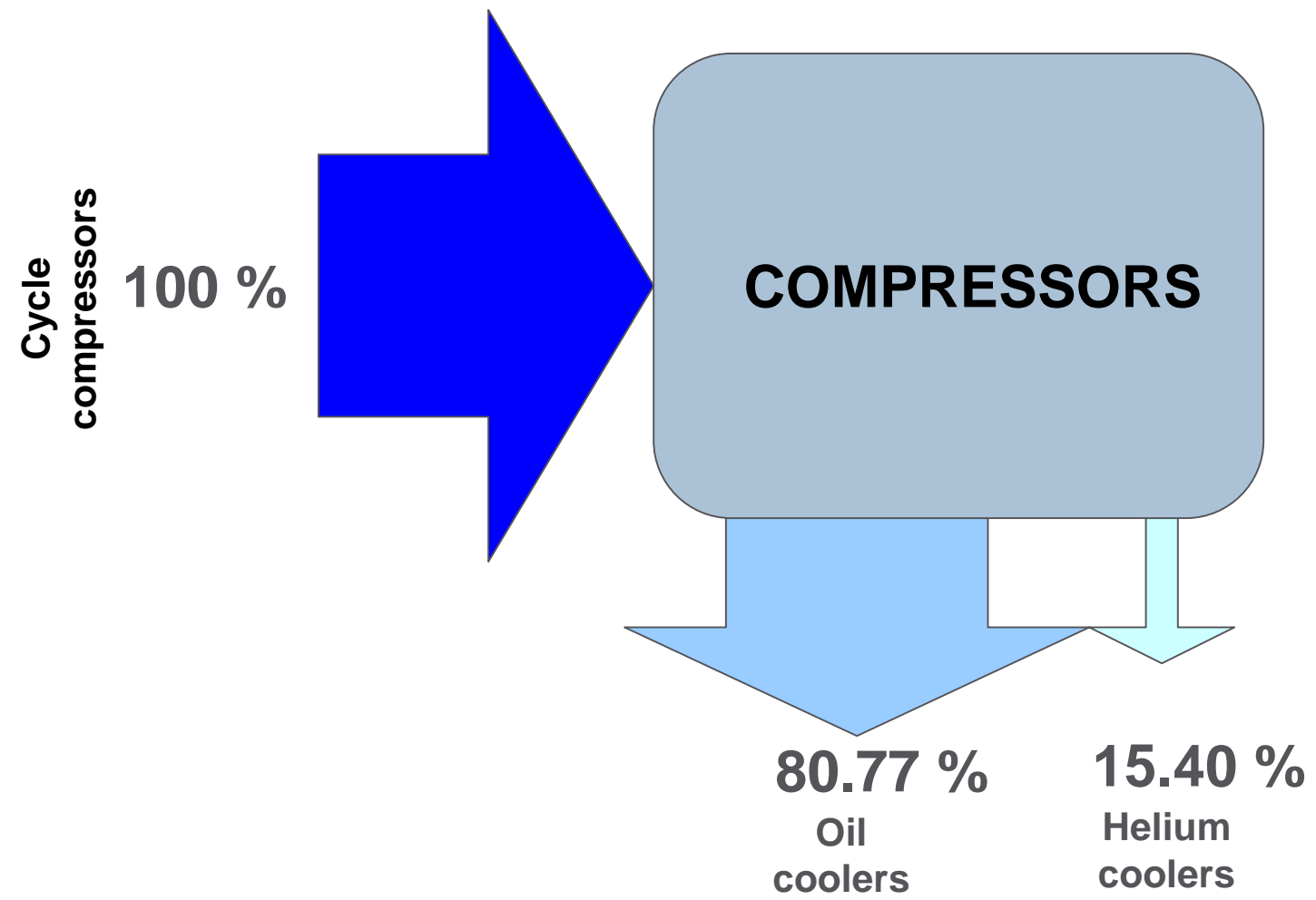
Screw compressor – Oil compression

- The mass flow of the oil is 43 times more important than Helium's
- An oil lubricated screw compressor for Helium is an oil pump!
- Fortunately, the oil volume flow is only 1% of Helium's.

Screw compressor – Oil separation system



Screw compressor – Energy



Screw compressor – Compression station



Cryogenics
Lurgi
Zimmer

24

Air Liquide, world leader in gases for industry, health and the environment



Screw compressor – Compression station



Cryogenics
Lurgi
Zimmer

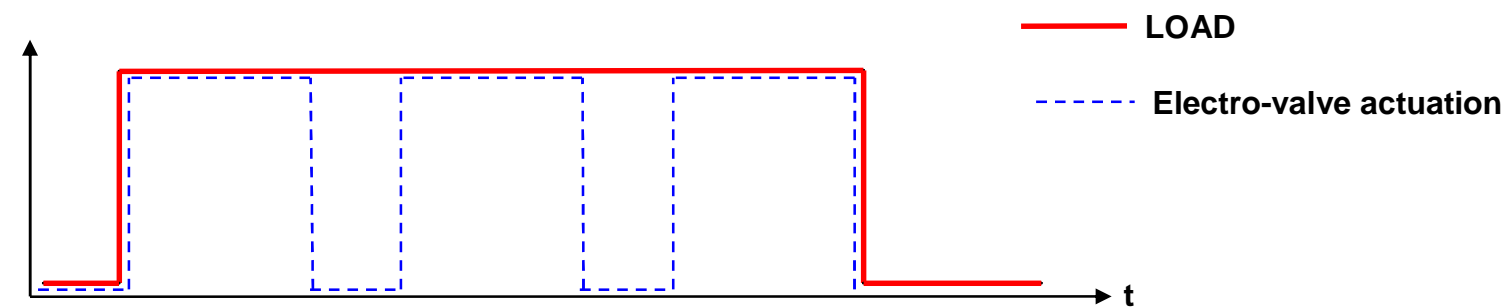
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 **AIR LIQUIDE**
GLOBAL E&C SOLUTIONS

Screw Compressors – Slide Valve operation

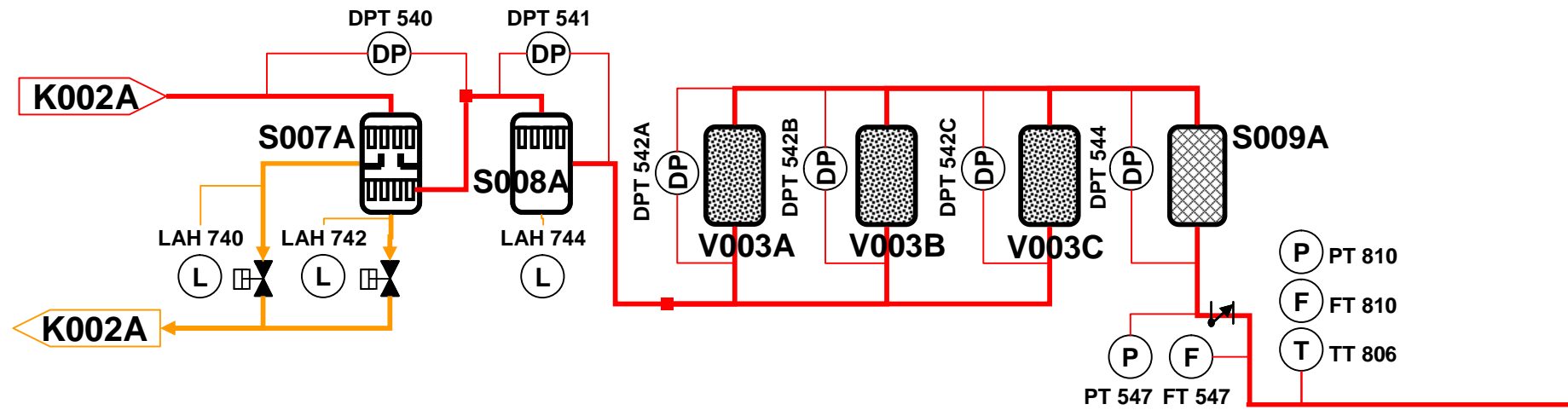
- The slide valve position is controlled using 2 electrovalves allowing moving an electro-distributor. The electro-distributor has 3 positions:
 - ▣ NEUTRAL (both electrovalves are “off”)
 - ▣ LOAD (the “loading” electrovalve is “on”)
 - ▣ UNLOAD (the “unloading” electrovalve is “on”)
- A piston directed by the electro-distributor actuates the slide valve.
- The accuracy of the slide valves is +/- 2%
- As electro-valves' operation is “on-off”, the loading/unloading speed could be difficult to control. To ensure smooth operation, the slide valves are actuated by pulse:



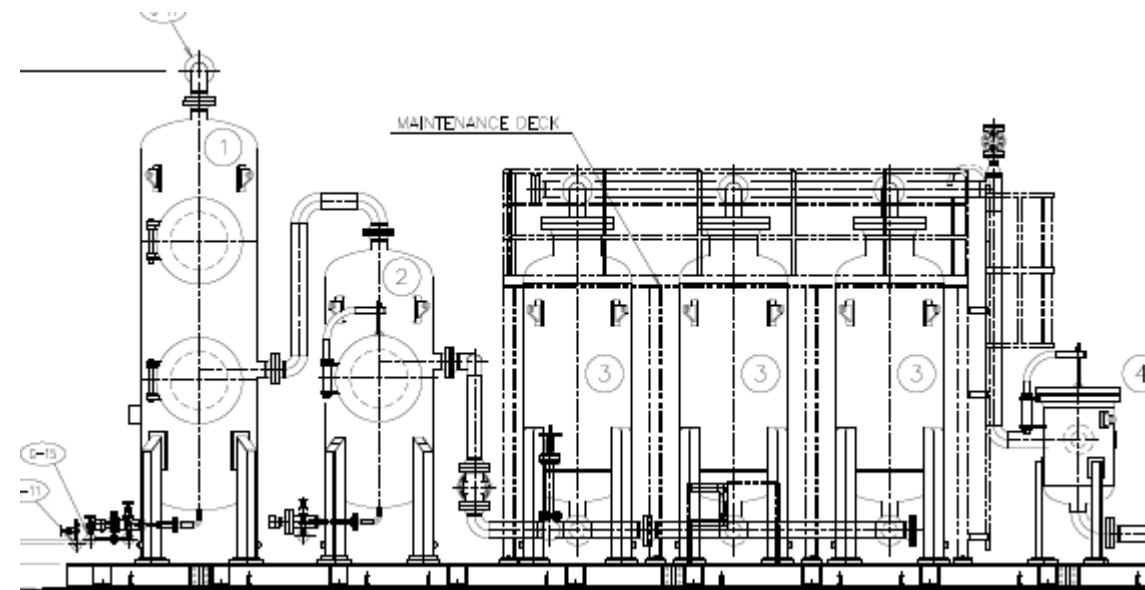
Course Agenda

- Introduction
- Screw compressors
- **Oil Removal Systems**
- Process of the Helium Compression
- Process regulation

Oil Removal System



- S007 A: Coalescer
- S008 A: Back up coalescer
- V003 A, B and C: Oil adsorbers (charcoal)
- S009 A: Outlet filter



ORS – Principle

- The oil presents 2 forms within the Helium flow:
 - ▣ Aerosol
 - ▣ Vapour

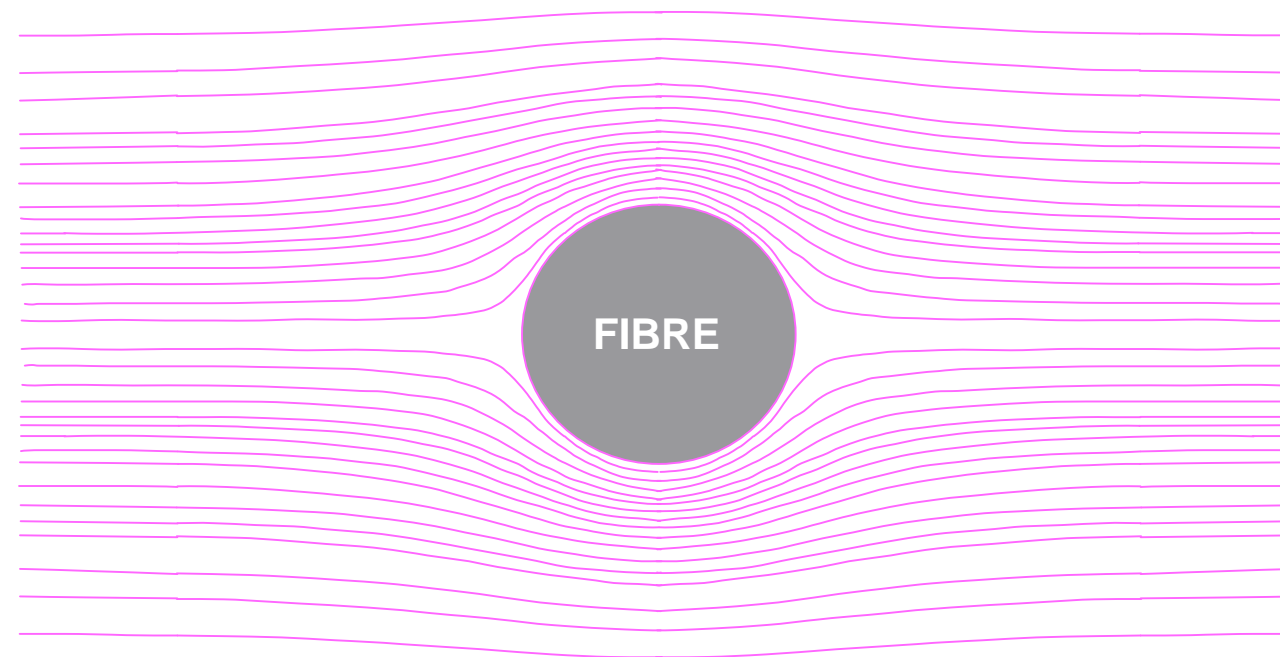
AEROSOL

- The oil is mainly in the form of aerosol.
- Aerosol is removed by coalescence, which has not effect on vapour.
- Aerosol is removed with a cartridge filled with the filtering media.

VAPOUR

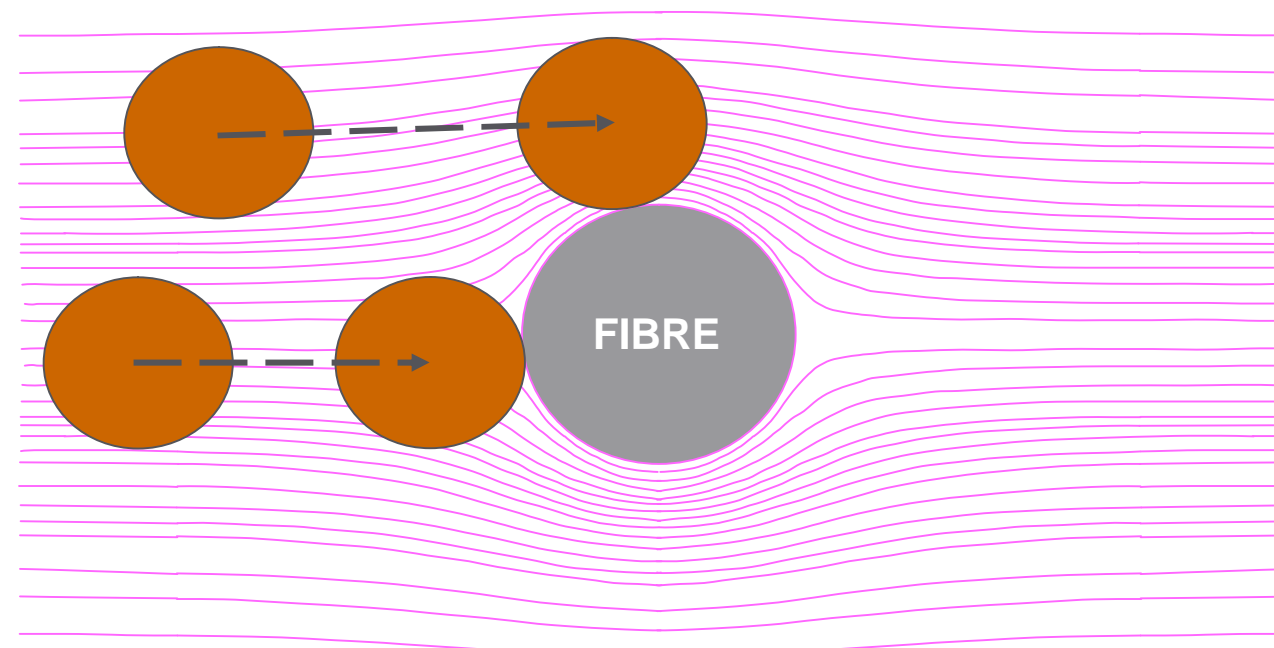
- A minor part of the oil is in the form of vapour.
- Vapour is removed by adsorption, after all aerosol has been removed.
- Vapour is removed with a vessel filled with charcoal.

