TECHNOLOGY OF COMPONENTS USED FOR HELIUM REFRIGERATION

Guy GISTAU-BAGUER

THE OIL LUBRICATED SCREW COMPRESSOR

THE OIL LUBRICATED SCREW COMPRESSOR

How does it work ?

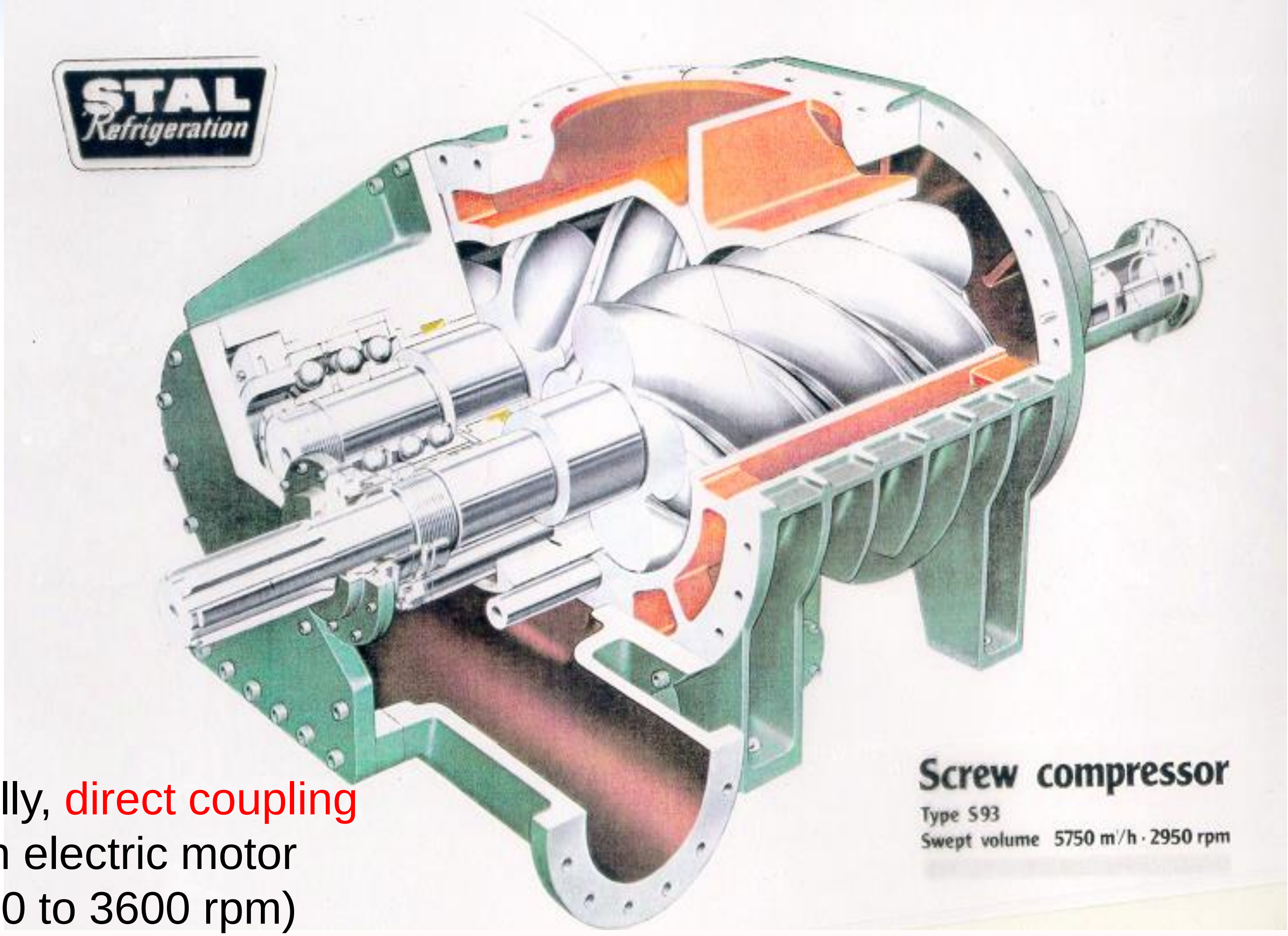
Why does it need oil ?

HISTORY

The basic idea can be found in a German patent, number 4121,
applied by Heinrich Krigar, on 24th March **1878** !

1934	Lysholm patent (SRM), first machine	
1940	Dry compression, timing gears,	high rpm, high noise level, low CR
1950	Oil injection, still timing gears,	lower rpm, lower noise level, higher CR,
1957	Oil injection, no more gears	lower rpm, lower noise level, higher CR,
1960	Symmetrical rotor profiles, capacity control	
1980	Asymmetrical rotor profiles,	higher efficiency, quieter operation

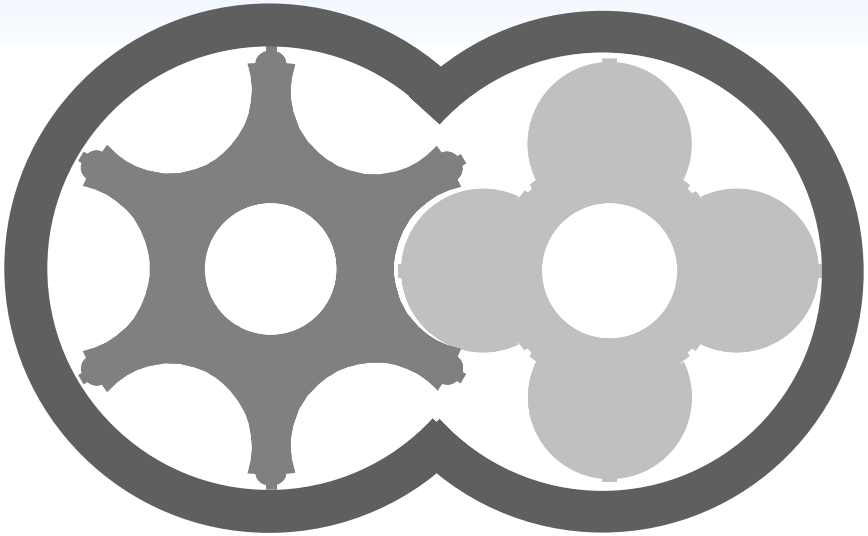
A SCREW COMPRESSOR



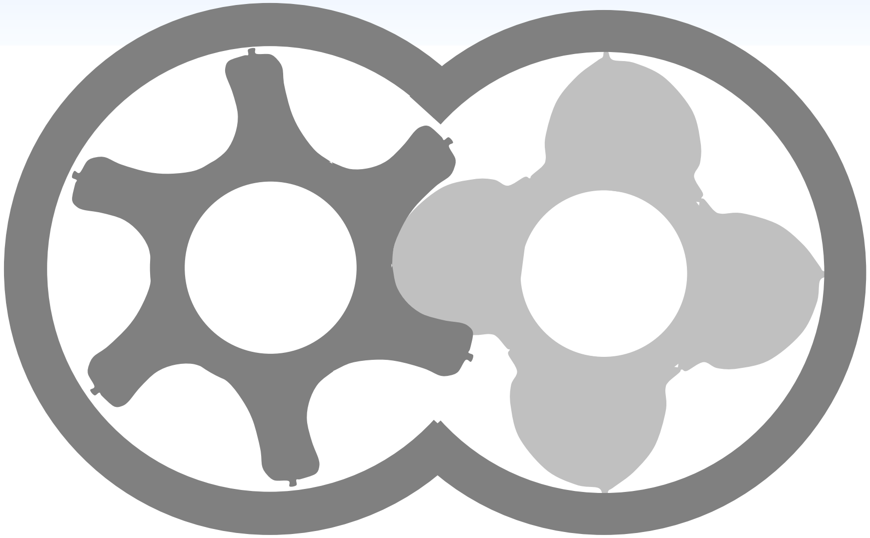
Generally, direct coupling to an electric motor (3000 to 3600 rpm)