ORS – Coalescence – Flow pattern



ORS – Coalescence – Flow pattern – Inertial impaction

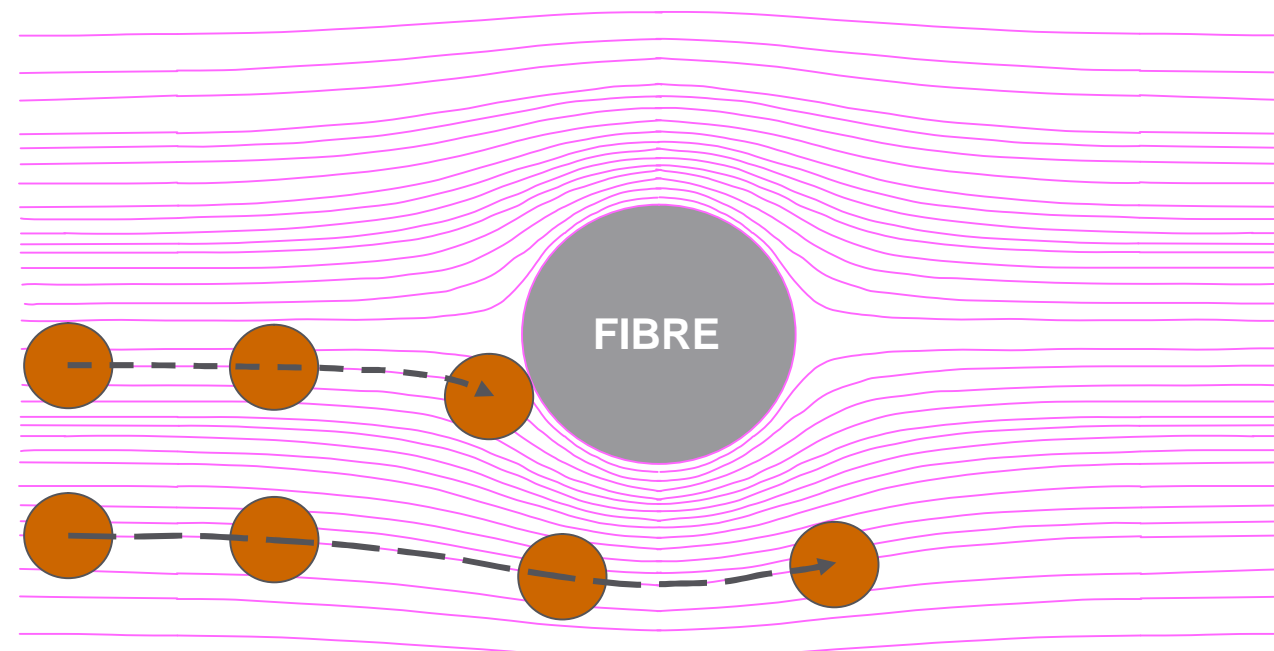
LARGE PARTICLES ($> 3 \mu\text{m}$)



Large particles have a too high momentum to allow them to follow the gas stream. They collide with fibres.

ORS – Coalescence – Flow pattern – Direct interception

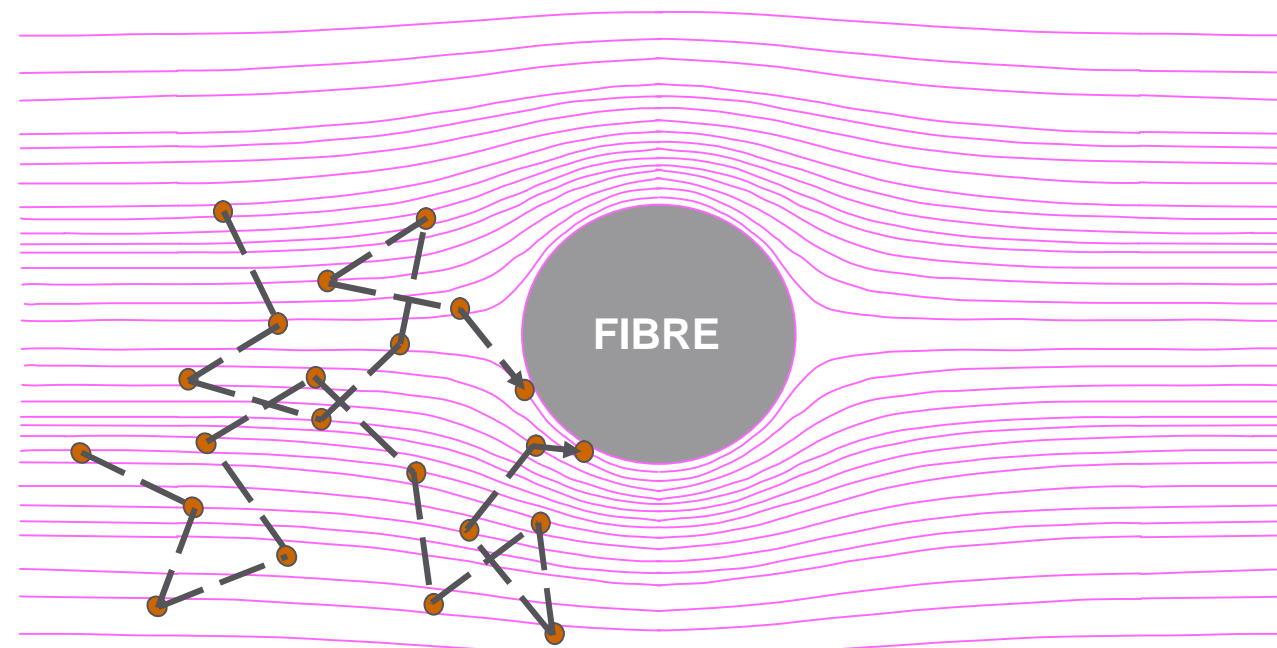
MIDDLE SIZE PARTICLES (0.5 to 3 μ m)



Middle size particles follow the gas stream.
They are collected when their pathway is close enough to a fibre. Not all of them are collected.

ORS – Coalescence – Flow pattern – Brownian movement

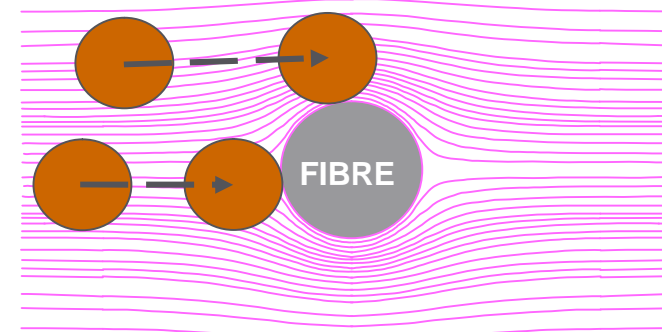
VERY SMALL PARTICLES ($< 0.5 \mu\text{m}$)



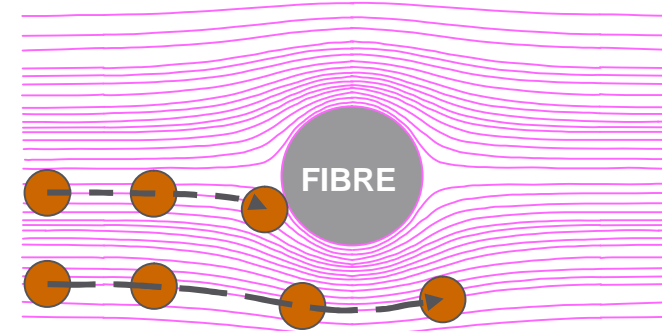
Very small particles are randomly moved by collision with gas molecules.
The smaller the particles, the higher the Brownian movement, thus a highest probability of collision with a fibre.