ROTOR PROFILES

SYMETRICAL



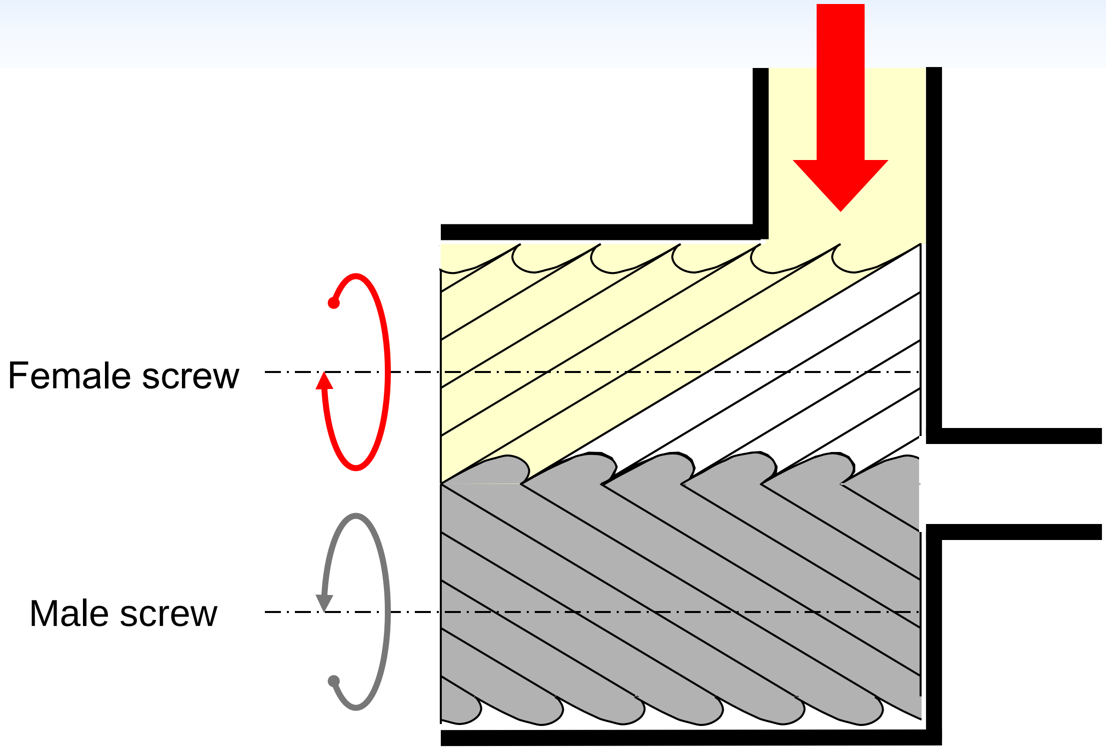
ASSYMETRICAL



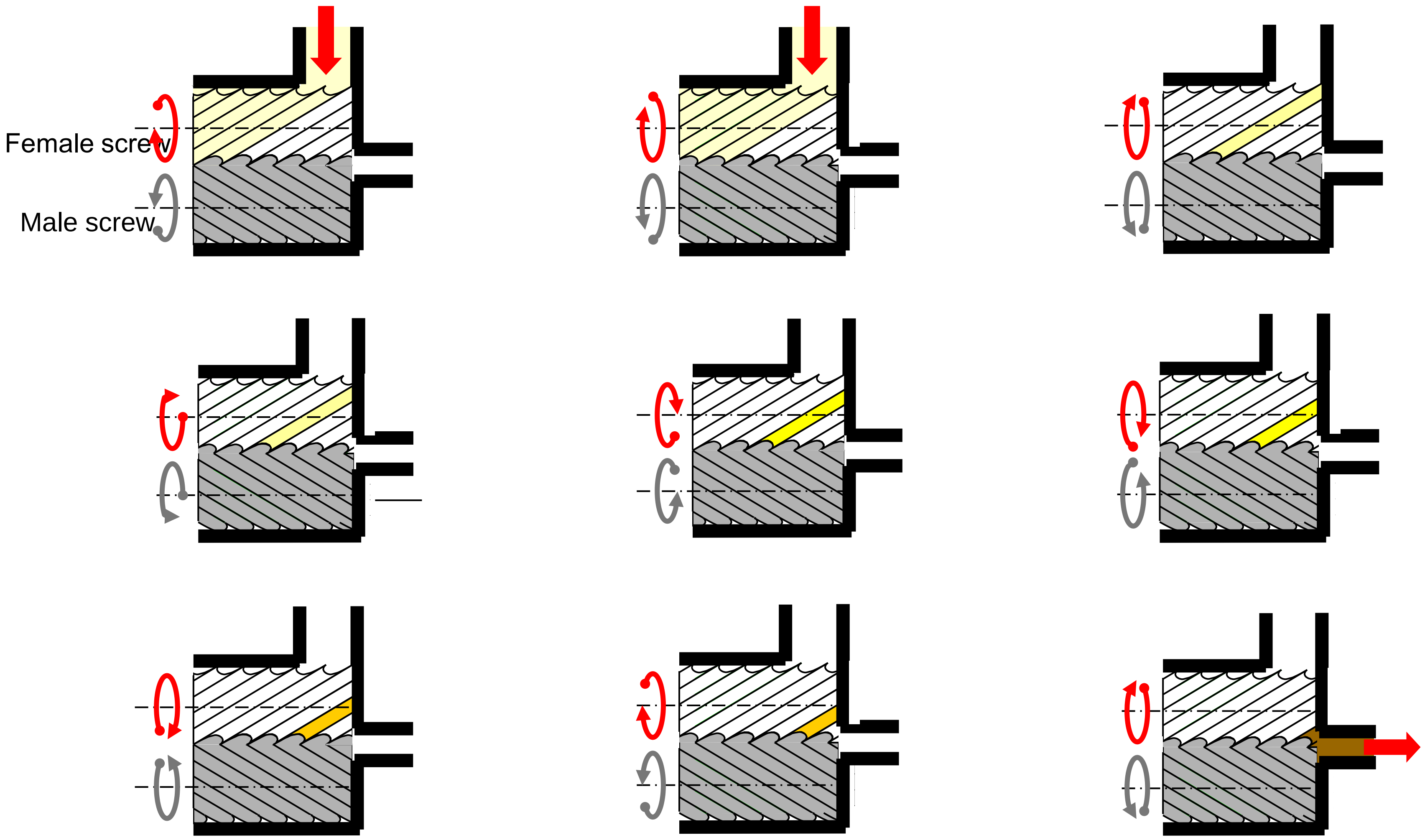
SCREWS

Screw machining

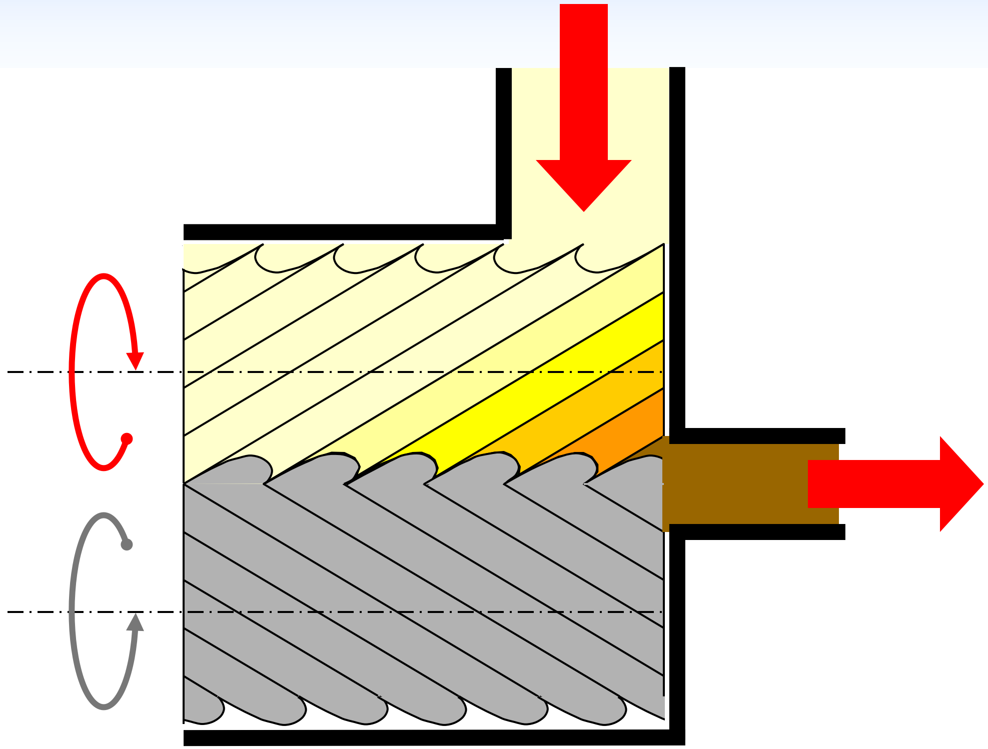
OPERATION



OPERATION

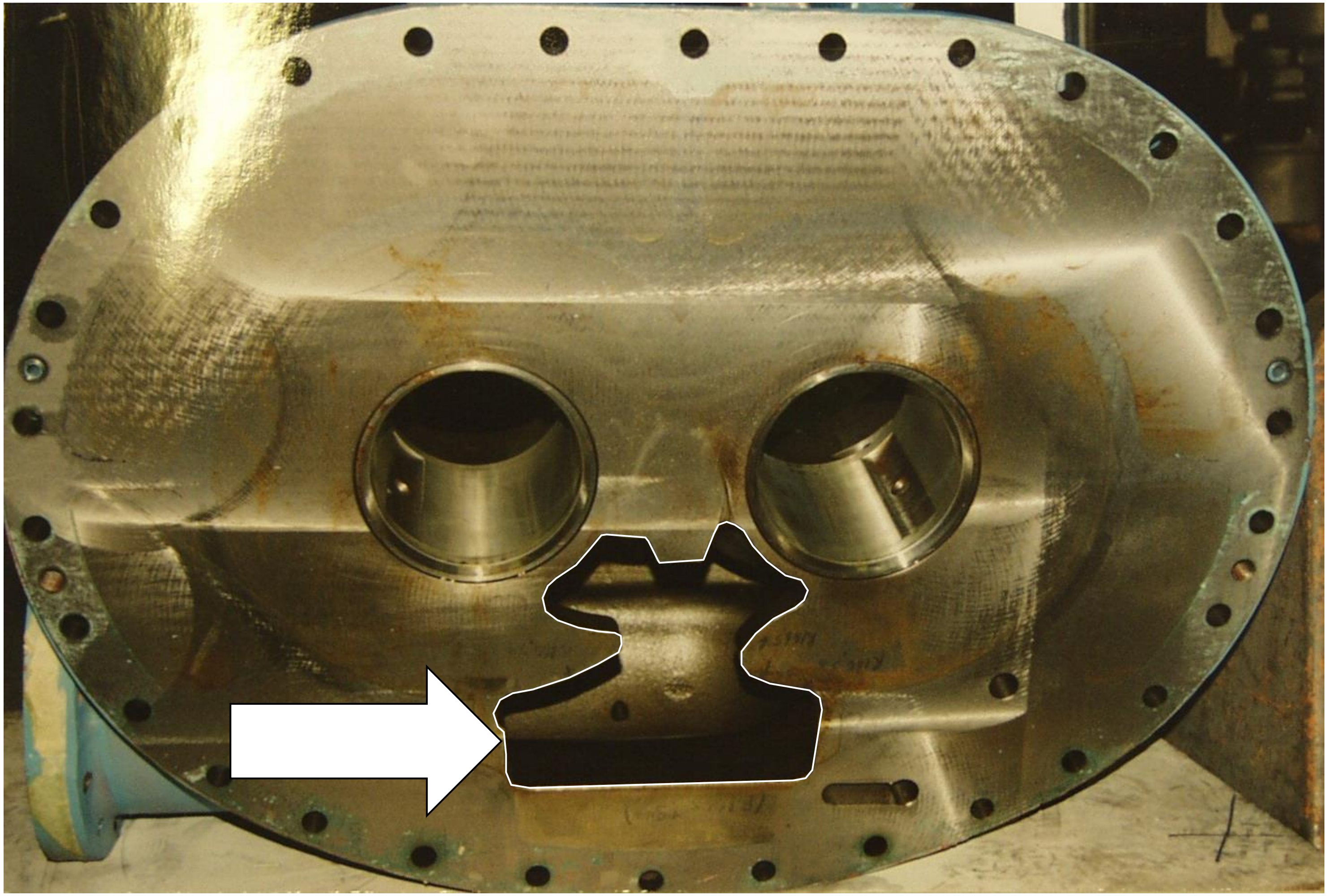


OPERATION

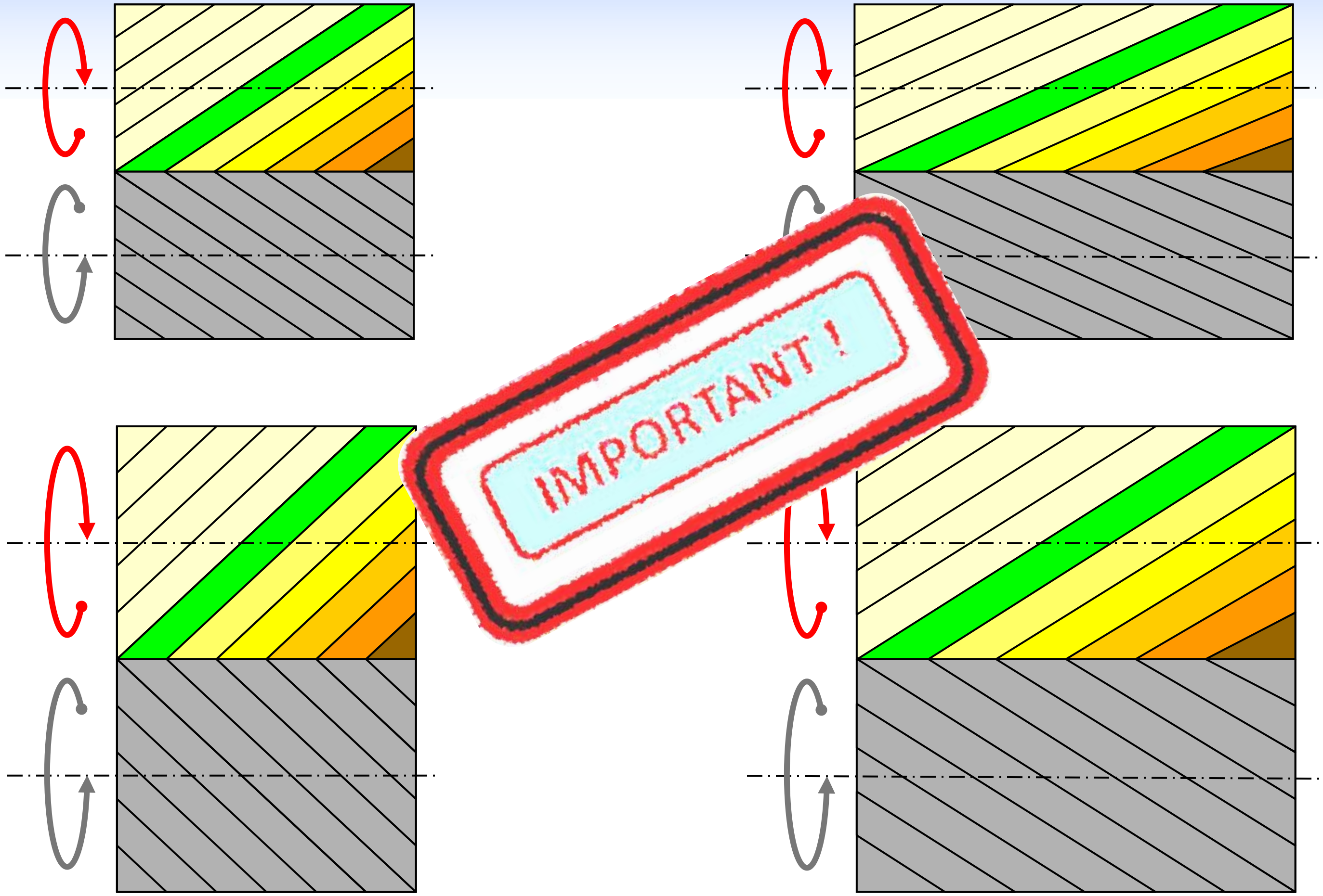


LET’S PLAY WITH THE MODEL !