ORS – Coalescence – Aerosol capture processes

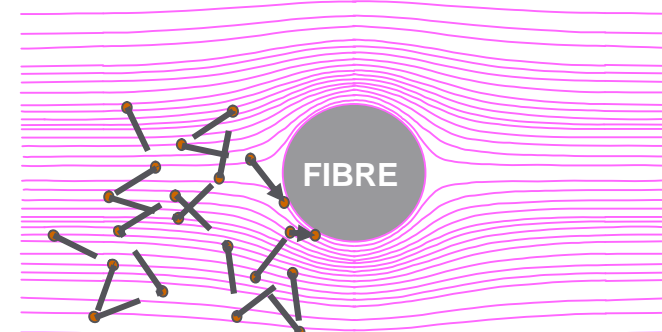
INERTIAL IMPACTION



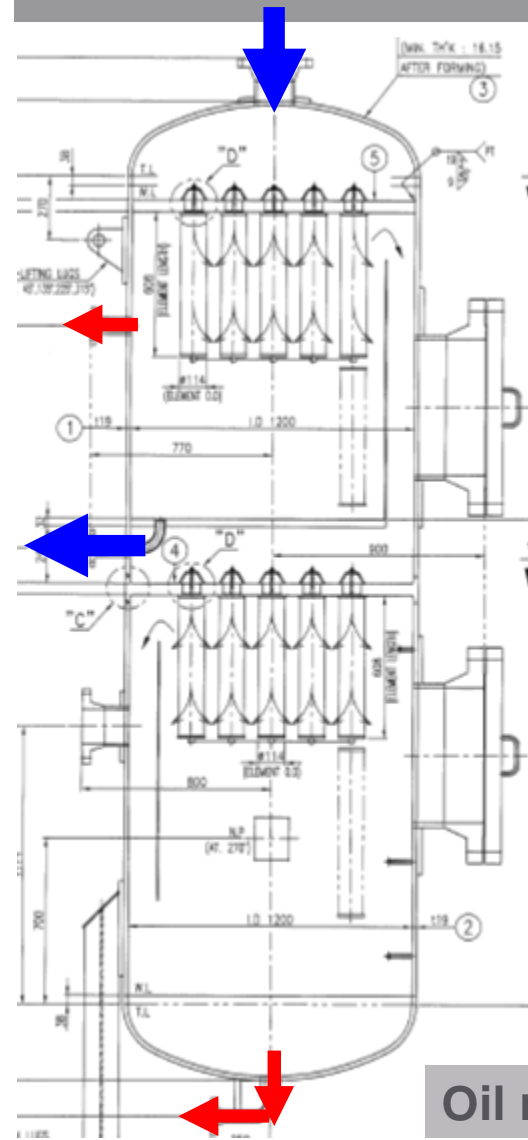
DIRECT INTERCEPTION



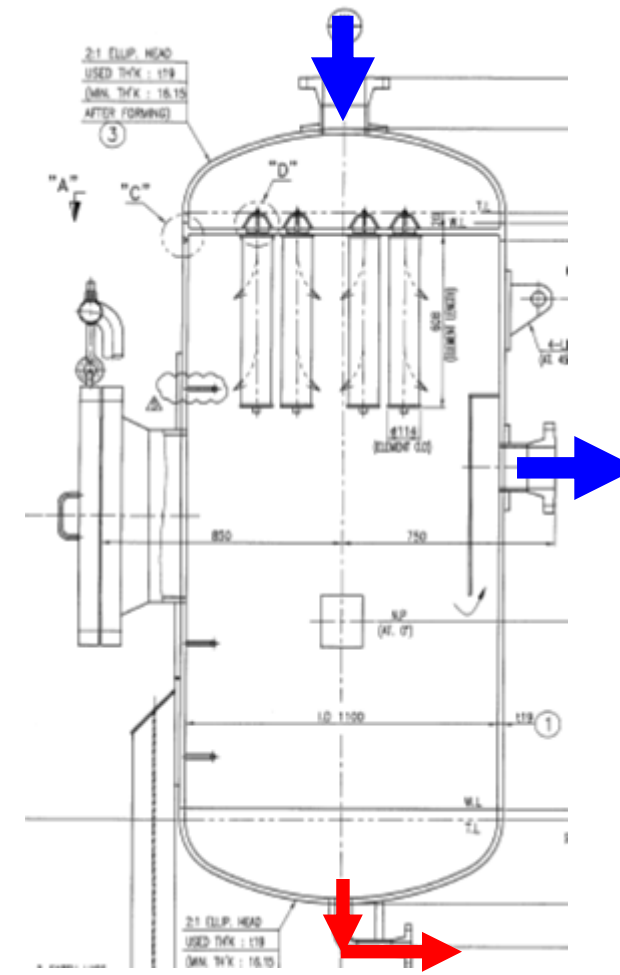
BROWNIAN MOVEMENT



ORS – Coalescence – Aerosol capture processes

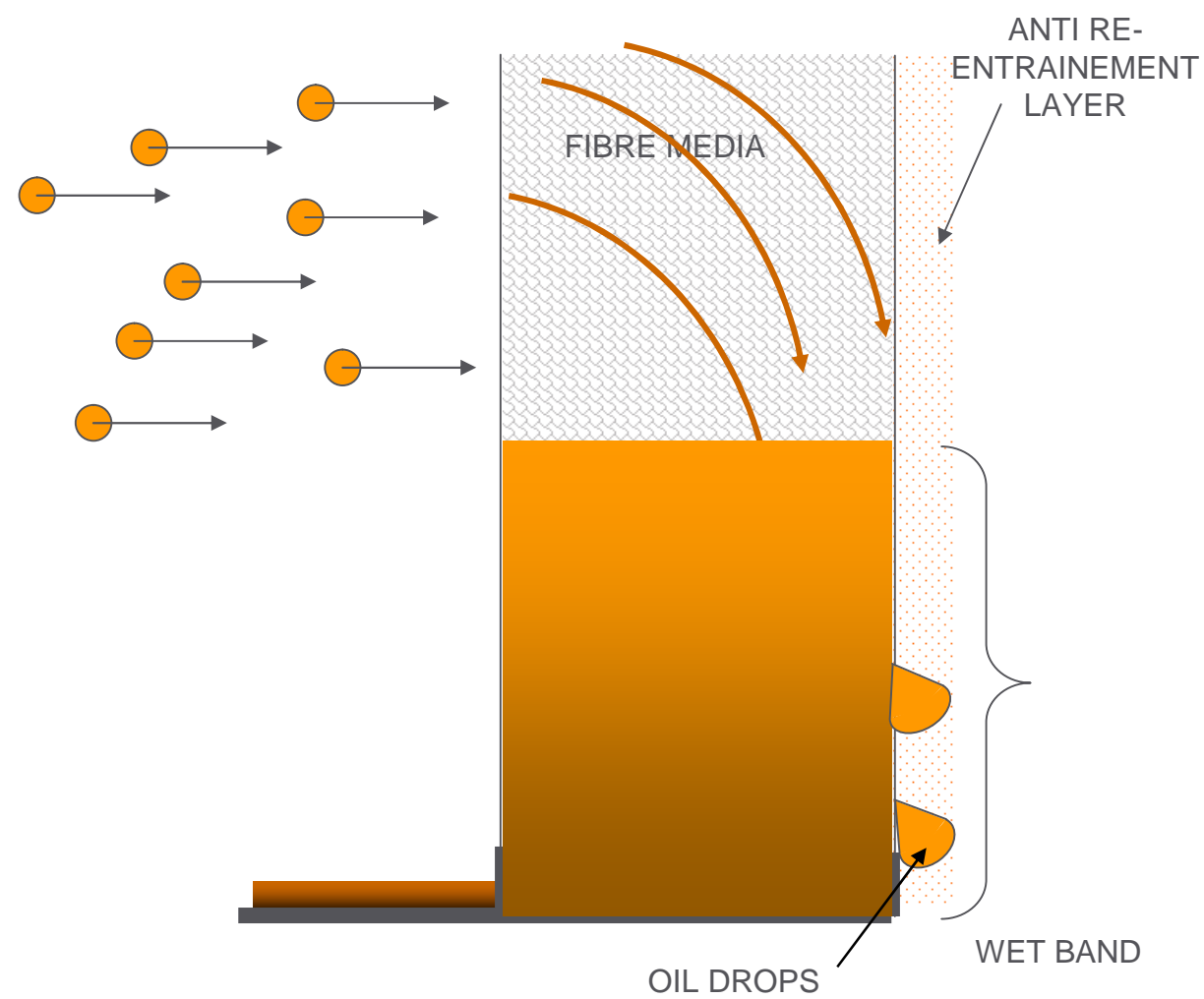


Oil removal vessel

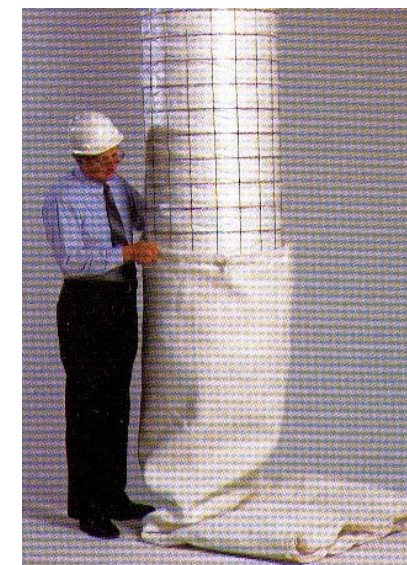


Back up oil removal vessel

ORS – Coalescence – Cartridge cross section

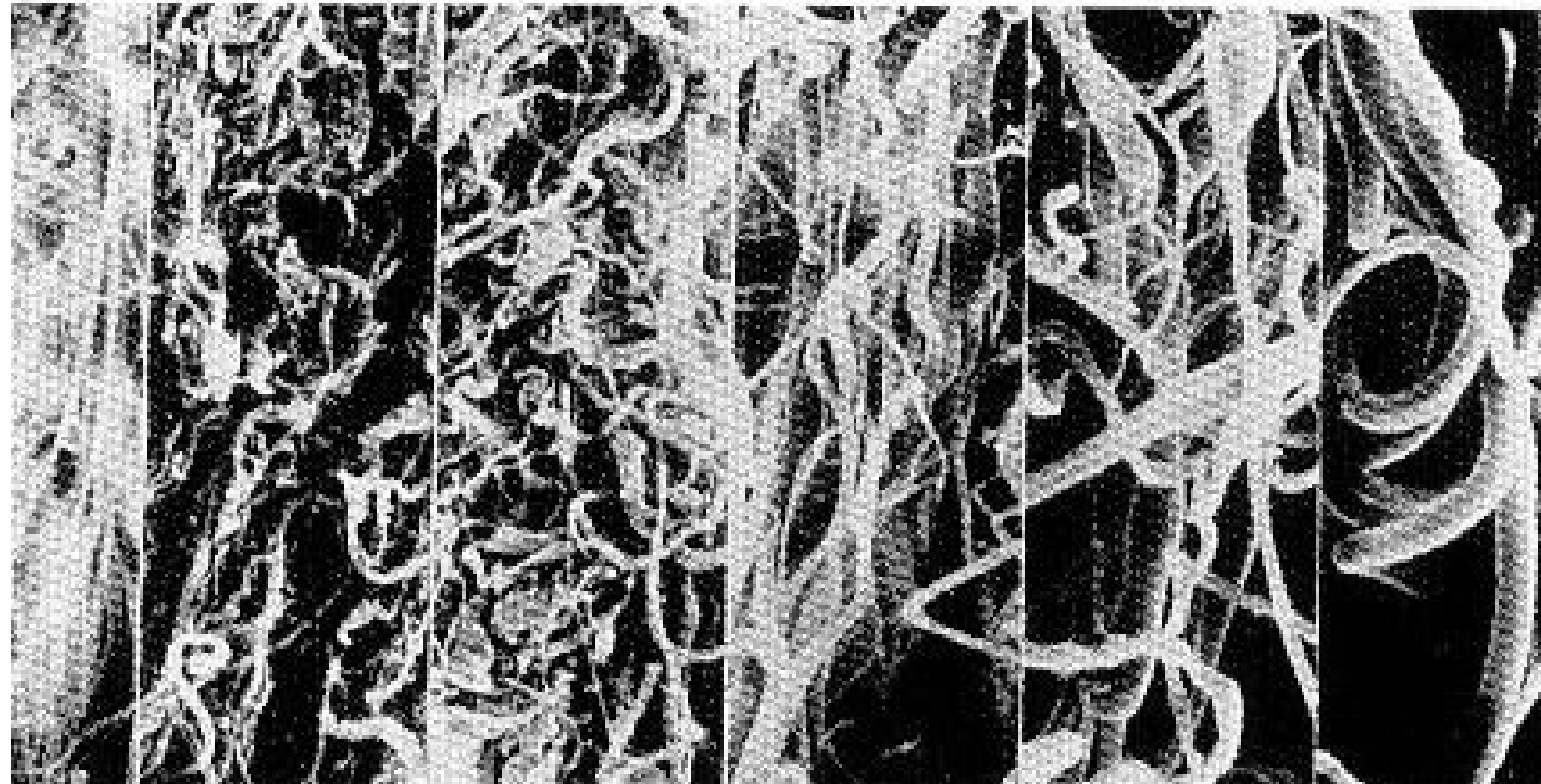


Small Cartridge



Large Cartridge

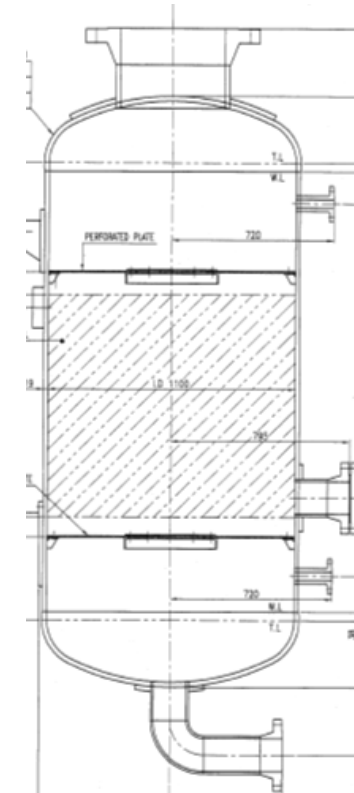
ORS – Coalescence – Filtering media



- For small cartridges, “blotting” paper is rolled.
- For large cartridges, the media is stuffed into a cage.

ORS – Adsorption process

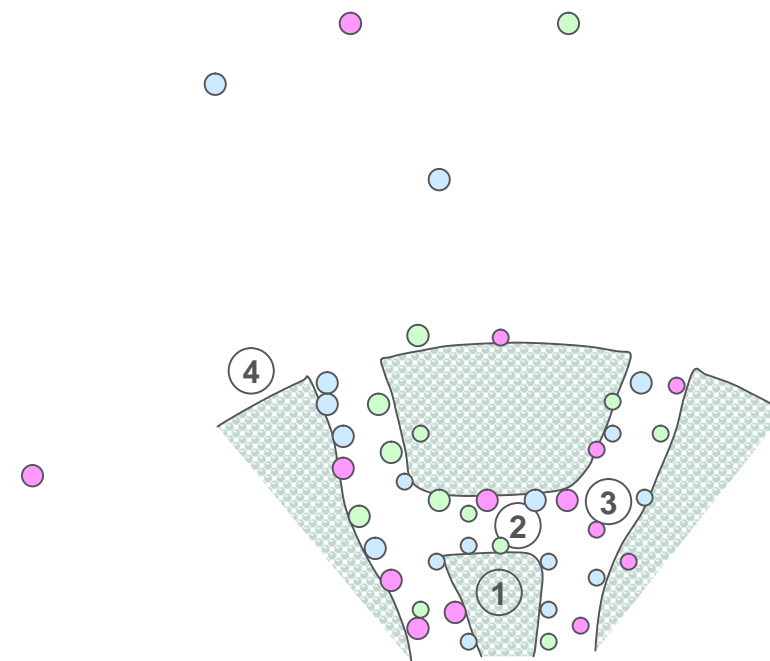
- Adsorption is a selective purification process:
 - ▣ The adsorbant has a selective affinity with the impurity you want to remove from the gas (polarity, Van Der Waals weak interactions etc.)
 - ▣ While Helium mixed with oil in vapour form circulates through the charcoals, the oil molecules bond to the adsorbant.
- The adsorbers are designed to operate continuously during 2 years. However, when the adsorption capacity is full, the adsorbers need to be regenerated using dry and hot N₂



ORS – Adsorption – The 4 steps of mass transfer

Adsorption involves 4 different physical phenomena:

- Internal diffusion in the sorbed phase
- Adsorption on the surface of the adsorbent
- Diffusion of the fluid phase into the pores
- Diffusion between the external surfaces of the adsorbent and the surrounding fluid.



ORS – Oil selection - Treatment

- Oil must be treated before use
- Impurities to eliminate:
 - ▣ Air: related to the fabrication process,
 - ▣ Water: oil is very hygroscopic,
 - ▣ The high vapour pressure molecules.
- Method: heating under vacuum.
- During filling of the oil, the contact with atmosphere must be limited in order not to contaminate the oil.

SAFETY NOTE:

**Avoid any contact with skin or mucous membranes.
Oil deteriorates paint.**

MAINTENANCE

OIL

Operate with neutral gas, **no** oxygen and **moderate** temperature.
Long life time (>100000 h).

COALESCERS

As there are no solid particles carried by Helium, no risk of plugging.
Long life time.

ADSORBERS

The life time depends on the quality of the oil treatment.
Long life time.
Regenerate/Change the adsorbent.

FILTER

No specific maintenance: only usual maintenance for filters.

Course Agenda

- Introduction
- Screw compressors
- Oil Removal Systems

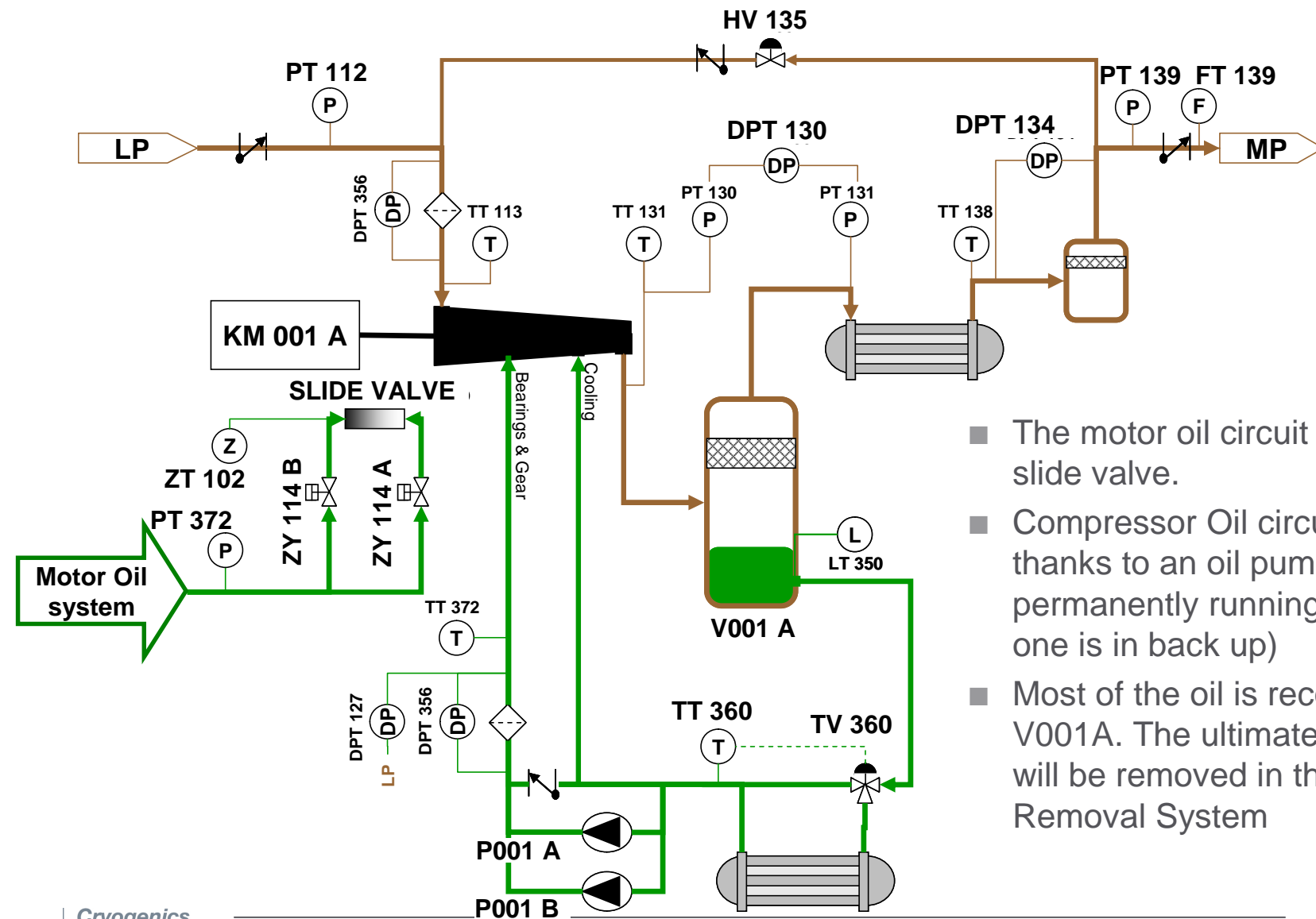
■ Process of the Helium Compression

- Process regulation

Process of the Helium Compression

- Helium is compressed up to 21 bara, in two successive compression steps (1.05 bara → 4.8 bara → 21.0 bara).
- Oil is injected in each compressor and is removed in 2 steps:
 - ▣ Oil separator at LP discharge and HP discharge
 - ▣ Oil Removal System at HP Compressors' discharge
- A surge drum acts as a buffer and connects HP discharge to LP suction.