THE DISCHARGE PORT



VOLUME FLOW



The volume flow of a screw compressor varies:

- according to the length of the screw,
- according to the diameter of the screw.

THE OIL LUBRICATED SCREW COMPRESSOR

How does it work ?

Why does it need oil ?

THE ADIABATIC COMPRESSION OF HELIUM

$$\frac{T_{dis}}{T_{suc}} = \left(\frac{P_{dis}}{P_{suc}}\right)^{\frac{\gamma - 1}{\gamma}}$$

For helium, REFPROP returns : $\gamma = 1{,}6747$

Example : compression of helium, from 1.05, 300 K, up to 15 bar

$$T_{dis} = 300 \times \left(\frac{15}{1{,}05}\right)^{\frac{1{,}6747 - 1}{1{,}6747}} = 876 \text{ K !} \qquad \text{or } 603\ °\text{C}$$

Obviously, the adiabatic compression of helium is too difficult !

THE DUTY OF OIL

Oil is injected during the compression phase.

It is finely dispersed.

Its contact area with helium is very large.

It absorbs, by fast heat exchange with helium, the major part of the compression heat.

It improves leak tightness between the rotors.

Accessorily, it lubricates the compressor.

HOW MUCH OIL IS NECESSARY ?

To cool 1 g/s of helium from 864 K to 300 K, one needs to withdraw :

Cp of helium

(876 - 300) x 5.2 = 2995 W

If one wants to reduce the increase of temperature, a part of the 2930 W has to be absorbed.

Let 's aim at 80°C (353 K) : we shall remove 2720 W.

If oil, the Cp of which is 1,95 J/g, is injected at 45 °C, we have to mix :

2720/1,95 x (353 - 318) = 40 grams of oil per gram of helium !

An oil lubricated screw compressor for helium is mainly an **oil pump** !

But the oil versus helium volume flow ratio is 8.6 %.

ISOTHERMAL EFFECTIVENESS OF SCREW COMPRESSORS

$$\frac{\text{isothermal compression power}}{\text{actual compression power}} = 0.45 \text{ to } 0.58$$

(at motor terminal)

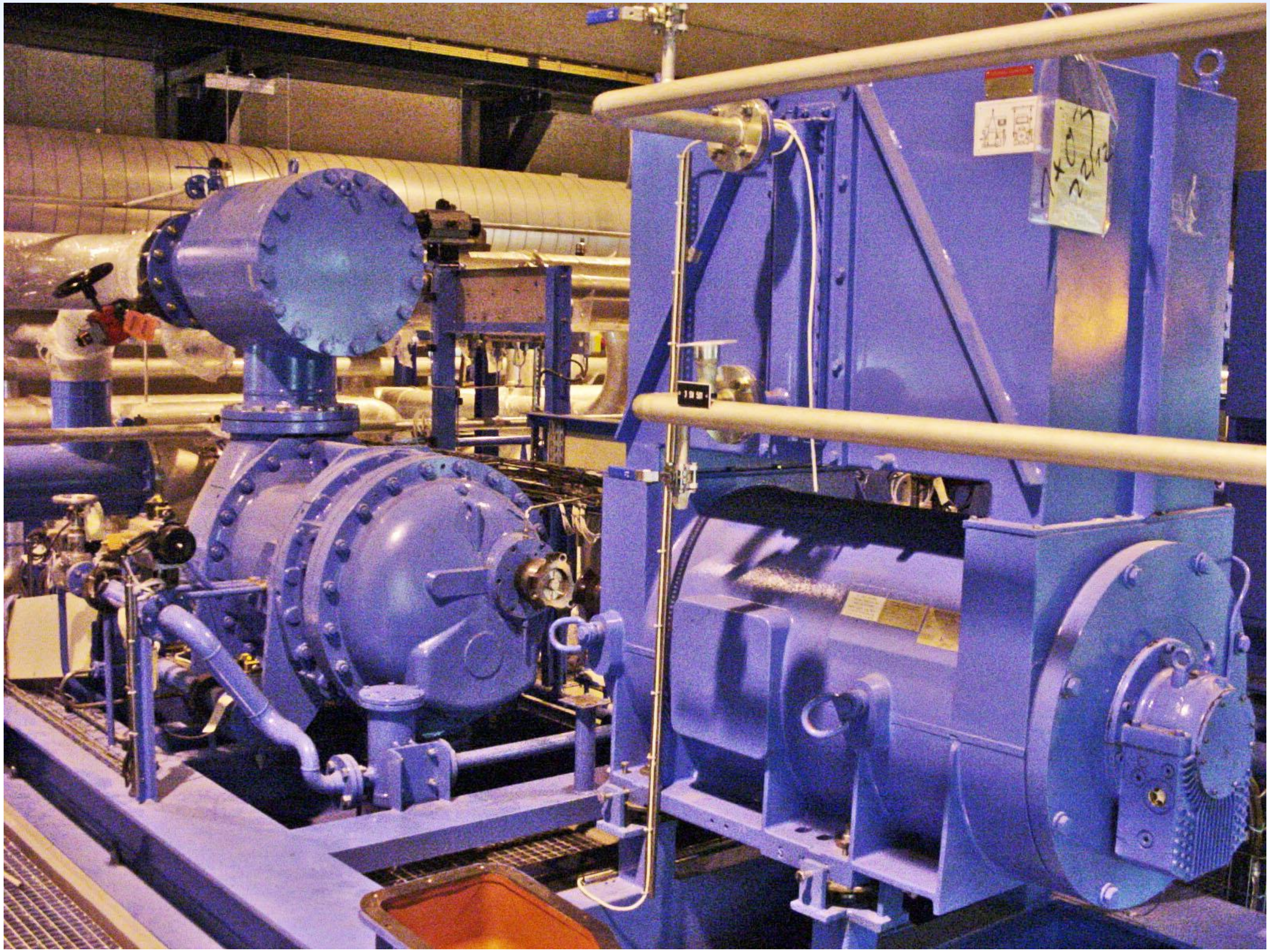
WHERE DOES ENERGY GO?

Assuming that all the energy is released through oil and helium coolers.

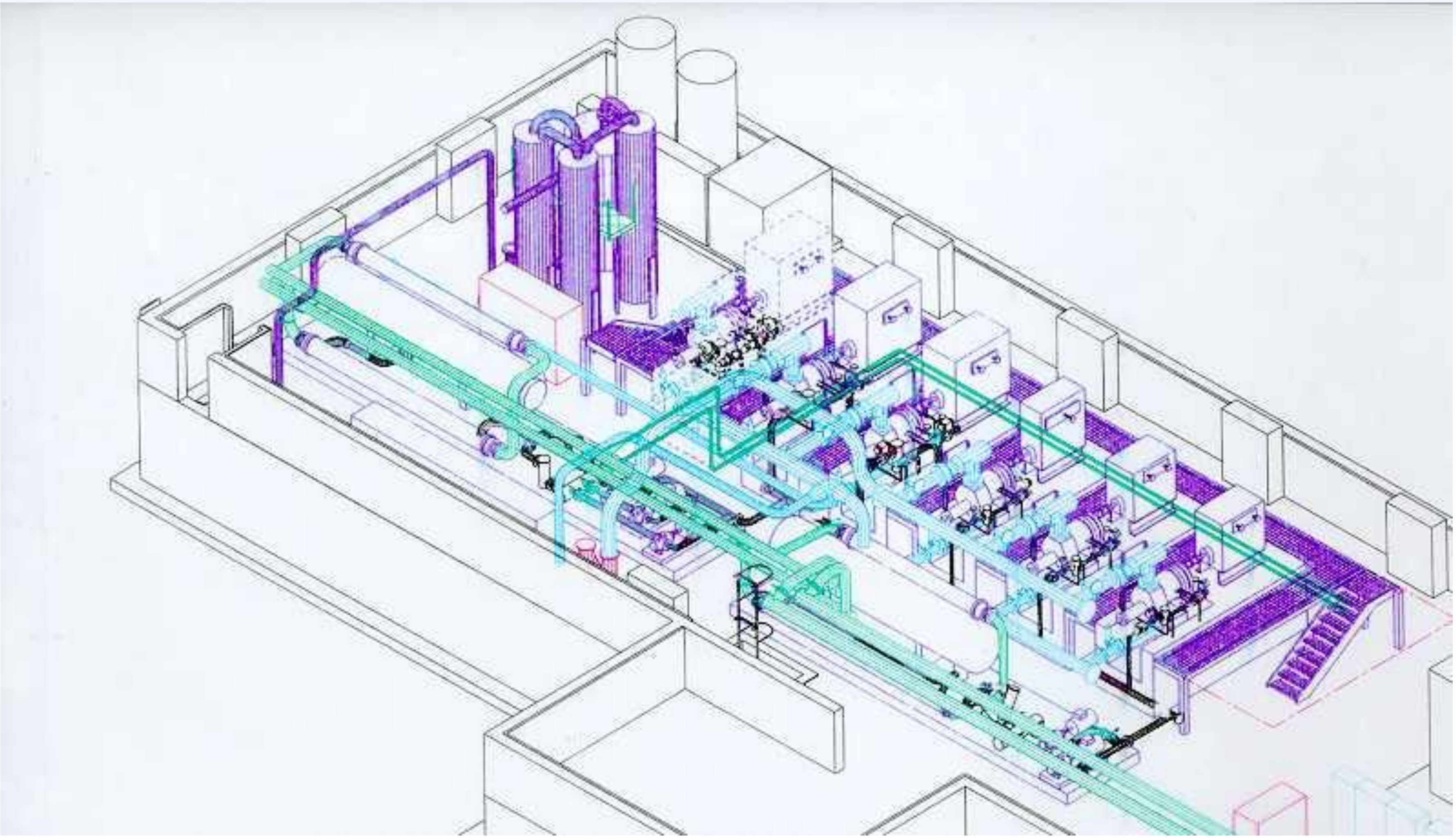
Mass flow	(g/s)	100,00	
Suction pressure	(bar)	1,05	
Suction temperature	(ºC)	20,00	
Discharge pressure	(bar)	14,00	
Shaft power	(kW)	284,00	
Oil injection temperature	(°C)	45,00	
Compressor discharge temperature	(ºC)	80,00	
Oil cooler power	(kW)	245,96	**0,87**
He cooler power	(kW)	25,96	**0,09**

About 10 to 15 % of the energy is released in the ambient.