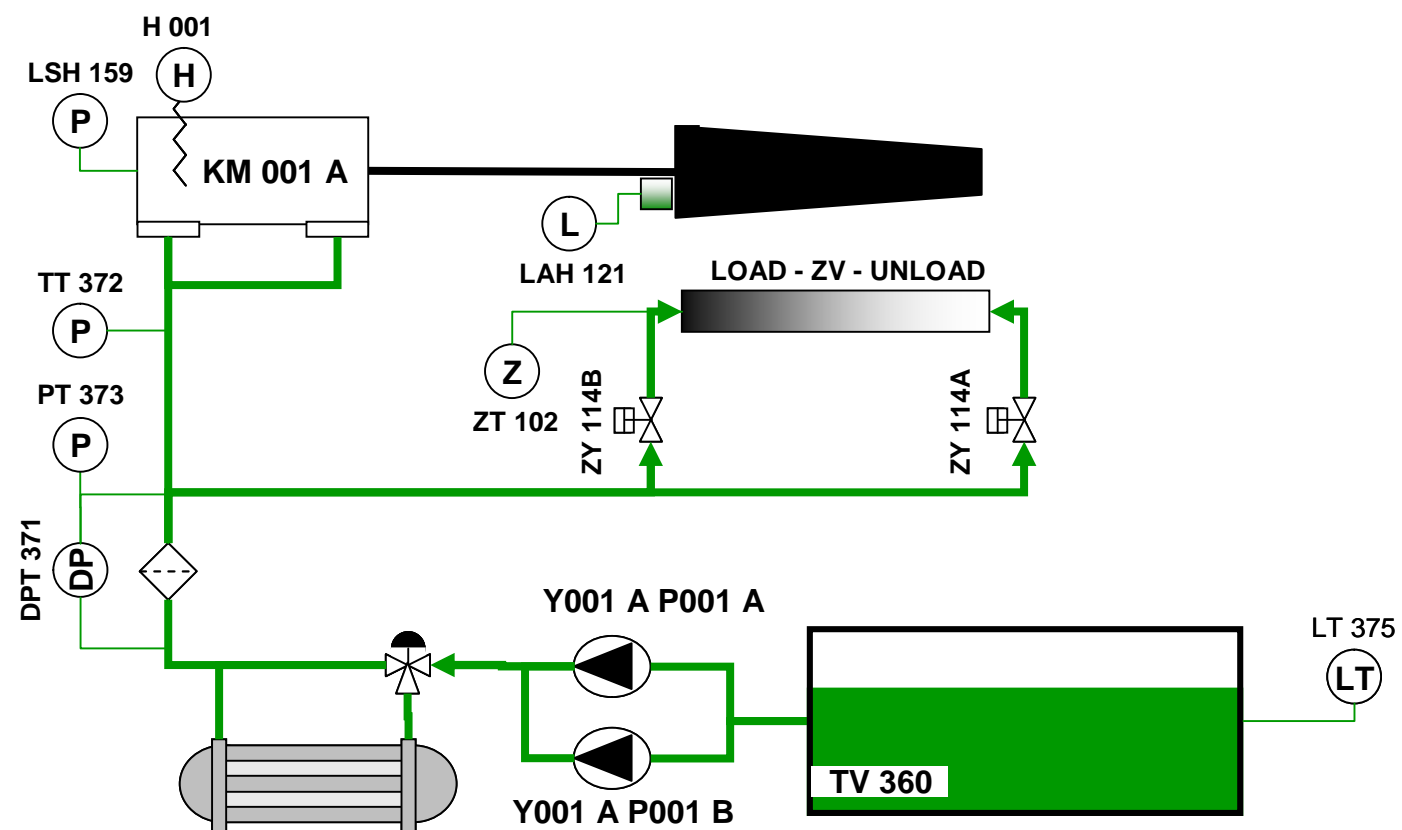
Process of the Helium Compression – LP Compressor Oil System



- The motor oil circuit operates the slide valve.
- Compressor Oil circuit circulates thanks to an oil pump (one is permanently running, the other one is in back up)
- Most of the oil is recovered in V001A. The ultimate traces of oil will be removed in the Oil Removal System

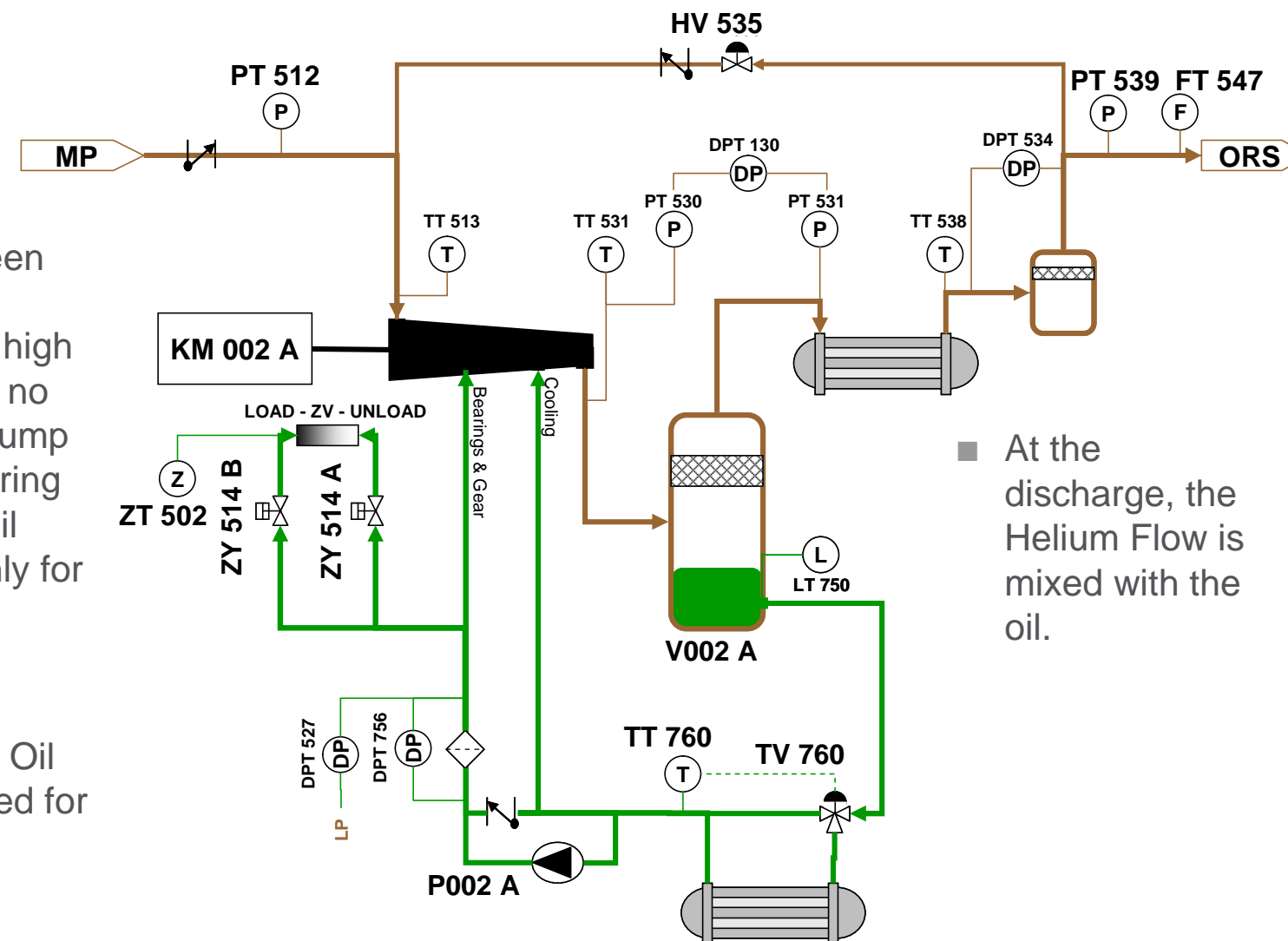
Process of the Helium Compression – LP Motor Oil System

- The motor oil circuit:
 - ▣ Operates the slide valve
 - ▣ Lubricates the motor.
- One pump is permanently running, the other one is in back up.



Process of the Helium Compression – HP Compressor Oil System

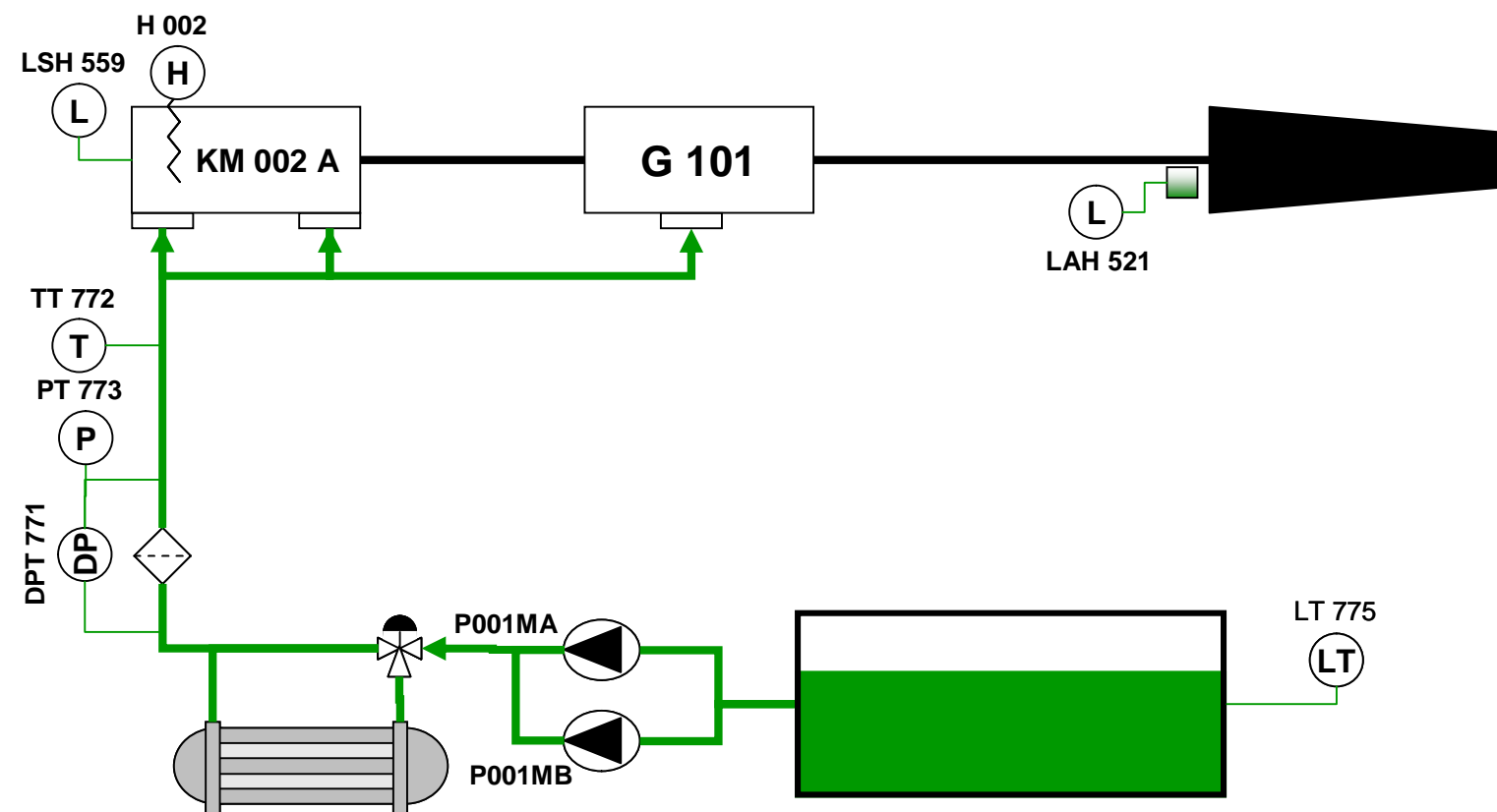
- The pressure difference between suction and discharge being high enough, there is no need for an oil pump to be running during operation. The oil pump is used only for start up and shutdown post lubrication.
- The compressor Oil circuit is also used for slide valves' operation.



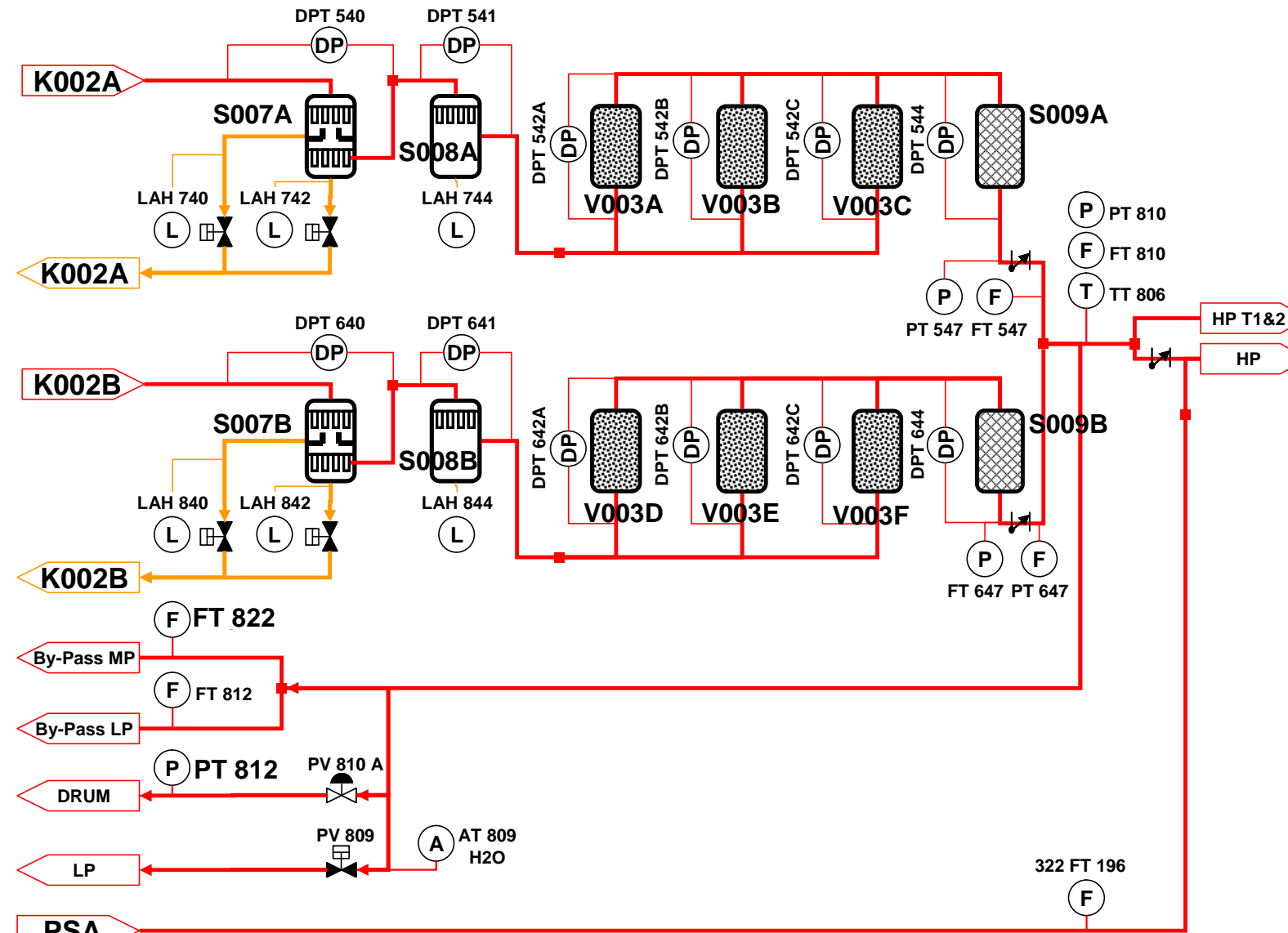
- At the discharge, the Helium Flow is mixed with the oil.

Process of the Helium Compression – HP Motor Oil System

- The motor oil circuit lubricates the motor and the gear box.
- One pump is permanently running, the other one is in back up.