COMPRESSOR AND MOTOR



A LARGE COMPRESSION STATION



LHC COMPRESSION STATION

THE OIL REMOVAL SYSTEM

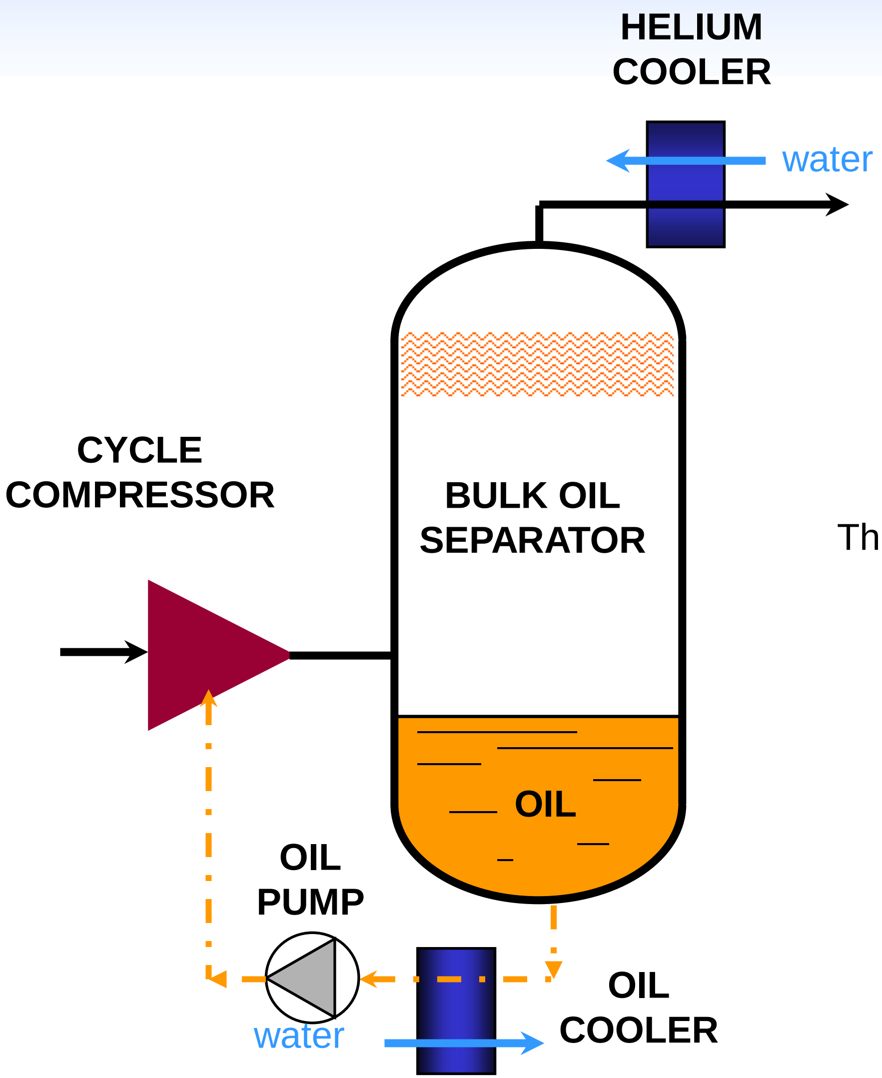
OIL IN HELIUM AT THE DISCHARGE SIDE OF A SCREW COMPRESSOR

A big quantity of liquid

A lot of aerosols

A little bit of vapour

BULK OIL SEPARATOR



There is also an horizontal version of such a bulk oil separator

OIL IN HELIUM
AT THE DISCHARGE SIDE
OF THE BULK OIL SEPARATOR

A LOT OF AEROSOLS

A LITTLE BIT OF VAPOUR

AEROSOL SEPARATION

PROCESS : COALESCENCE

Agglomerate small particles

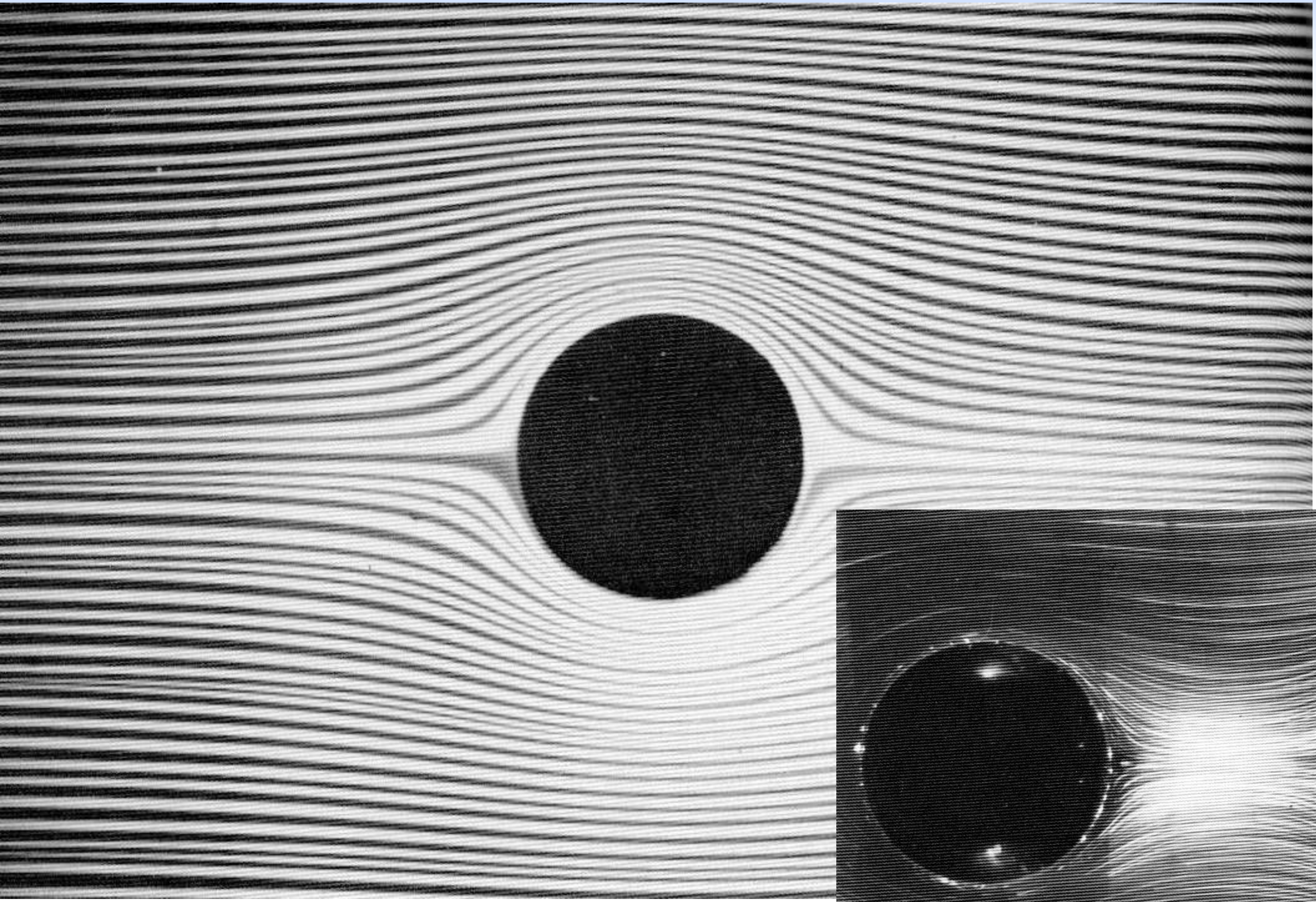
into **bigger ones**

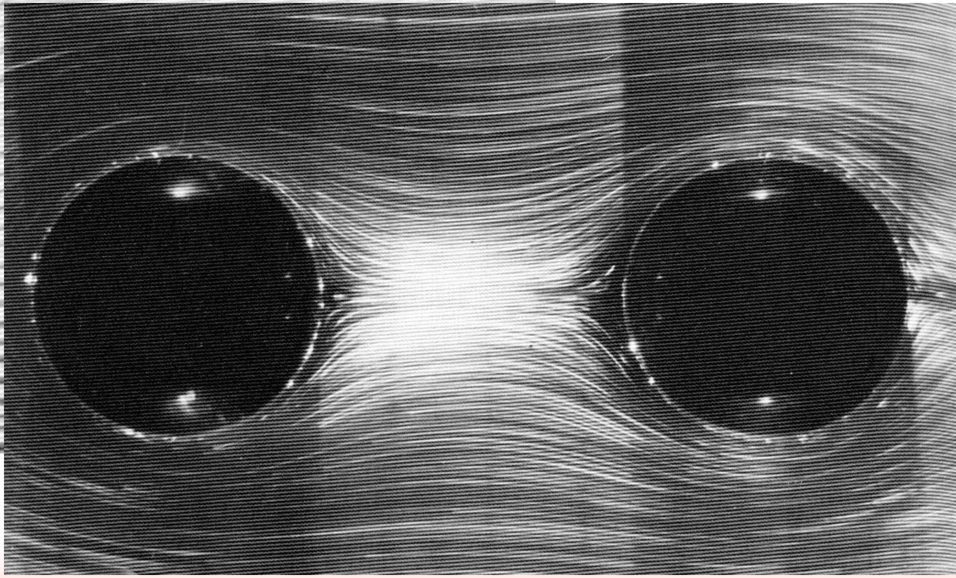
in order they can be easily separated by gravity.

No effect on vapour

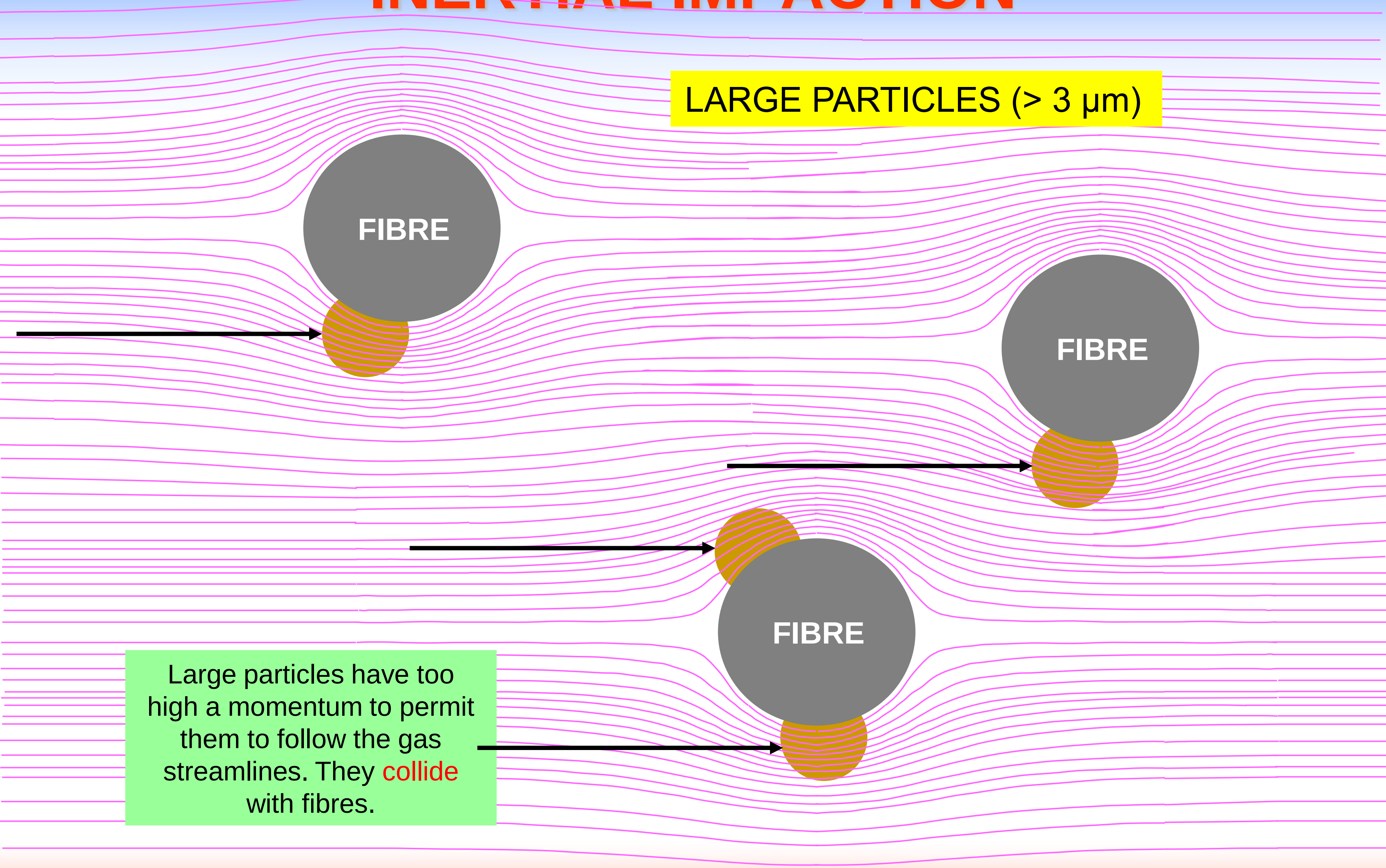
Obviously!

FLOW PATTERN





INERTIAL IMPACTION

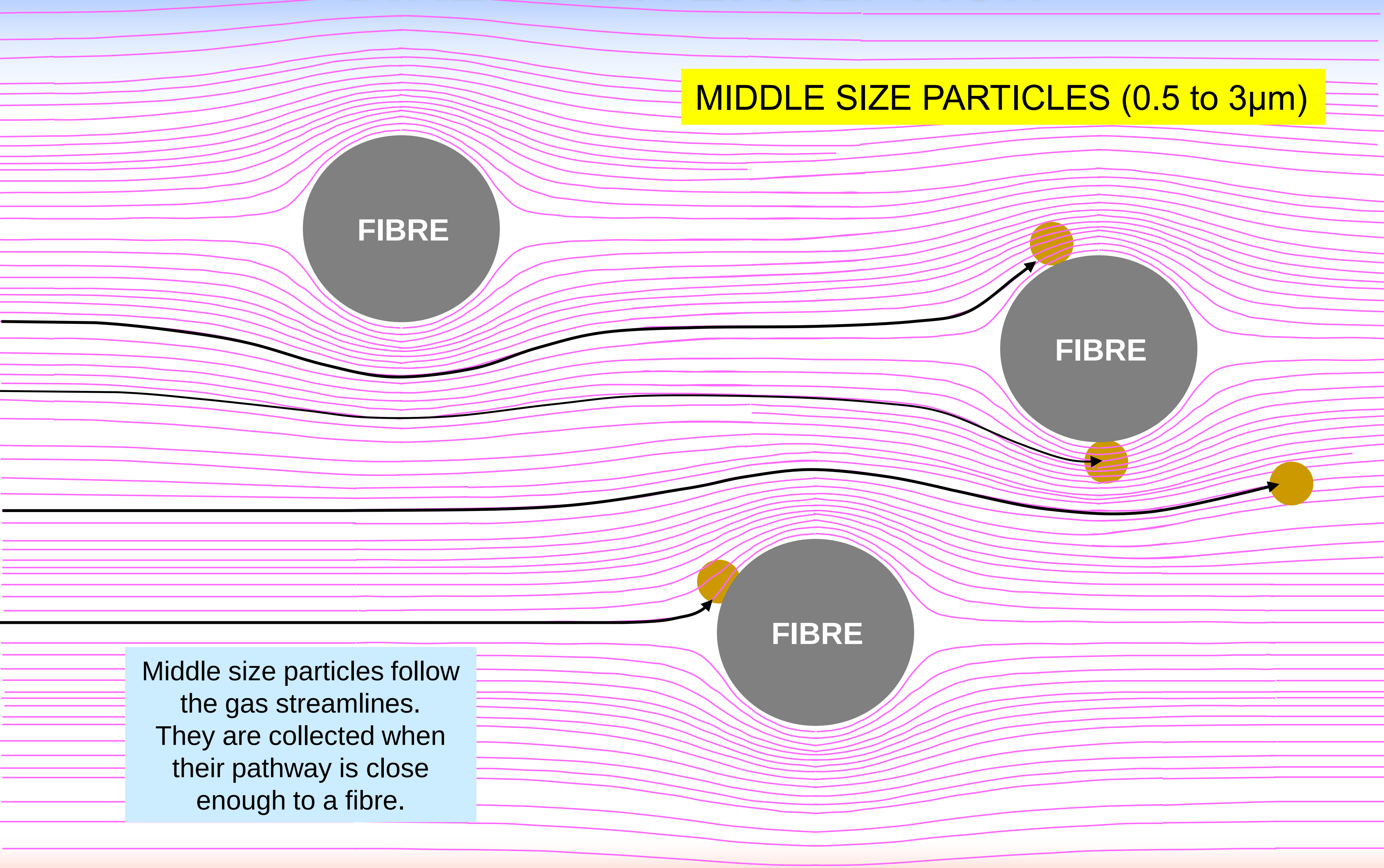


LARGE PARTICLES (> 3 µm)

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

DIRECT INTERCEPTION

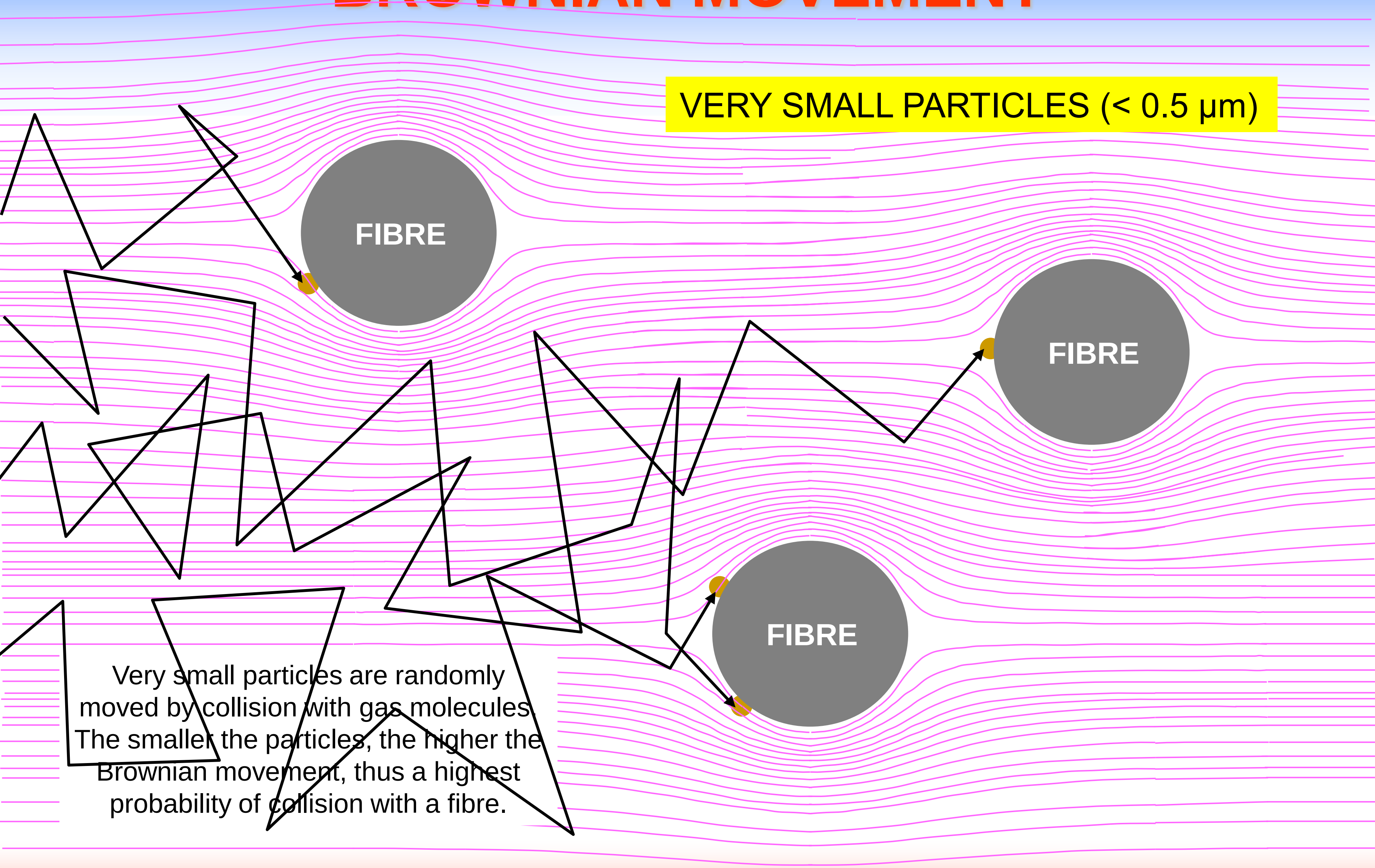
MIDDLE SIZE PARTICLES (0.5 to 3µm)



Middle size particles follow the gas streamlines. They are collected when their pathway is close enough to a fibre.

BROWNIAN MOVEMENT

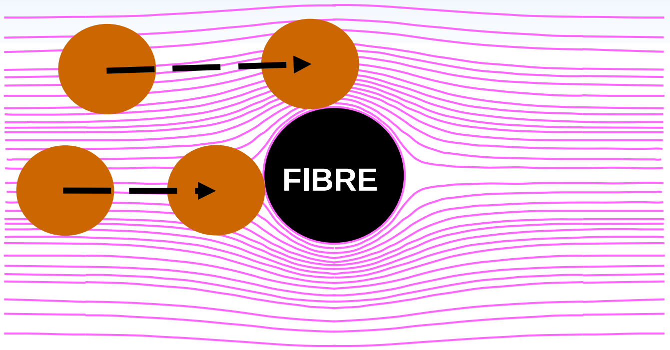
VERY SMALL PARTICLES (< 0.5 µm)



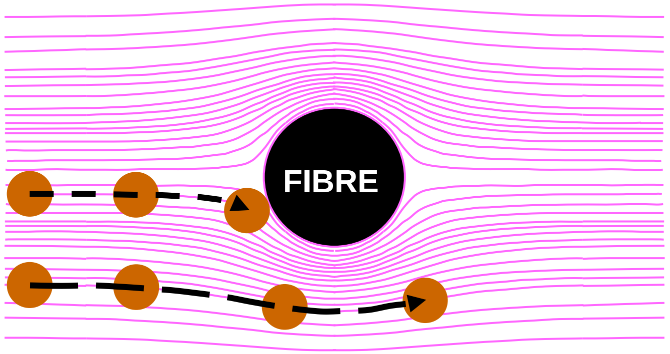
Very small particles are randomly moved by collision with gas molecules. The smaller the particles, the higher the Brownian movement, thus a highest probability of collision with a fibre.