Process of the Helium Compression – Oil Removal System



Course Agenda

- Introduction
- Screw compressors
- Oil Removal Systems
- Process of the Helium Compression
- **Process regulation**
 - ▣ Sequence overview
 - ▣ Recycle valves
 - ▣ Capacity adjustment
 - ▣ Start Up
 - ▣ Stop

Compression station sequence overview

G000: CYCLE COMPRESSOR GENERAL SEQUENCE

G000-100: Selection window
Oil Pumps selection
"Master" compressor selection

G000-200: Pressure control

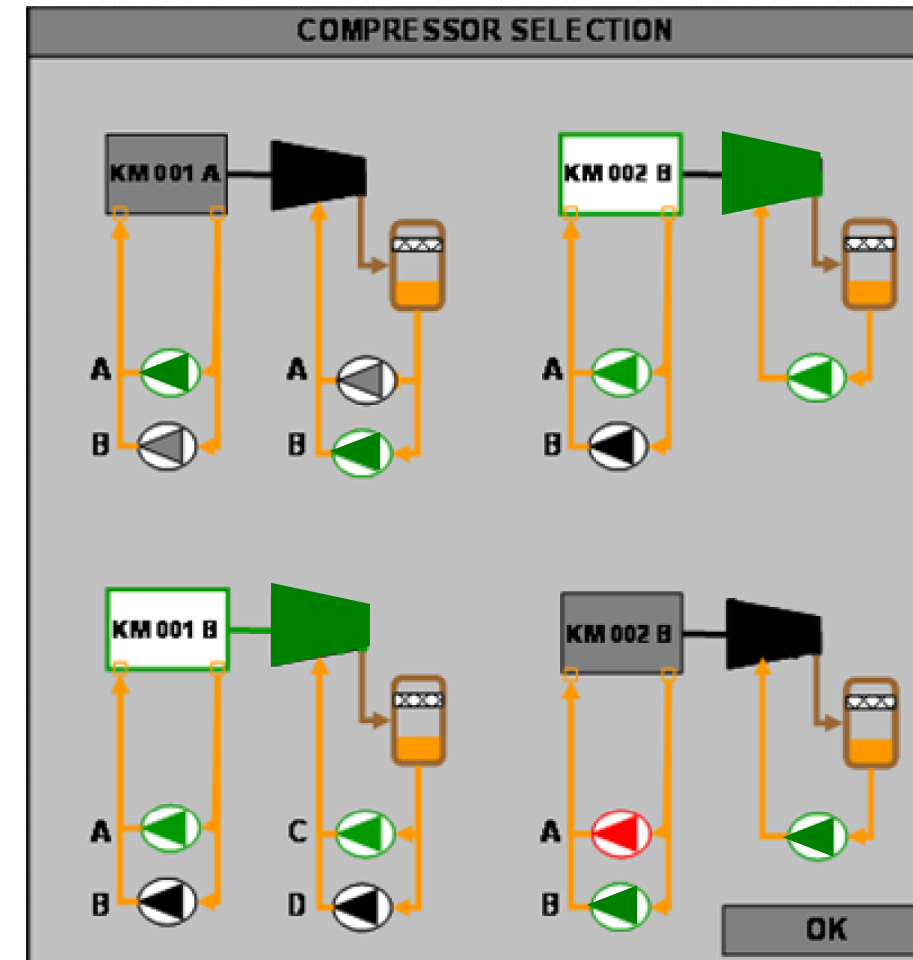
G000-300: HP Auto Start

G000-400: LP Auto Start

G000-500: Operation
LP & HP Running

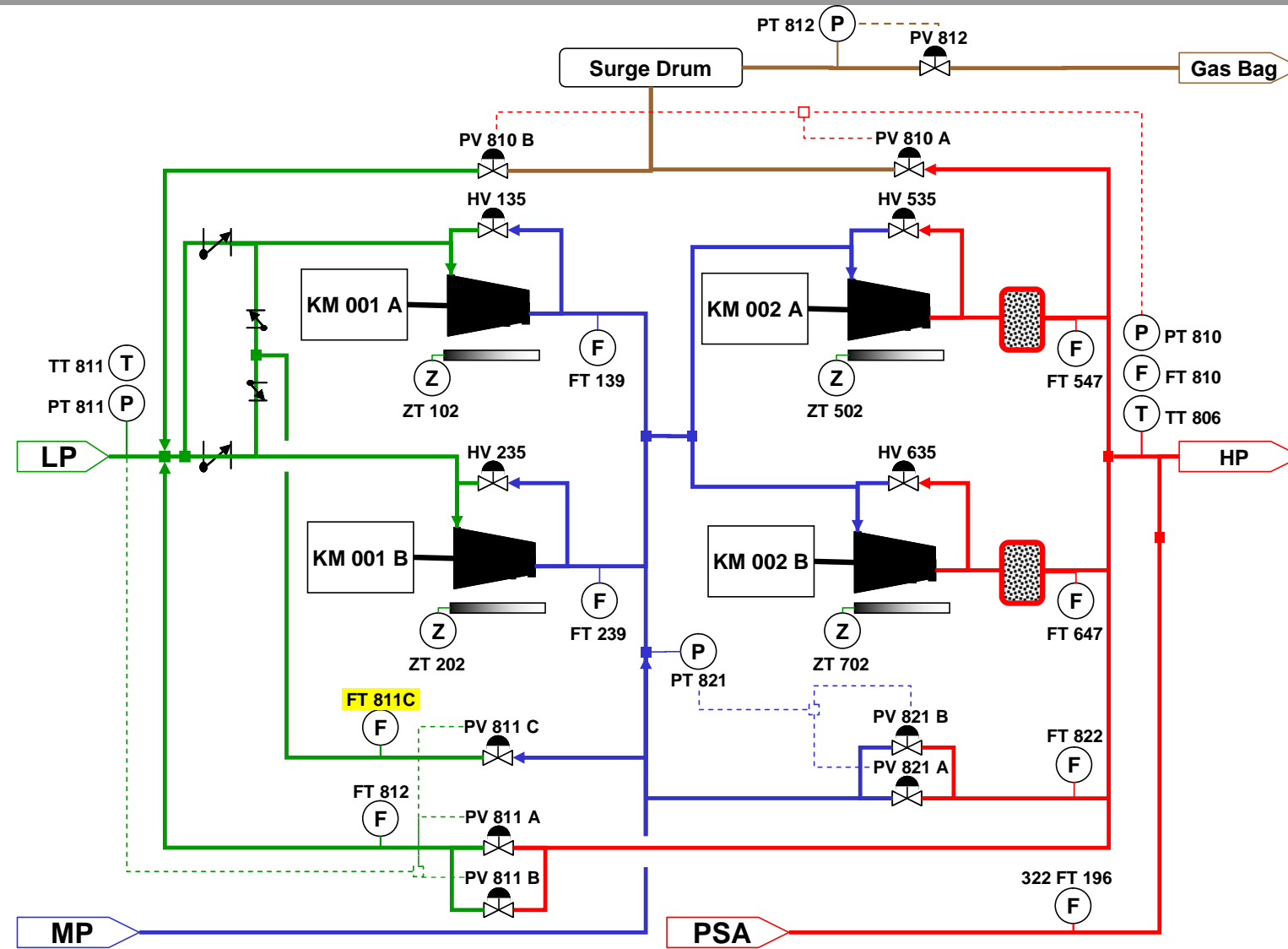
G000-600: Stop Compressors

G000-700: Stop control loops,
close recycle valves (except spill
back valve)



- Selected Equipments are shown in Green;
- Unavailable Equipments (default) will appear in red, and will not be selectable.

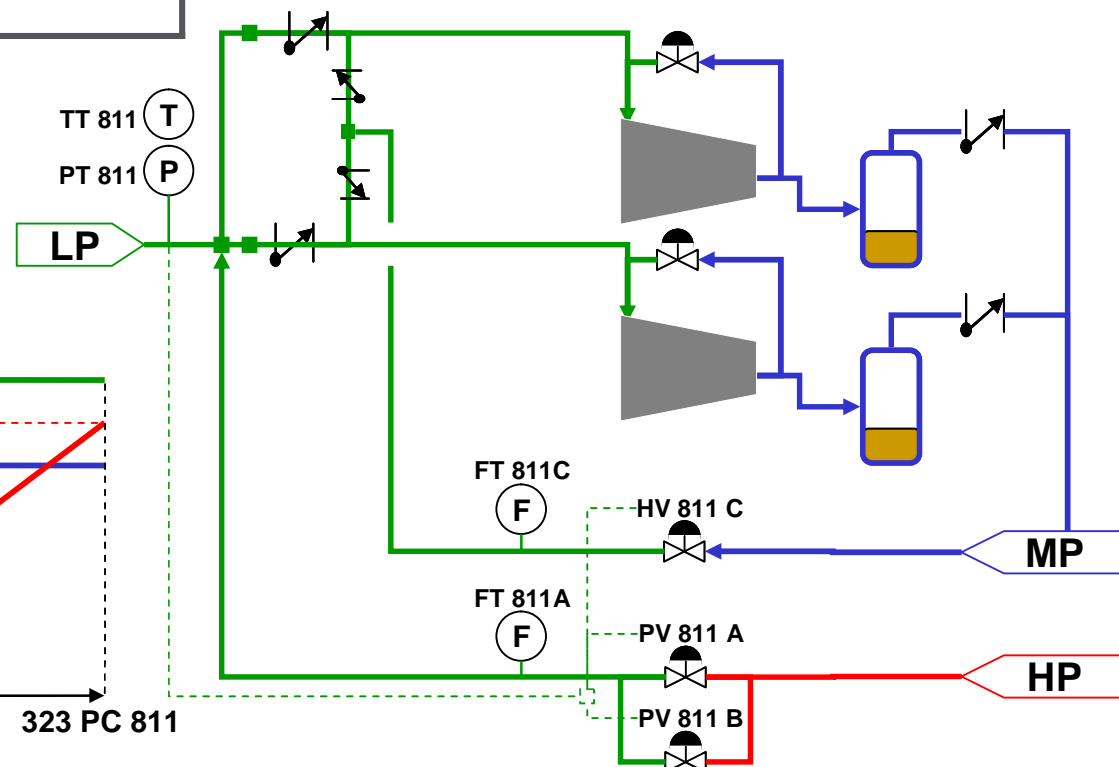
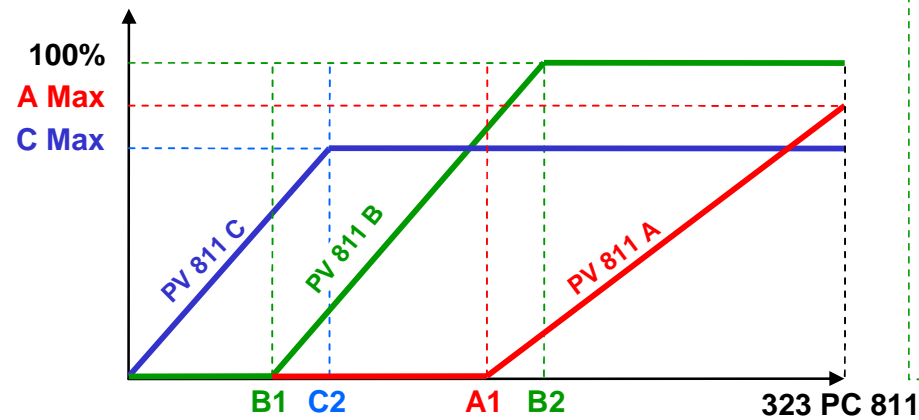
Process Regulation – Pressure Regulation



Process Regulation – Pressure Regulation – LP

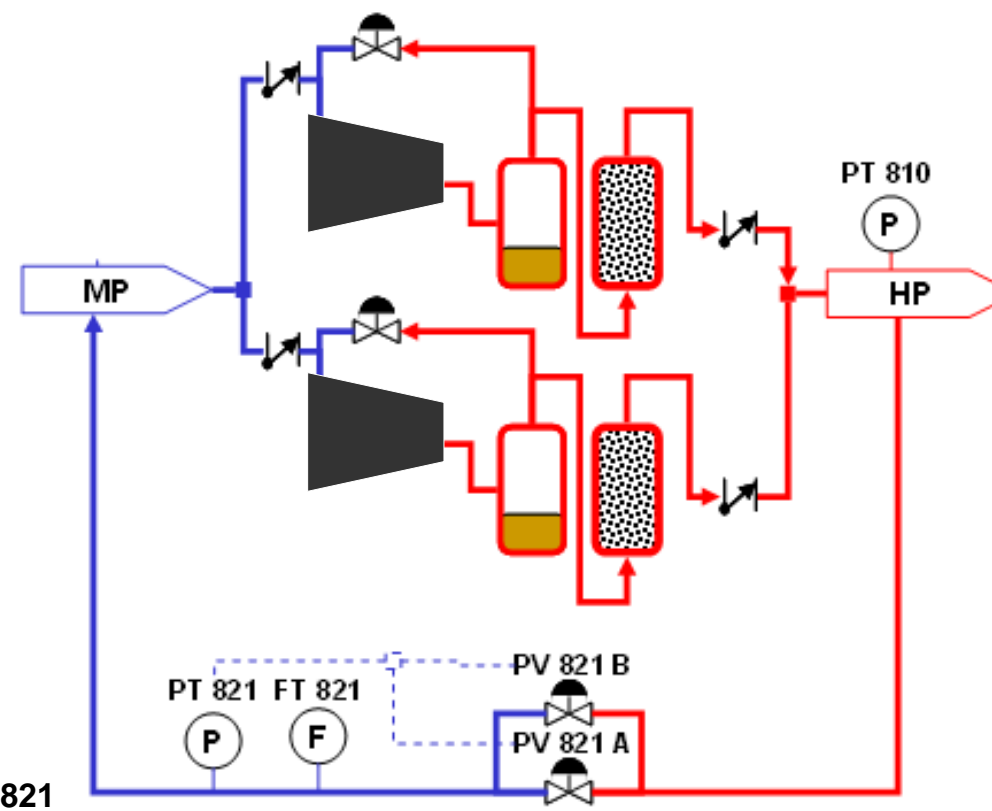
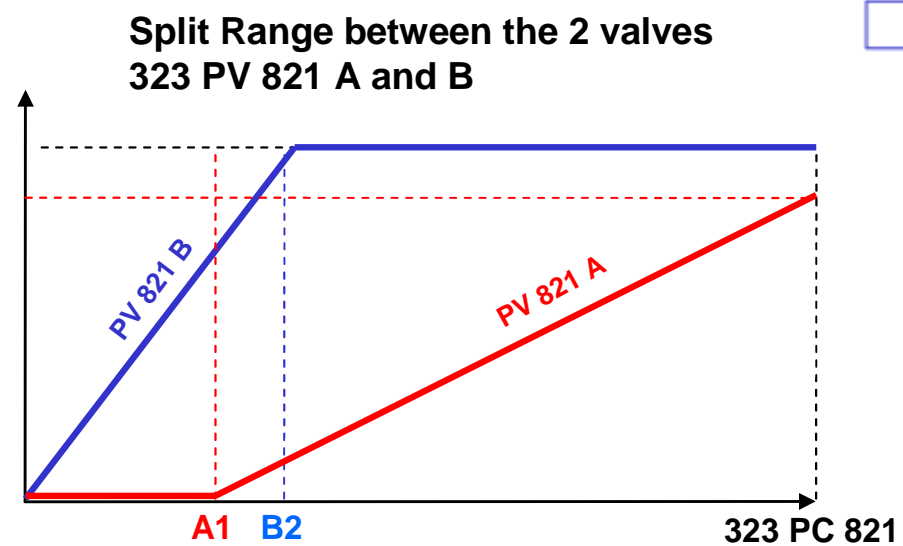
Controller	323 PIC 811
Actuator	323 PV 811 A (from HP) 323 PV 811 B (from HP) 323 PV 811 C (from MP)
Set Point	~ 1.05 bara
Action	Indirect