AEROSOL CAPTURE PROCESS

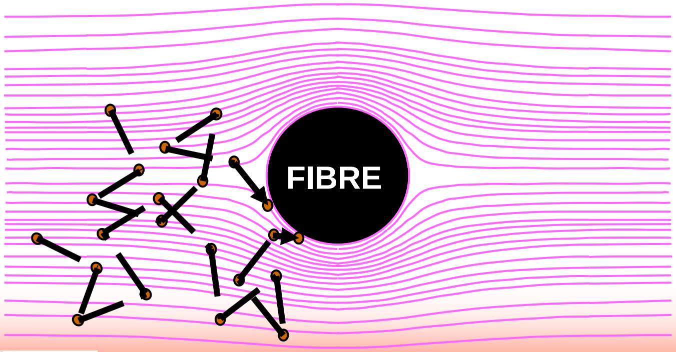
INERTIAL IMPACTION



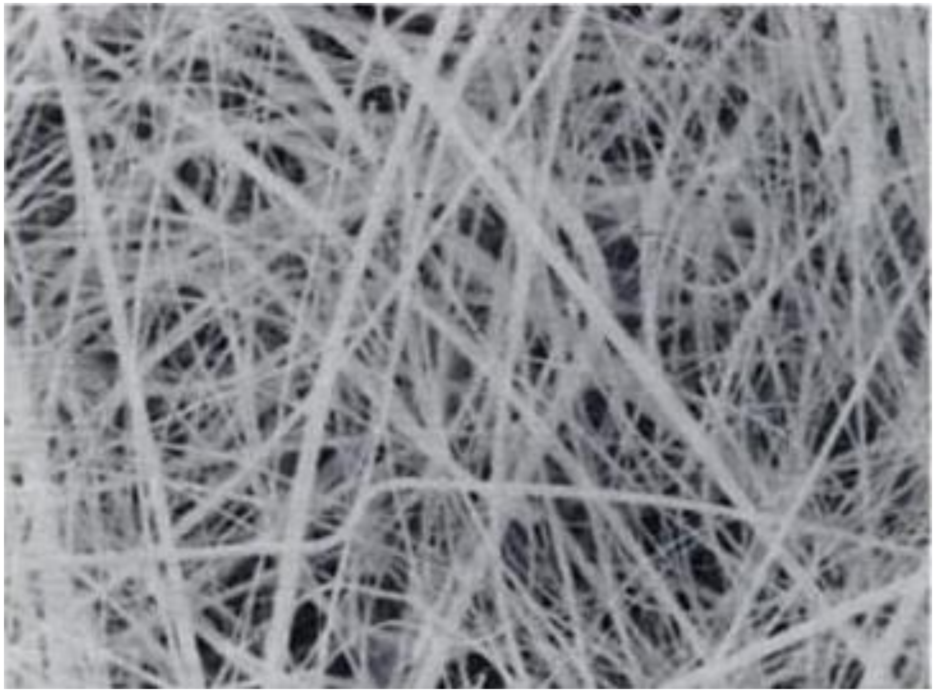
DIRECT INTERCEPTION

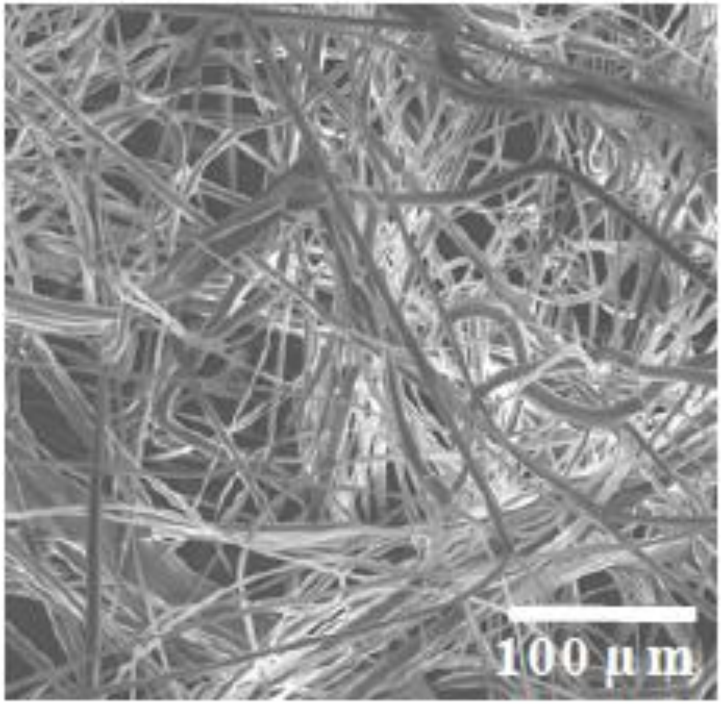


BROWNIAN MOVEMENT



FILTERING MEDIA





SURPRISING BEHAVIOUR !

It is not obvious to have an idea of the behaviour of an oil aerosol !

Oil in helium at 20 bar, 80 °C

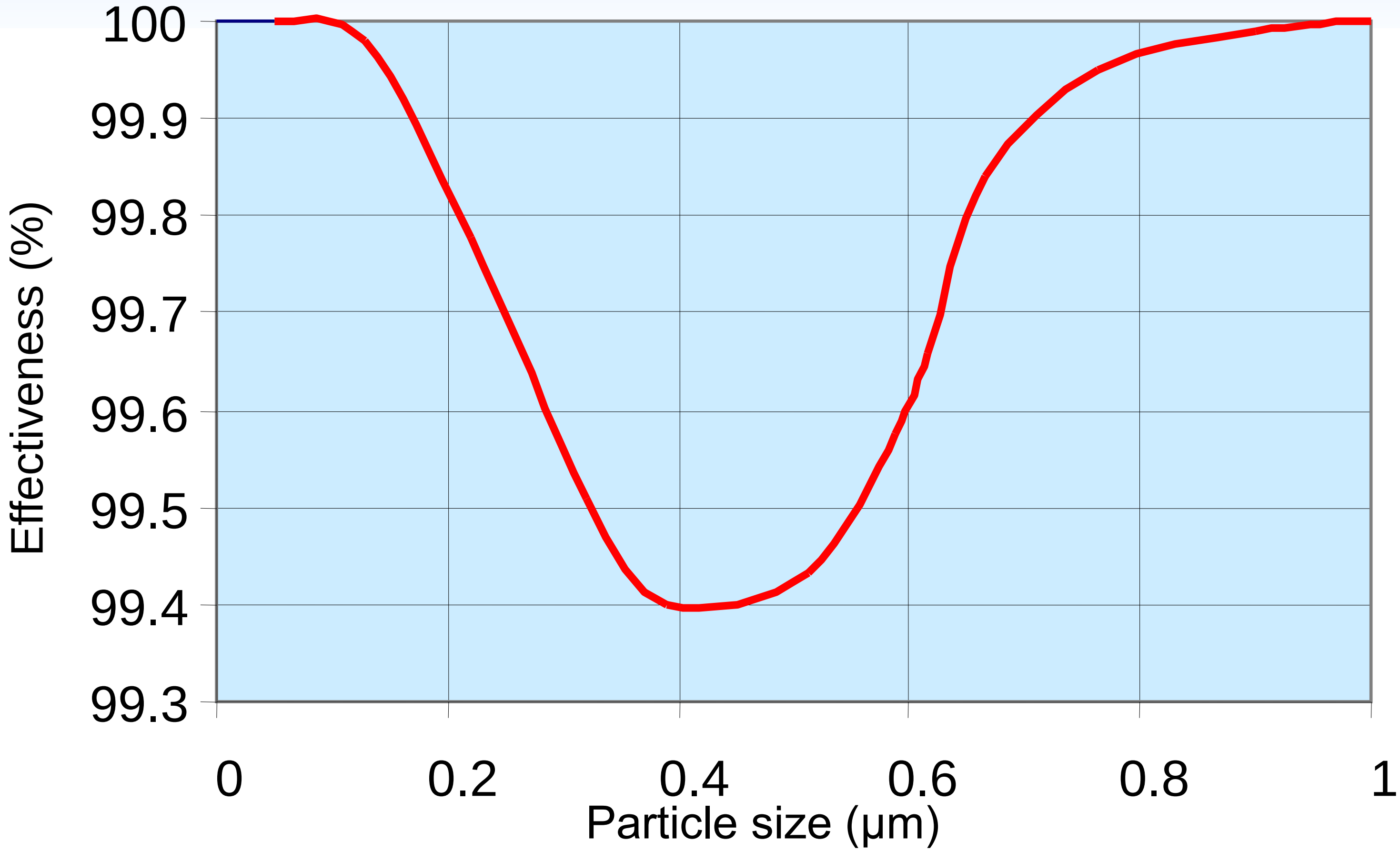
Droplet diameter	(µm)	0.016	0.12	0.91
Falling velocity	(mm/s)	0.01	0.1	1.0

Thumb rule : velocity in mm/s = diameter in µm

The result of this calculation for very small diameters is certainly affected by Brownian movement of helium molecules…