Split Range between the 3 valves
323 PV 811 A, B and C



Process Regulation – Pressure Regulation – MP

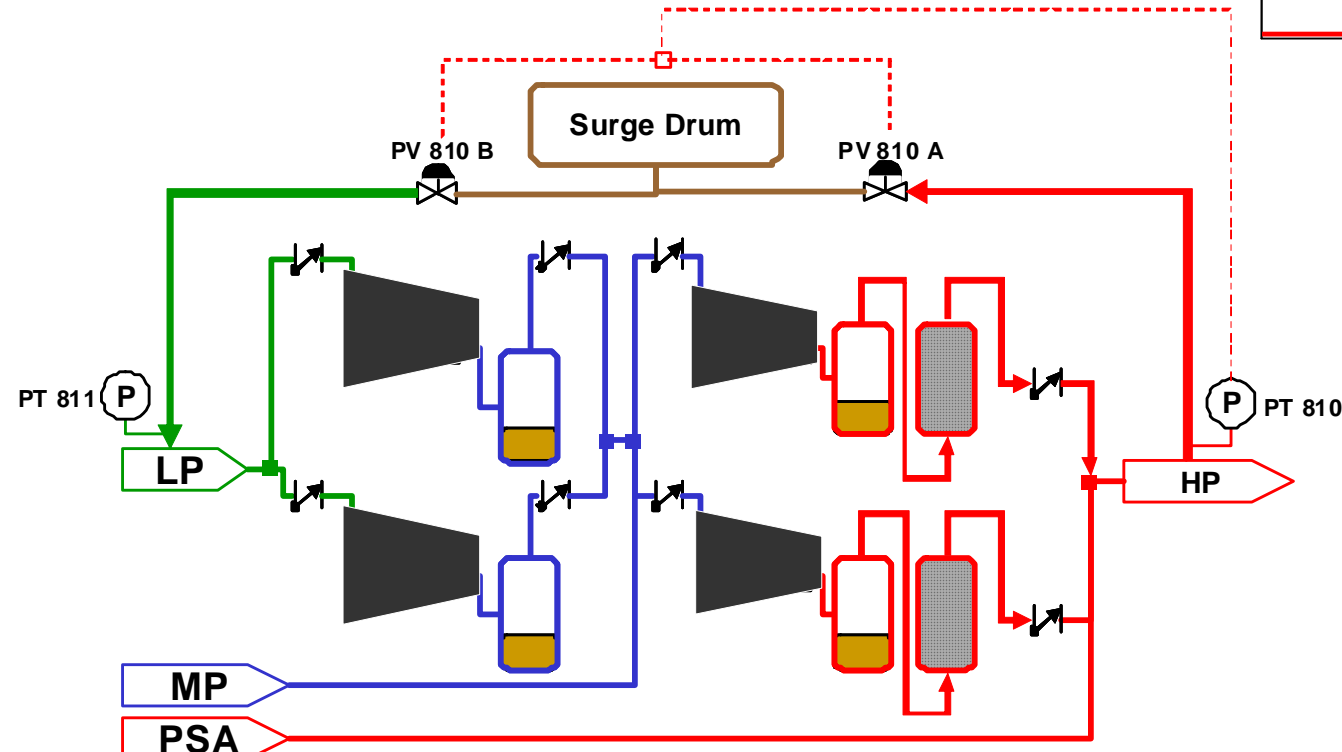
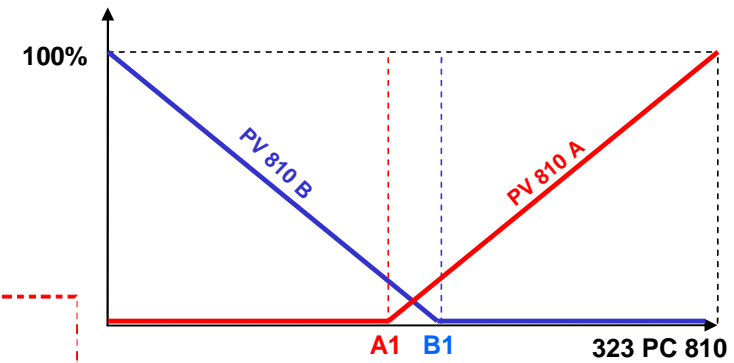
Controller	323 PIC 821
Actuator	323 PV 821 A 323 PV 821 B
Set Point	~ 5.0 bara
Action	Indirect



Process Regulation – Pressure Regulation – HP

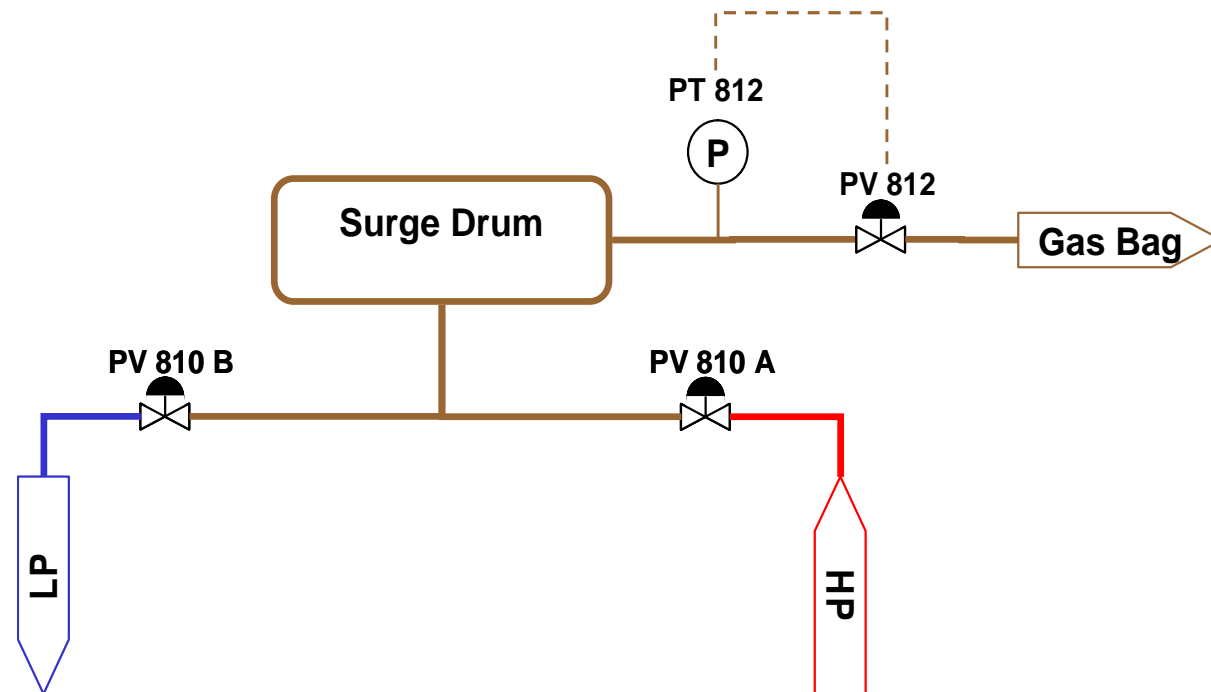
Controller	323 PIC 810
Actuator	323 PV 810 A 323 PV 810 B
Set Point	~ 21.0 bara
Action	Direct

Split Range between the 2 valves
323 PV 810 A and B



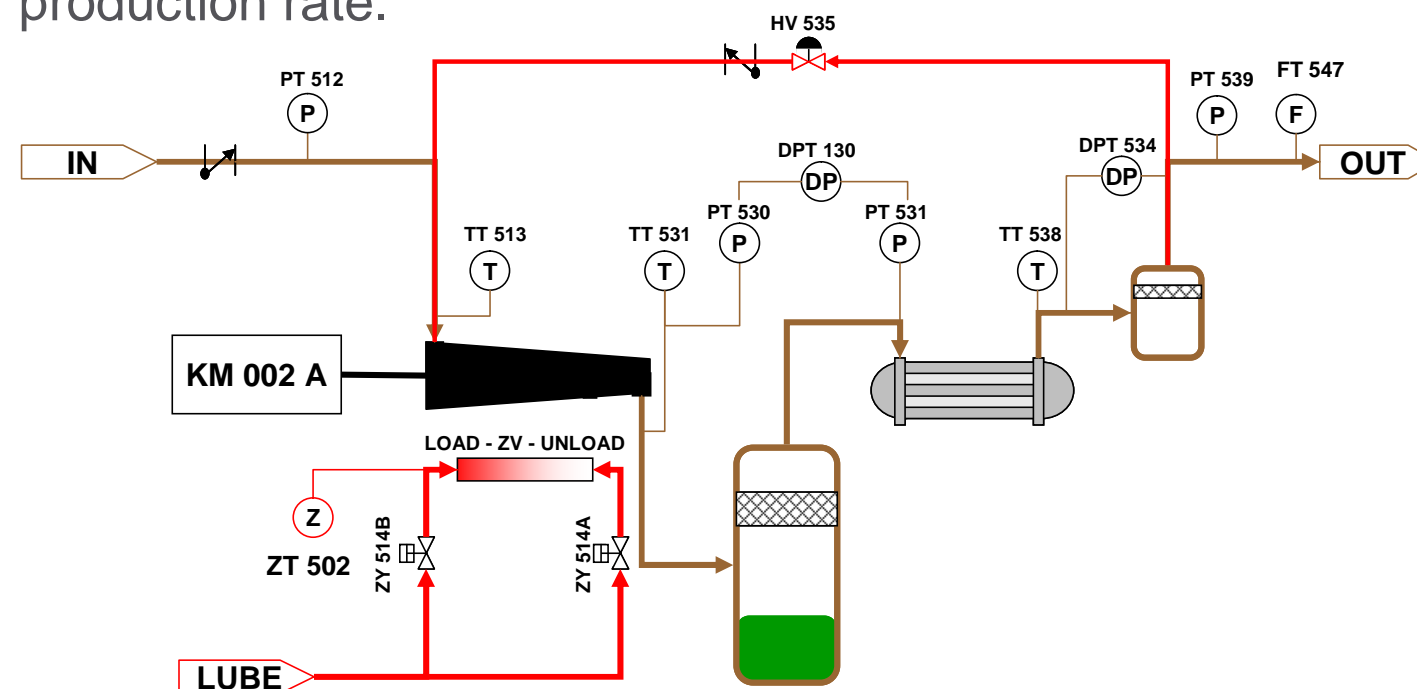
Process Regulation – Pressure Regulation – Surge Drum

Controller	323 PIC 812
Actuator	323 PV 812
Set Point	~ 17.0 bara
Action	Direct



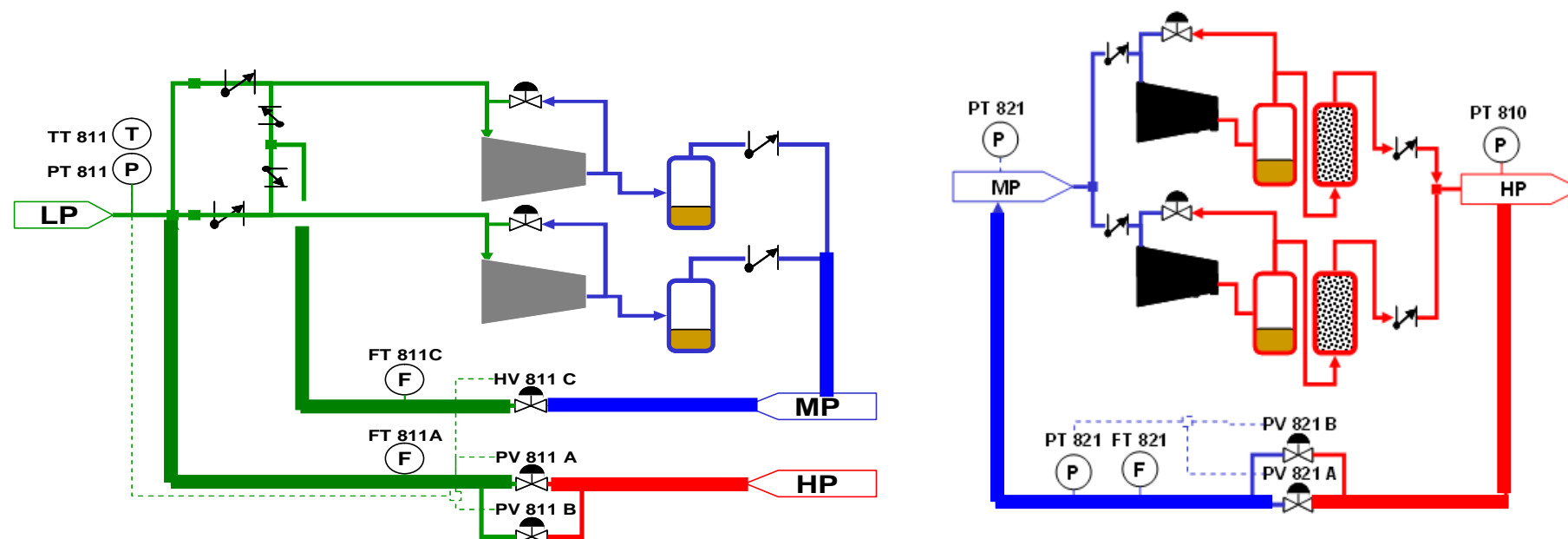
Process Regulation – Capacity regulation

- The capacity of the compression station is adjusted with the slide valves of each compressor.
 - With Spill Back Valve closed, the capacity can be adjusted from 25% to 100% of the maximum flow
 - Minimum load is 25%.
- The slide valves' targets will be set up at start up for a given production rate.

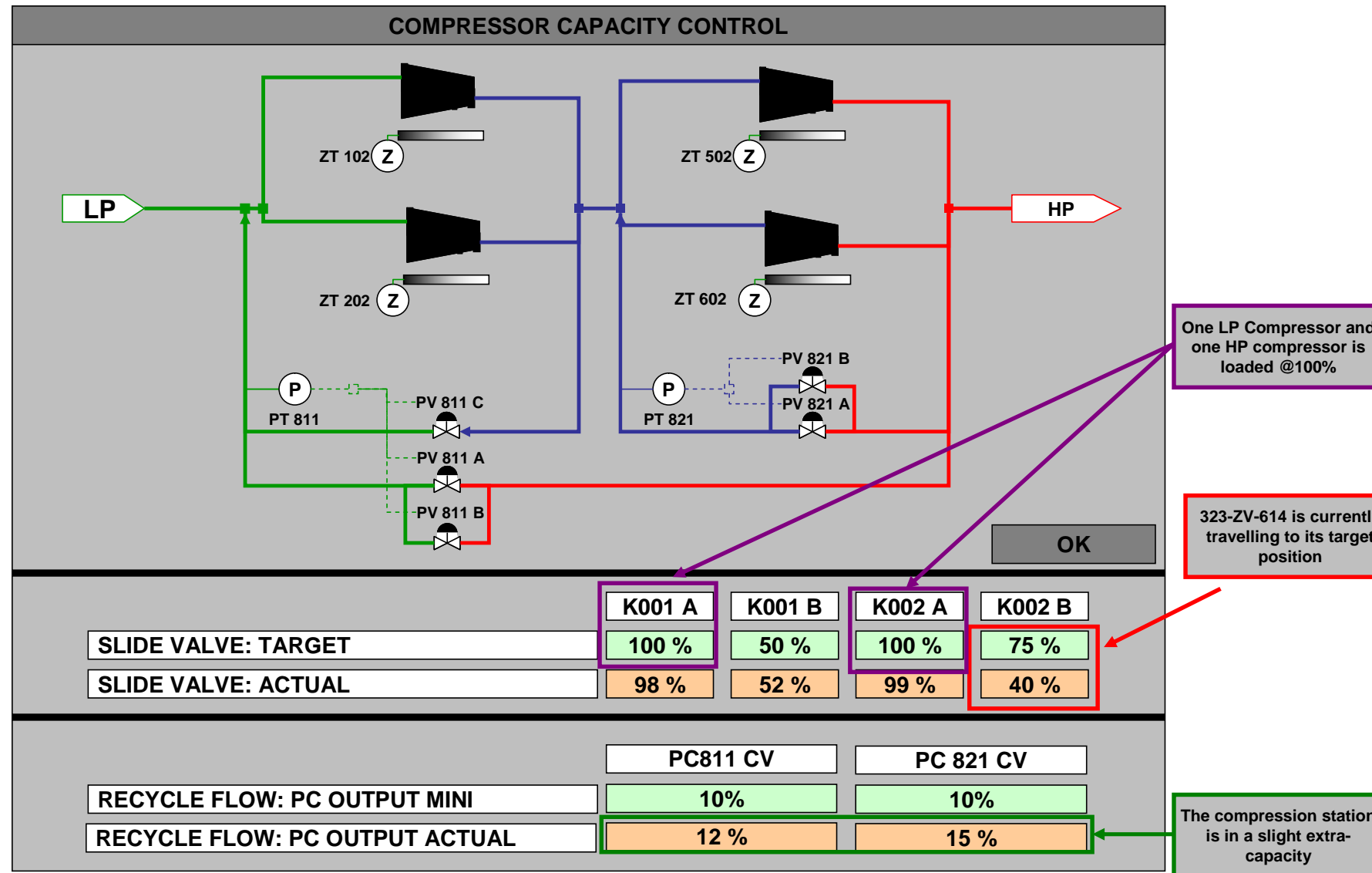


Process Regulation – Capacity regulation

- With restricted access, the targets of the slide valves can be adjusted during operation.
- The output of the pressure controllers 323-PC-811 and 821 reflects the need to modify the capacity:
 - ▣ If the output of 323-PC-811 is too high → LP compressors must be unloaded → 323-ZV-114/214 must be unloaded
 - ▣ If the output of 323-PC-821 is too high → HP compressors must be unloaded → 323-ZV-114/214 must be unloaded