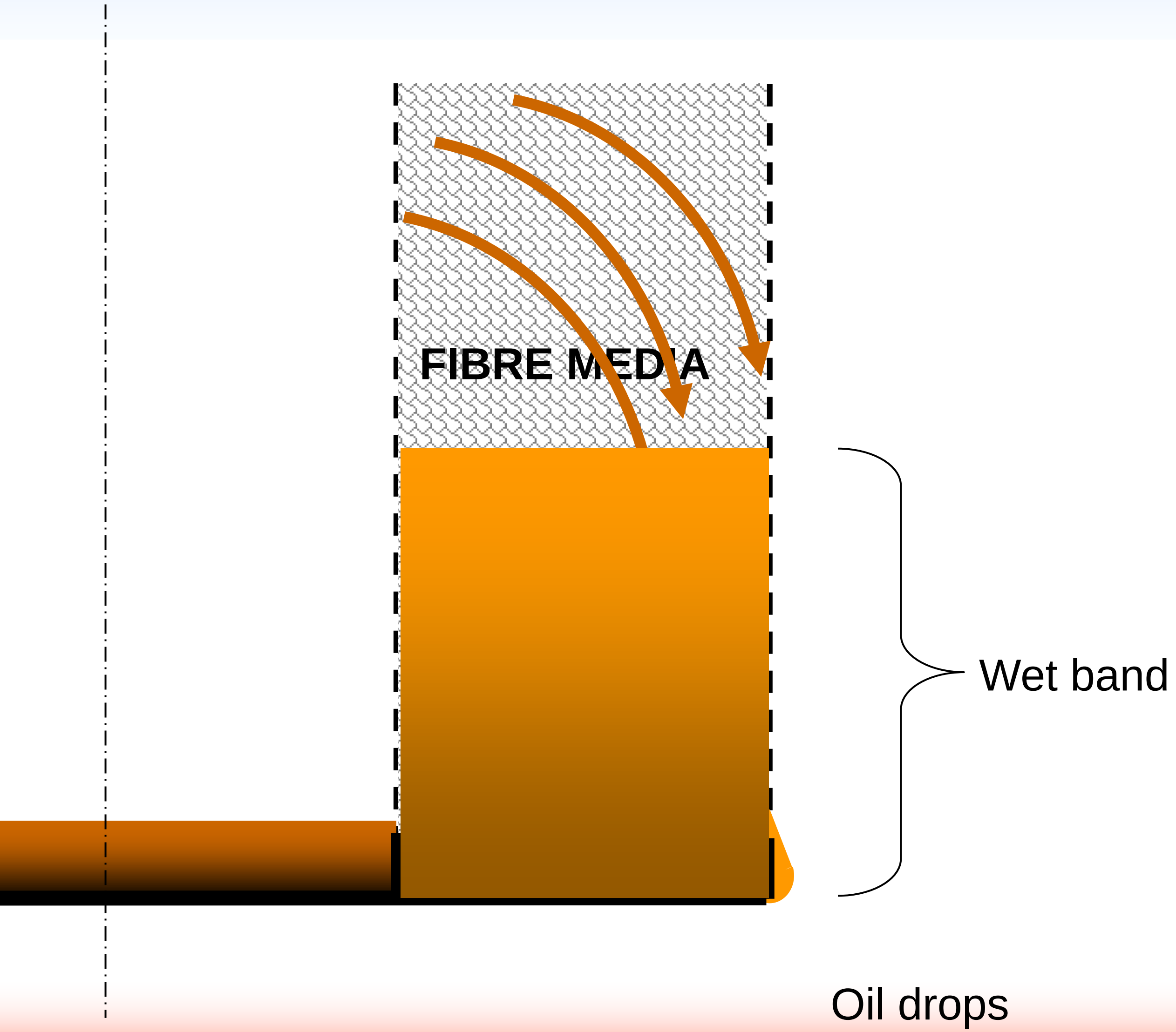
EFFECTIVENESS OF A COALESCER

VERSUS PARTICLE SIZE

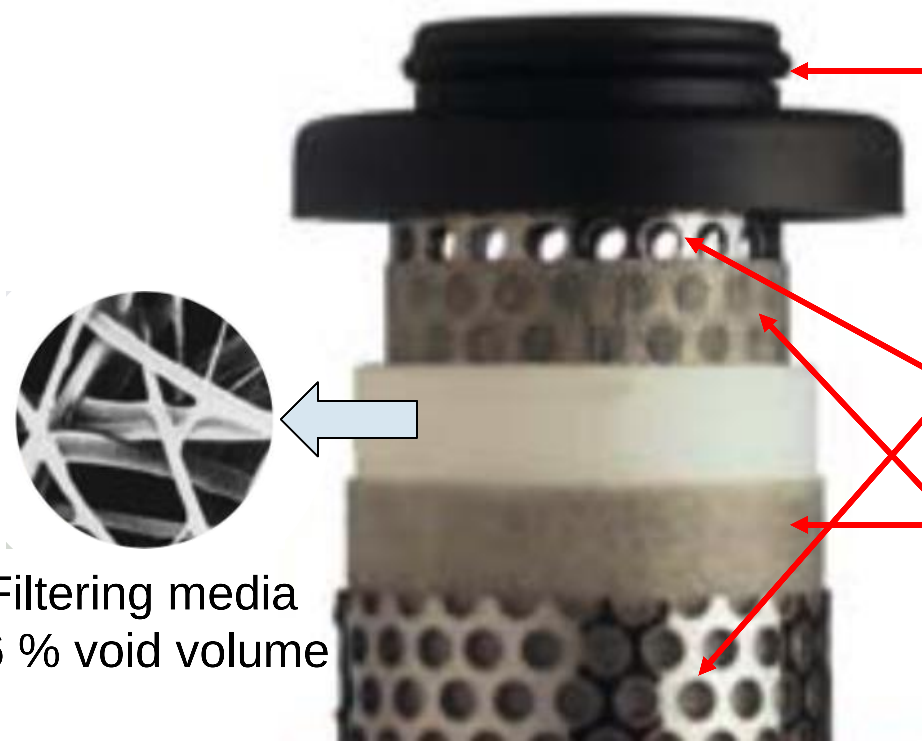


Provided that the cartridge sizing is correct !

CARTRIDGE CROSS SECTION



A SMALL CARTRIDGE



Domnick Hunter

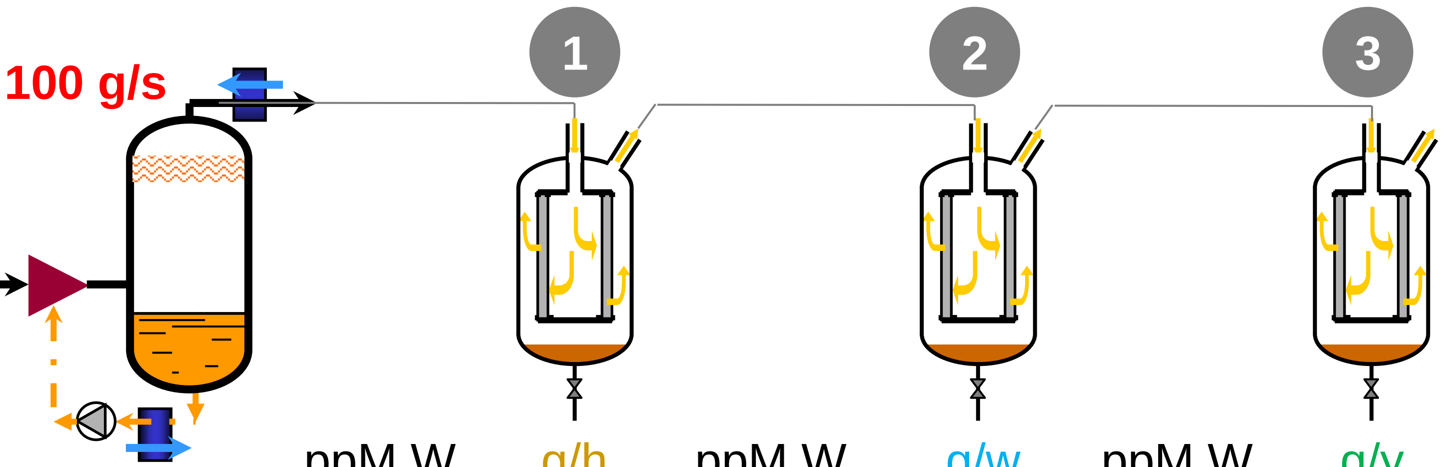
A LARGE CARTRIDGE

Media is stuffed into a metal cage.

HOW TO REACH AN ACCEPTABLE OIL CONCENTRATION ?

Assuming that the effectiveness of one stage of coalescer is 99 %, how many stages are to be implemented ?

From cartridge 1 to 3, the filtering media mesh is smaller.



Towards the cold box

ppM W	g/h	ppM W	g/w	ppM W	g/y	ppM W	g per 100000 h
5000	1800	50	432	0.5	1576	0.005	180
1000	360	10	86	0.1	315	0.001	36
100	36	1	9	0.01	31	0.0001	3.6
10	3.6	0.1	1	0.001	3	0.00001	0.36

TRAPPING OF OIL VAPOUR

PROCESS : ADSORPTION
AT ROOM TEMPERATURE
WITH ACTIVATED CHARCOAL

NOT EFFICIENT FOR AEROSOLS

Obviously!

SELECTION OF THE OIL

Viscosity : only for mechanical reasons (depends only on the compressor operation).

Vapour pressure : must be low (<10^{-6} mbar at 25 °C), in order to reduce oil vapour entrainment.

OIL TREATMENT

IMPURITIES TO ELIMINATE :

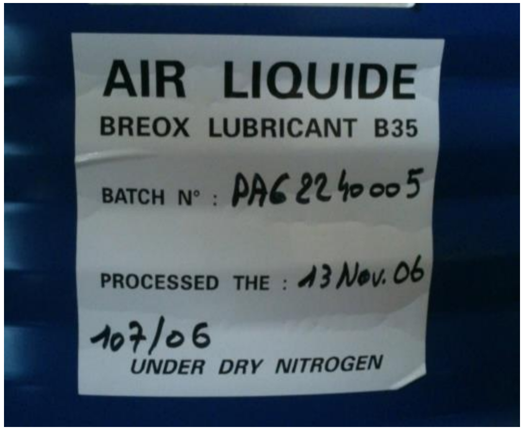
Air : related to the fabrication process

Water : oil is very hygroscopic

The high vapour pressure molecules.

METHOD :

Heating under vacuum.



Fill in and top up with processed oil !

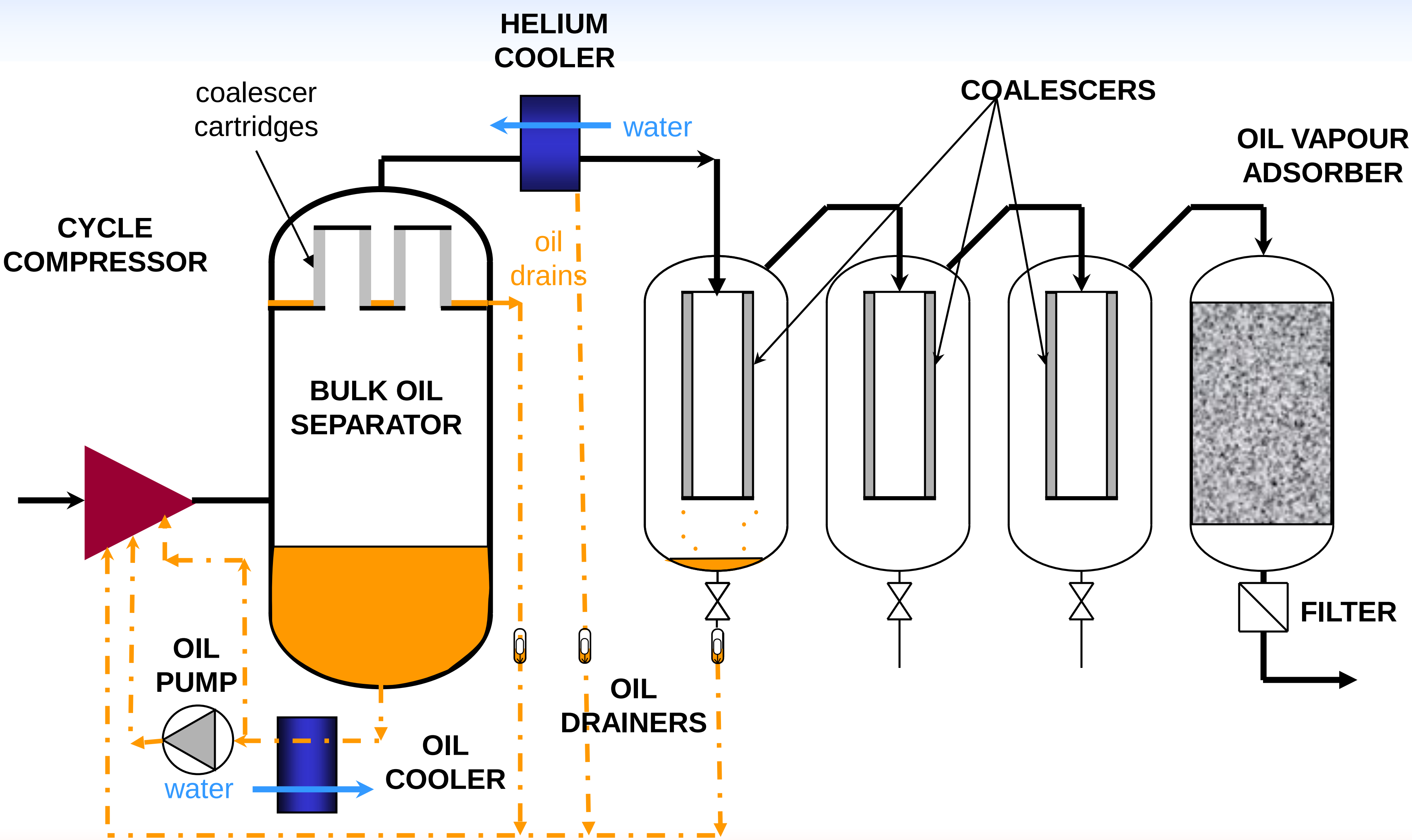
PRECAUTIONS RELATED TO BREOX OIL

Avoid any contact with skin or mucous membranes.