Process Regulation – Capacity regulation



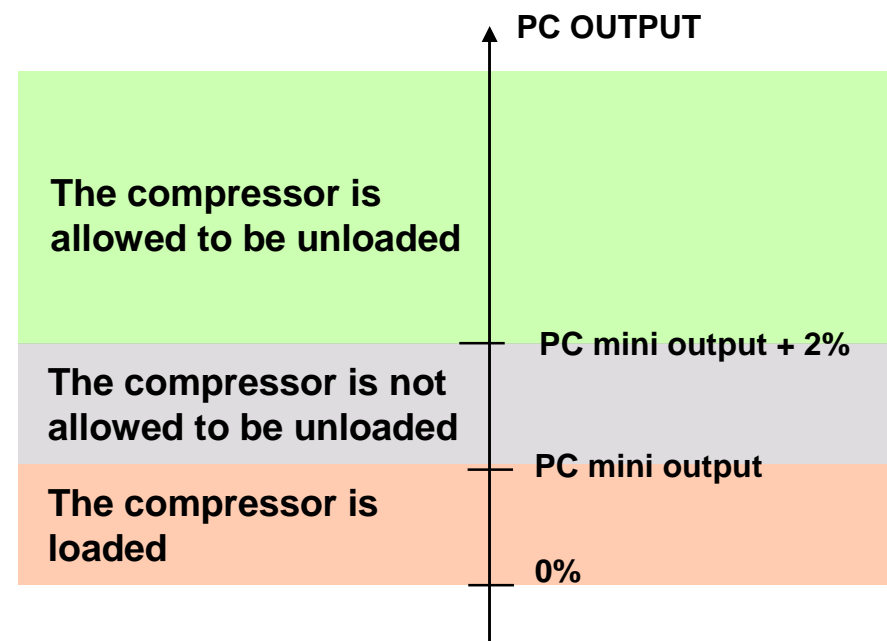
One LP Compressor and one HP compressor is loaded @100%

323-ZV-614 is currently travelling to its target position

The compression station is in a slight extra-capacity

Process Regulation – Capacity regulation – PC outputs mini

- During start up, a PC output mini are defined

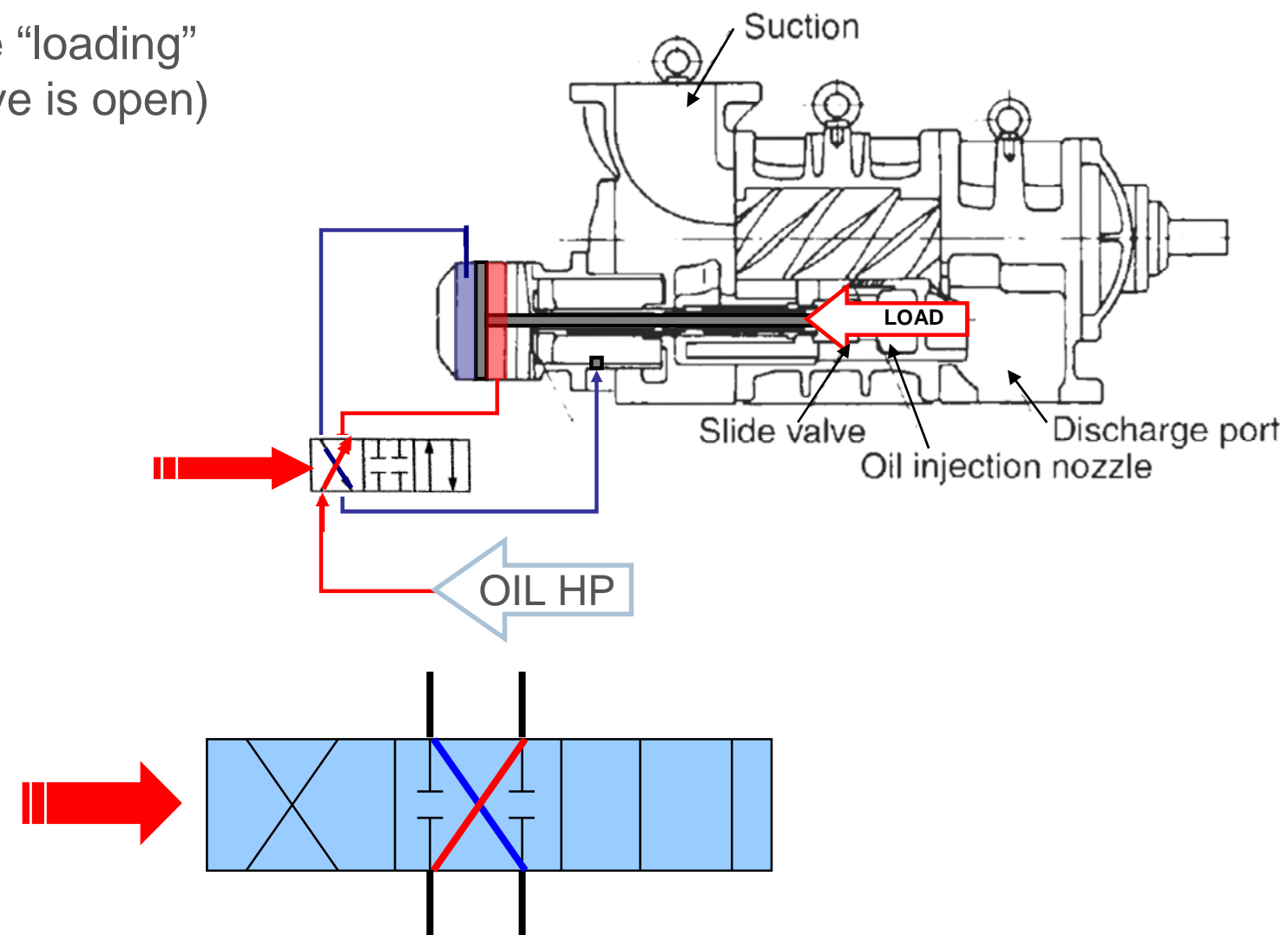


Process Regulation – Capacity regulation – LOAD CONDITIONS

<p>Initial condition: the pressure at compressor discharge is not too low: NO PSL 139</p> <p>This condition is valid at start up: when the Spill Back Valve closes, the pressure builds up at compressor discharge. When the pressure is high enough, the Slide Valve can be operated to adjust the load.</p>	
AND	<p>323-PT-811 (LP Pressure) is not too far from its set point</p> <p>323-PT-811 must be $> 323-PC-811 \text{ SP} - 0.02 \text{ bara}$</p> <p>While loading, LP pressure will decrease at short term.</p>
	<p>The diagram shows a vertical axis labeled 'PT'. Two horizontal lines represent setpoints: the upper one is 'PT 811 SP' and the lower one is 'PT 811 SP - 0.02 bara'. The region above the upper line is shaded green and labeled 'Load allowed'. The region below the lower line is shaded orange and labeled 'Load not allowed'.</p>
	OR
	<p>The other compressor is OFF</p> <p>In this case, the compressor is forced to 100% load</p>
	<p>323-PC-811 Output is $< 323-PC\text{-Output MINI}$</p>
	<p>323-ZT-102 $< \text{SV TARGET} - 2\%$</p> <p>In this case, the SV is loaded until the SV position is $\text{SV TARGET} - 1\%$</p>

Process Regulation – Capacity regulation – LOAD

- LOAD (the “loading” electrovalve is open)



Process Regulation – Capacity regulation – UNLOAD CONDITIONS

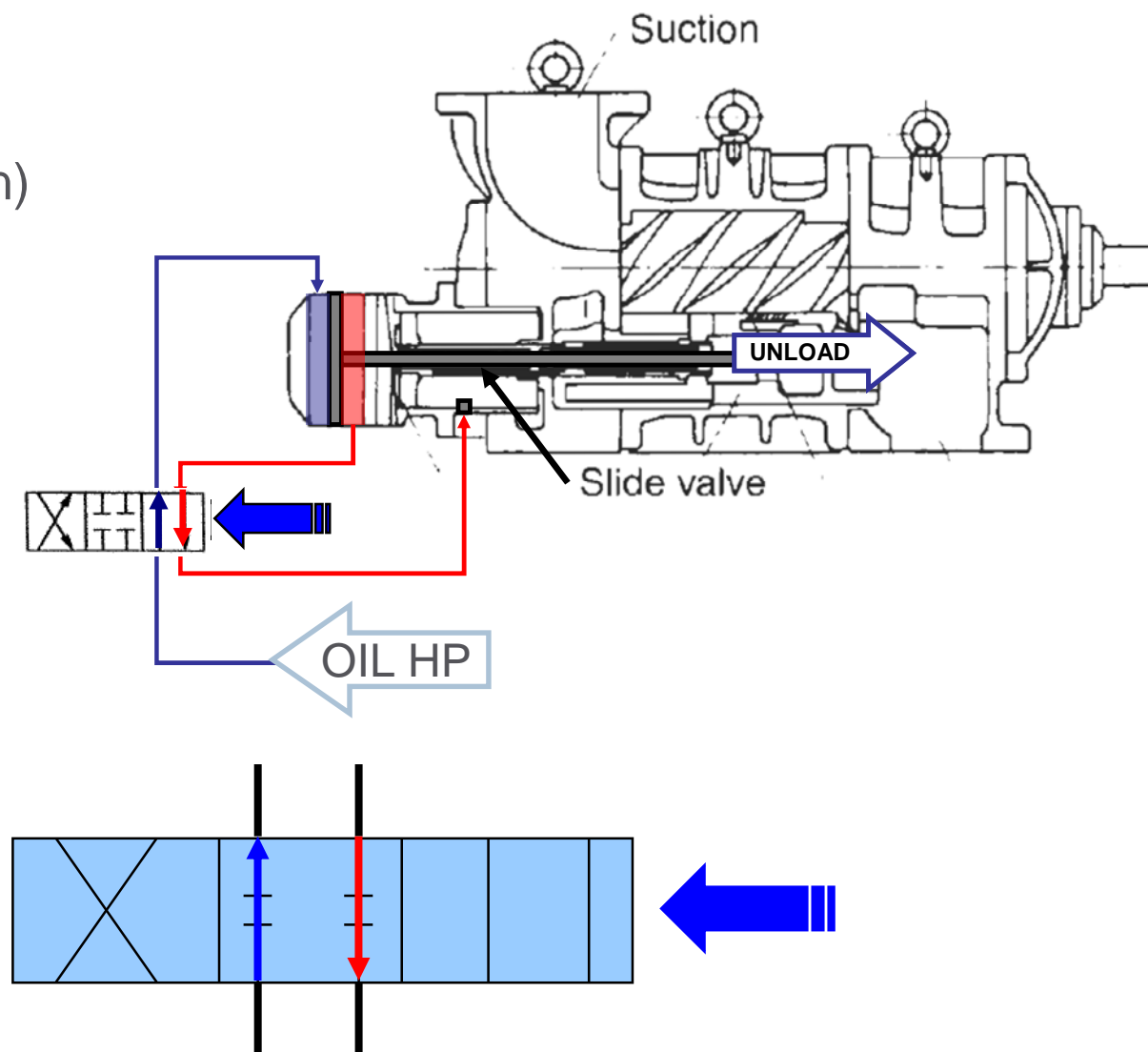
Initial condition: the pressure at compressor discharge is not too low: NO PSL 139

This condition is valid at start up: when the Spill Back Valve closes, the pressure builds up at compressor discharge. When the pressure is high enough, the Slide Valve can be operated to adjust the load.

AND	<p>323-PT-811 (LP Pressure) is not too far from its set point 323-PT-811 must be $< 323\text{-PC-811 SP} + 0.02 \text{ bara}$ While unloading, LP pressure will increase at short term.</p>	<p>The diagram shows a vertical axis labeled 'PT'. Two horizontal lines represent set points: the upper one is 'PT 811 SP + 0.02 bara' and the lower one is 'PT 811 SP'. The region above the upper line is shaded orange and labeled 'Unload not allowed'. The region below the lower line is shaded green and labeled 'Unload allowed'.</p>
	<p>323-PC-811 Output is $> 323\text{-PC-Output MINI} + 2\%$</p>	
	<p>323-ZT-102 $> \text{SV TARGET} + 2\%$ In this case, the SV is loaded until the SV position is $\text{SV TARGET} + 1\%$</p>	

Process Regulation – Capacity regulation – UNLOAD

- UNLOAD (the “unloading” electrovalve is open)



Process Regulation – LP Compr. Start Up – Ready to start conditions

■ Automatic RTS

- One of the HP Compressors is running
- Lube Oil Tank level OK
- Oil Separator Vessel level OK
- No moisture in compressor motor
- CW flow OK
- No shutdown conditions remaining and shutdown conditions are reset

■ Complete RTS conditions:

- Noise Hood ventilation fan is running
- The selected Compressor Oil Pump is running
- The selected Motor Lube Oil Pump is running
- The Compressor Oil system is at the right pressure
- The Motor Lube Oil system is at the right pressure

Process Regulation – LP Compressor Start Up Sequence

- START UP REQUEST FROM DCS:
 - ▣ Verification of Automatic RTS conditions
 - ▣ Pre-start actions:
 - Automatic start of Noise Hood Ventilation Fan
 - Automatic start of one Compressor Oil Pump
 - Automatic start of one Motor Lube Oil Pump
 - Unload SV
 - ▣ Verification of the complete RTS conditions
 - ▣ Start up of LP motor
 - ▣ Compressor start up:
 - The spill back valve ramps down to 0%
 - In parallel, the slide valve ramps up to its target position and the automatic control of the slide valve starts
 - Automatic control of the Compressor Oil Circuit starts

Process Regulation – HP Compr. Start Up – Ready to start conditions

■ Automatic RTS

- Lube Oil Tank level OK
- Oil Separator Vessel level OK
- Helium content: no moisture at HP discharge
- No moisture in compressor motor
- CW flow OK
- Oil level in ORS Vessels not too high
- No shutdown conditions remaining and shutdown conditions are reset

■ Complete RTS conditions:

- Noise Hood ventilation fan is running
- The Compressor Oil Pump is running
- The selected Motor Lube Oil Pump is running
- The Compressor Oil system is at the right pressure
- The Motor Lube Oil system is at the right pressure

Process Regulation – HP Compressor Start Up Sequence

- START UP REQUEST FROM DCS:
 - ▣ Verification of Automatic RTS conditions
 - ▣ Pre-start actions:
 - Automatic start of Noise Hood Ventilation Fan
 - Automatic start of the Compressor Oil Pump
 - Automatic start of one Motor Lube Oil Pump
 - Unload SV
 - ▣ Verification of the complete RTS conditions
 - ▣ Start up of HP motor
 - ▣ Compressor start up:
 - The spill back valve ramps down to 0%
 - In parallel, the slide valve ramps up to its target position and the automatic control of the slide valve starts
 - Automatic control of the Compressor Oil Circuit starts

Process Regulation – Stop Compression station - Overview

G000-600: Stop Compressors

G000-610: Stop the non
master LP Compressors

G000-620: Stop the non
master HP Compressors

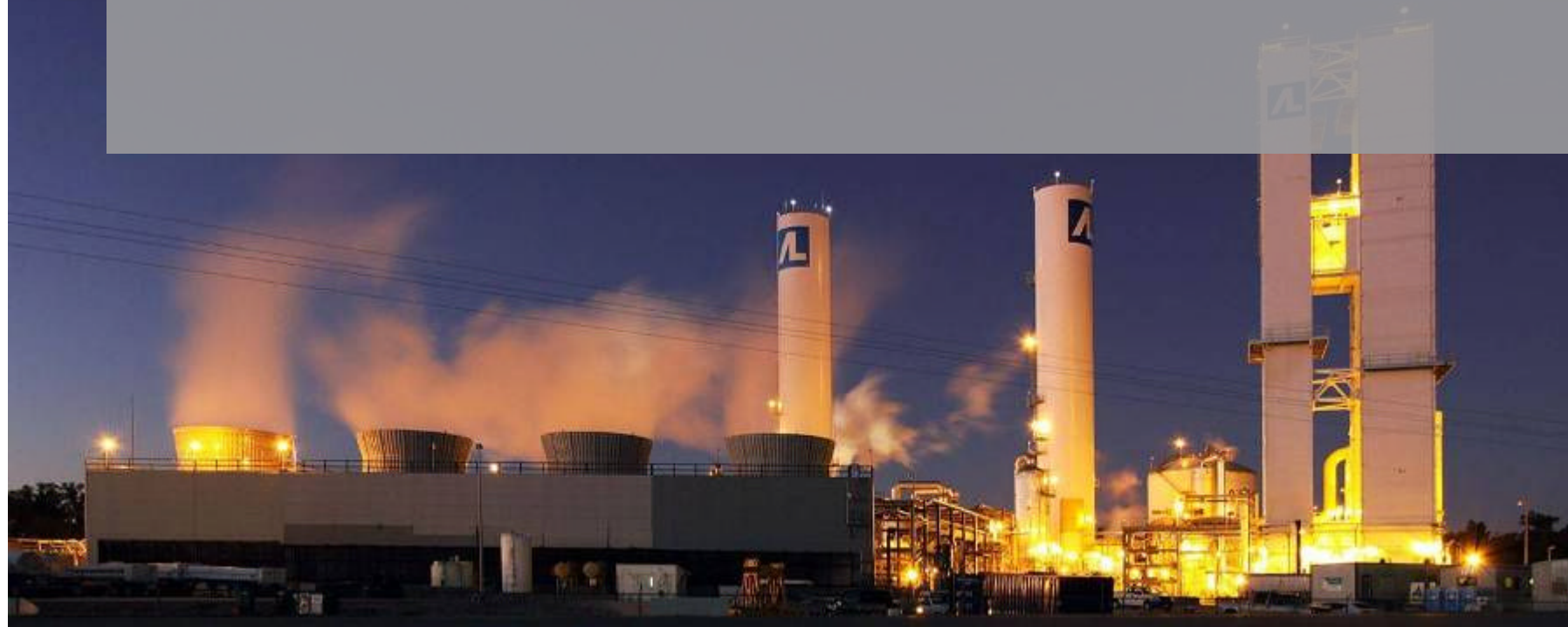
G000-630: Start HP
control with 3223-PV-810A
only (PV-810B closed)

G000-640: Stop the other
LP Compressor

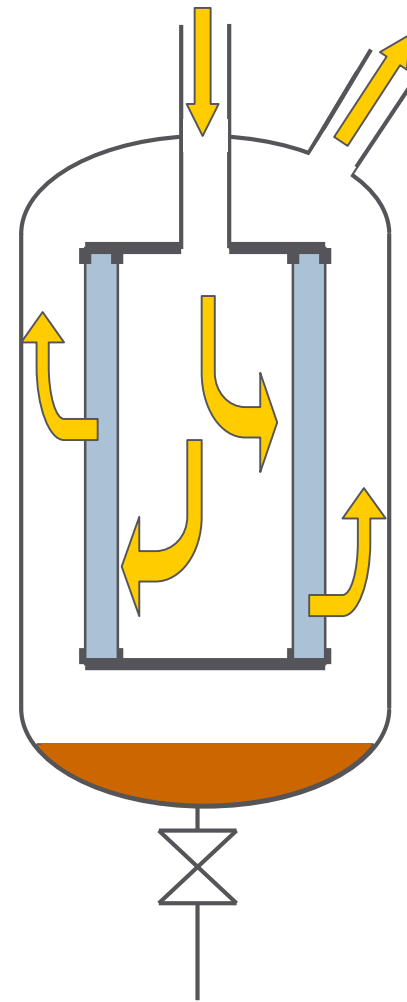
G000-650: Stop the other
HP Compressor



Thank you for your attention
Questions?



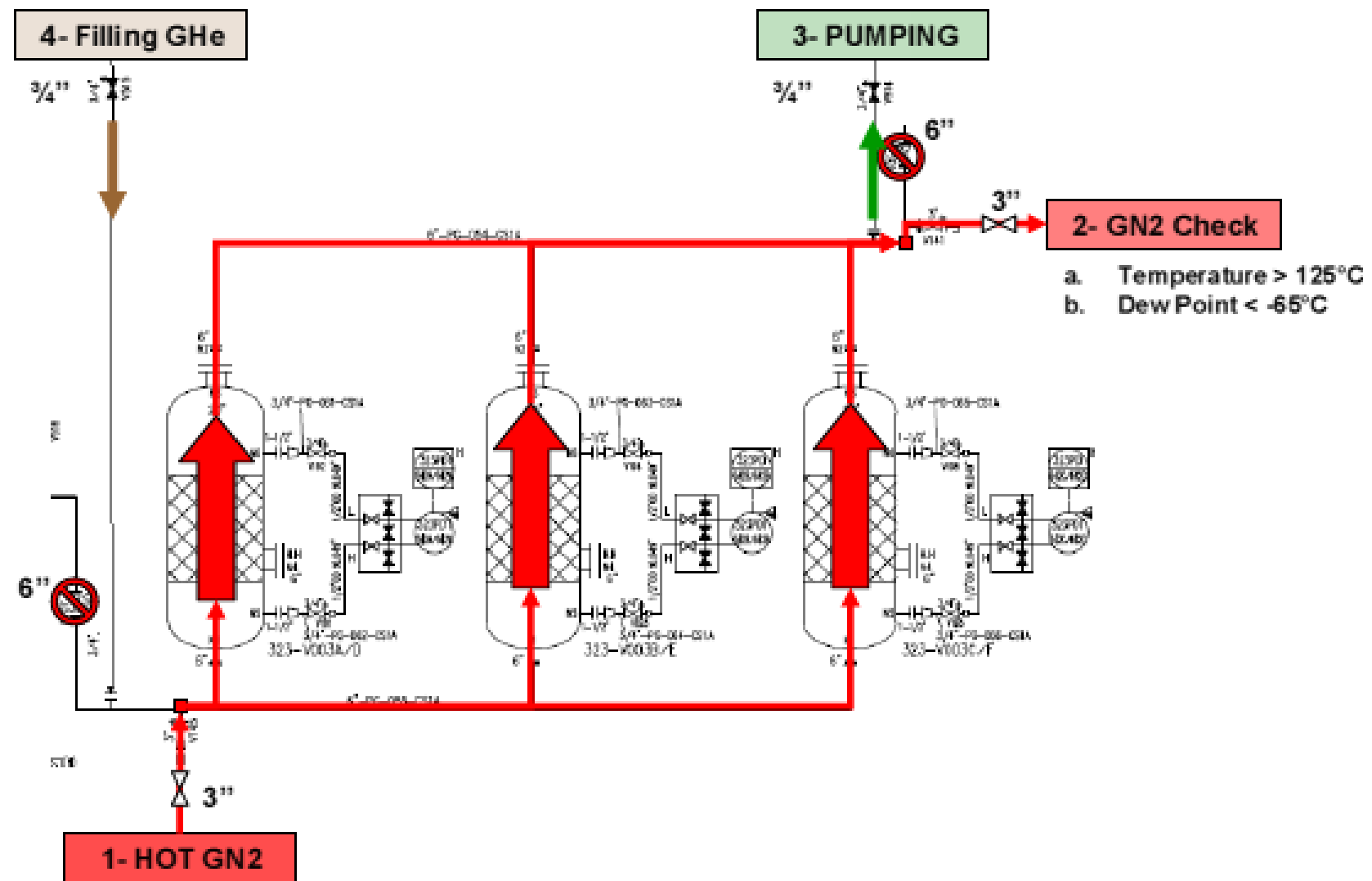
ORS – Coalescence – Cartridge Assembly



ORS – Drying of charcoals adsorbers

- 0. Isolate Adsorbers
- 1. Warm-up of the adsorbers to 125°C with hot GN 2 .
- 2. Drying of the adsorbers with 125°C GN 2 until the Dew-Point < -65°C.
- 3. Pumping to 10 mbar for 24 hours, while the adsorber temperature is still warm, using 323 P003.
- 4. Filling GHe.

ORS – Drying of charcoals adsorbers



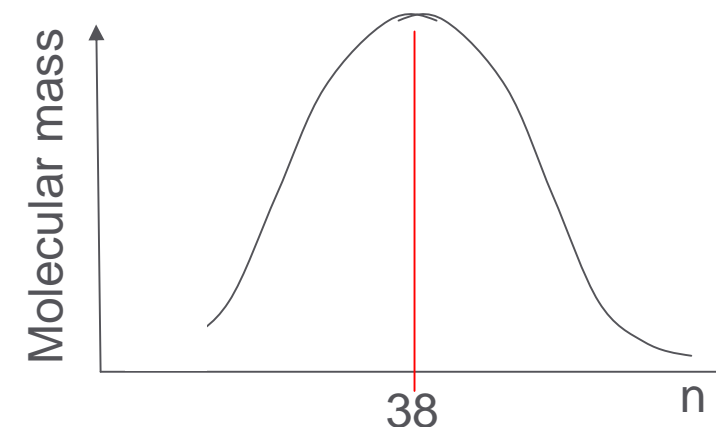
ORS – Oil selection

- Viscosity: only for mechanical reasons (depends only on the compressor operation).
- Vapour pressure: must be low (10^{-6} mb at 15°C) in order to reduce oil vapour entrainment
- Typical formula: $\text{C}_4\text{H}_9(\text{OC}_3\text{H}_6)_n - \text{OH}$
 - n is the number of motives (OC_3H_6) in the molecule
 - n is distributed according a Poisson curve.
- Vapour pressure at 25°C : $1,0 \times 10^{-11}$ mbar
- Vapour pressure at 25°C of the molecules with a low number of motives :

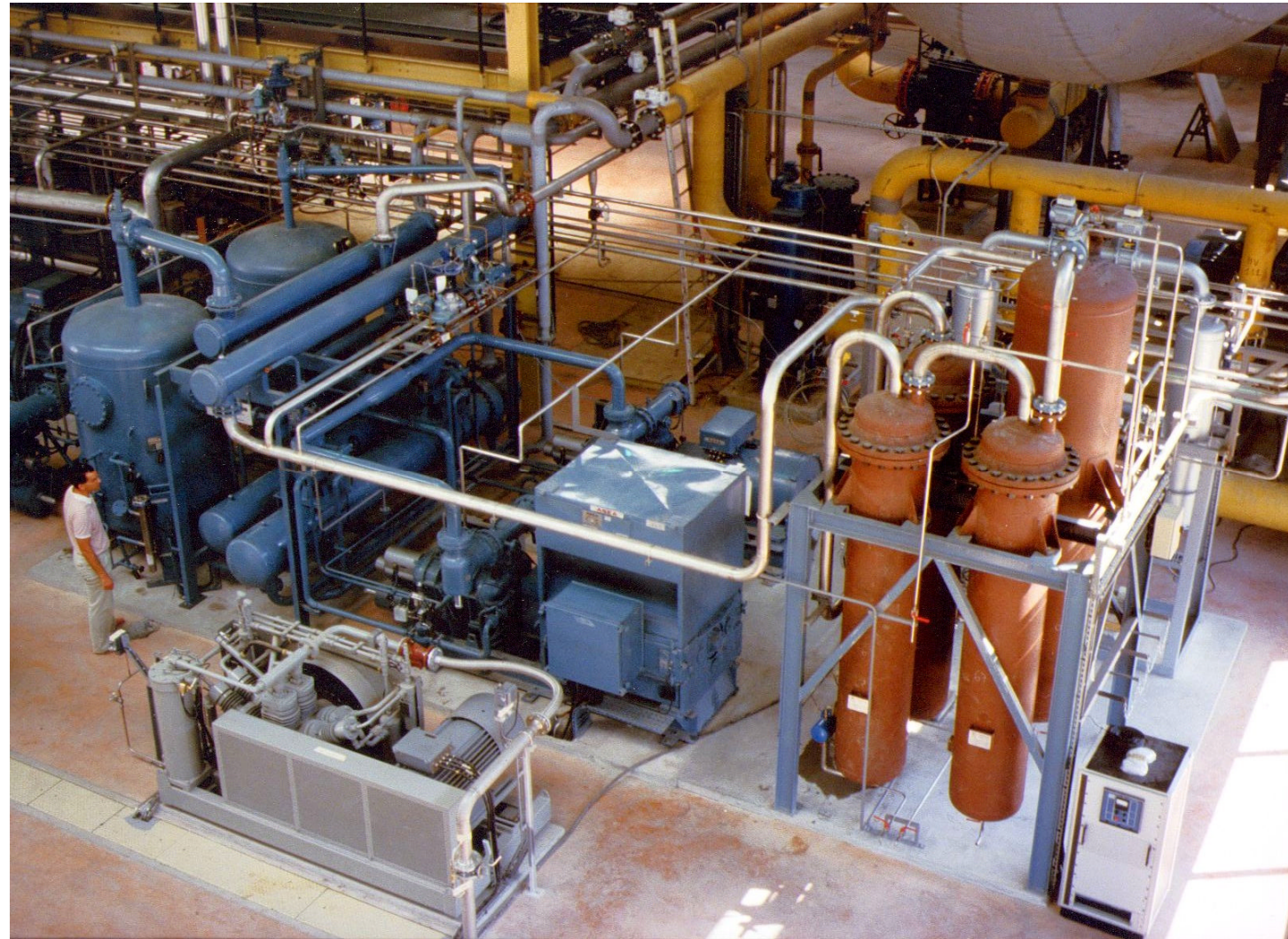
$\text{C}_4\text{H}_9(\text{OC}_3\text{H}_6)_1 - \text{OH}$ $1,0 \times 10^{-3}$ mbar

$\text{C}_4\text{H}_9(\text{OC}_3\text{H}_6)_2 - \text{OH}$ $6,1 \times 10^{-5}$ mbar

$\text{C}_4\text{H}_9(\text{OC}_3\text{H}_6)_3 - \text{OH}$ $2,2 \times 10^{-6}$ mbar



ORS – Tore Supra ORS



Cryogenics
Lurgi
Zimmer

75

Air Liquide, world leader in gases for industry, health and the environment



ORS – LHC



Cryogenics
Lurgi
Zimmer

76

Air Liquide, world leader in gases for industry, health and the environment