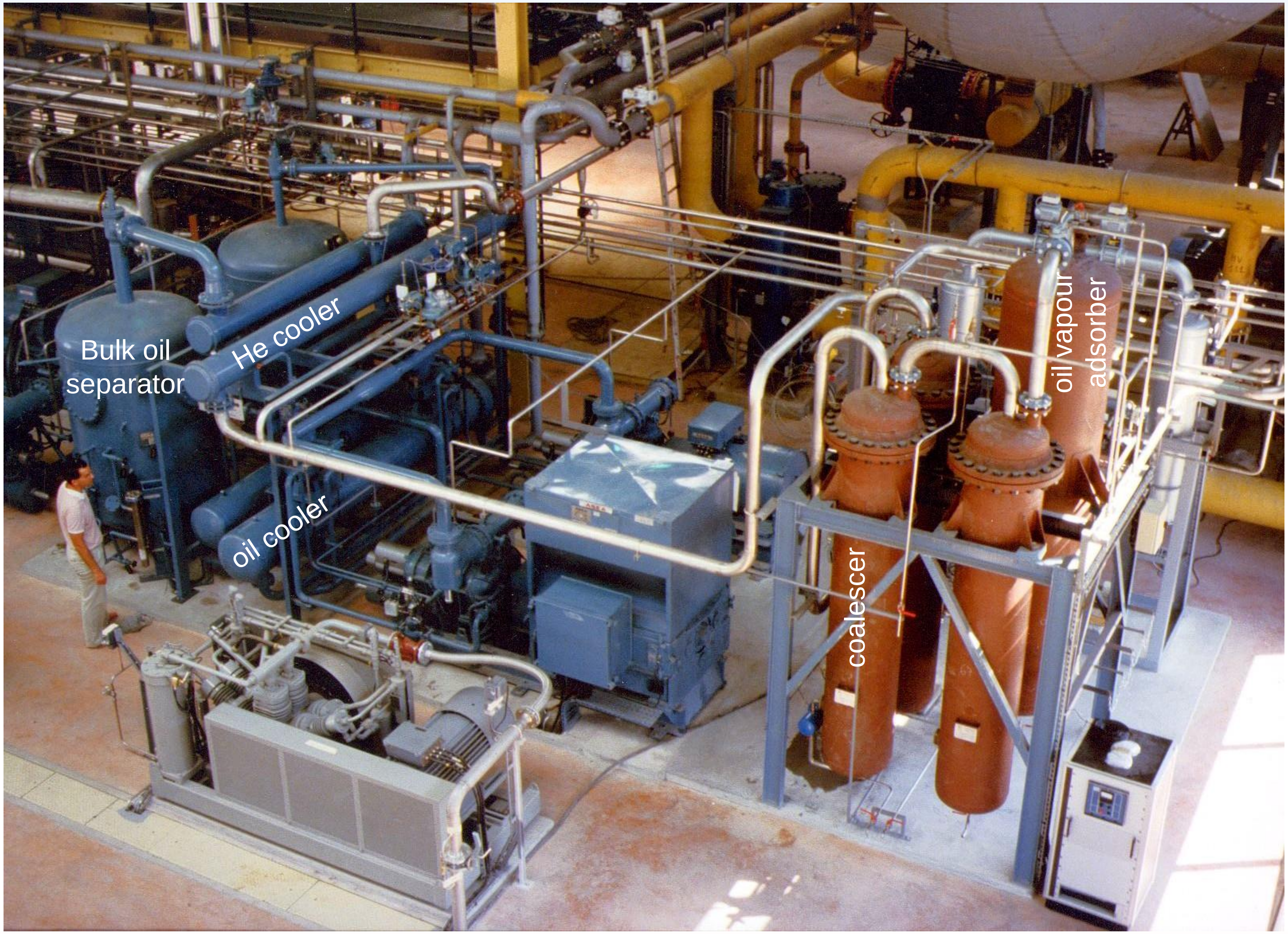
Oil deteriorates paint.

Use only Viton seals.

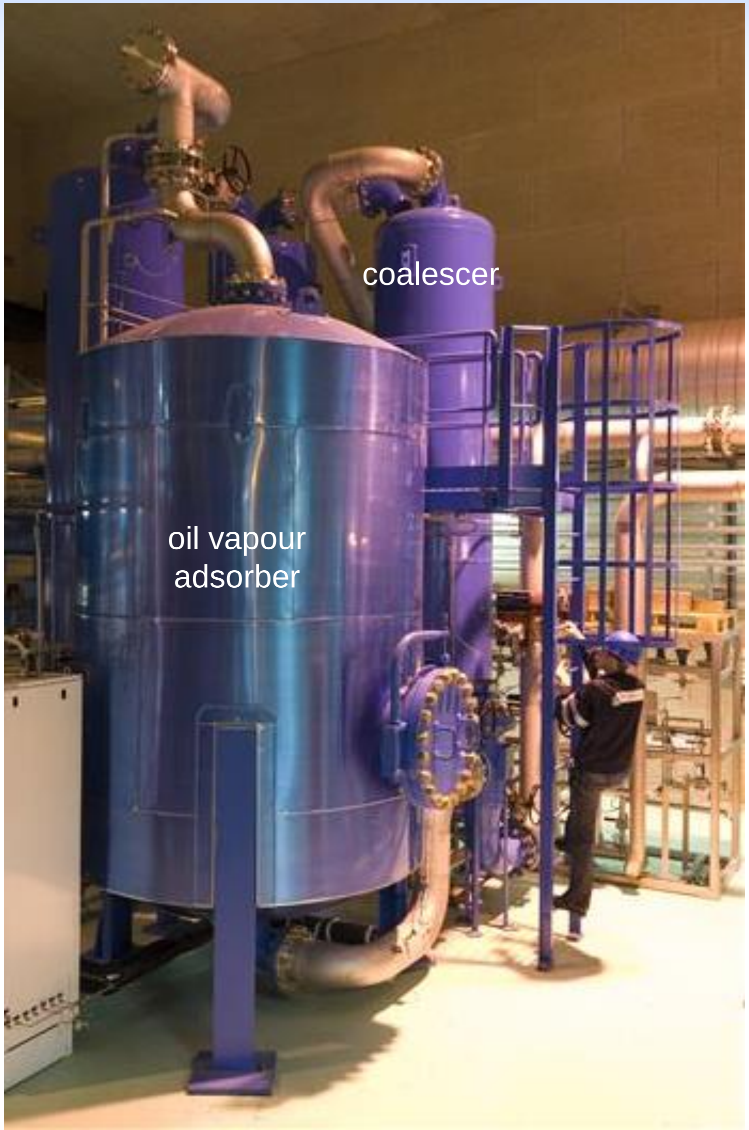
OIL SEPARATION SYSTEM



TORE SUPRA OIL REMOVAL SYSTEM



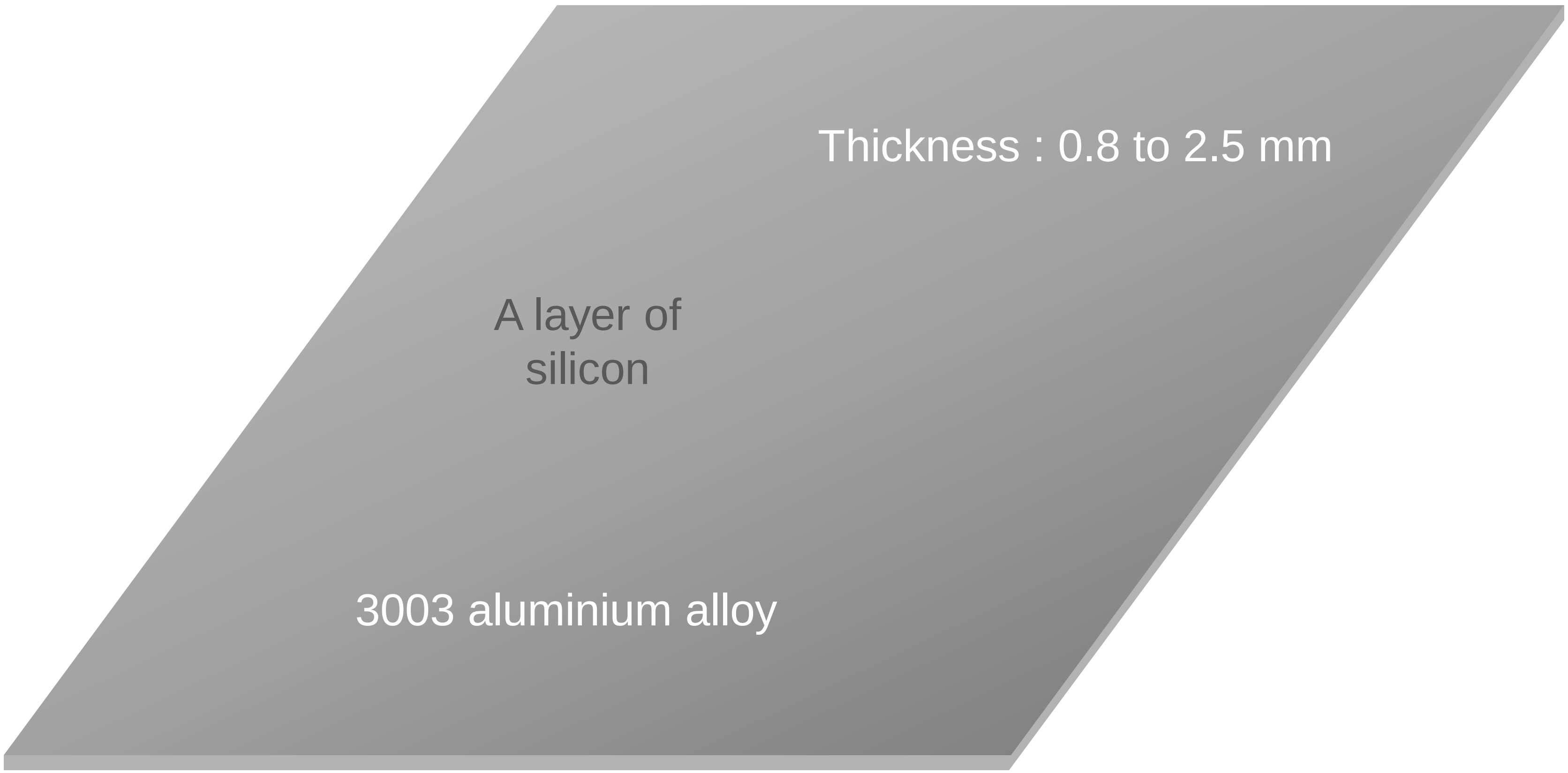
FINAL OIL REMOVAL SYSTEM OF LHC



THE BRASED
PLATE AND FIN HEAT EXCHANGERS

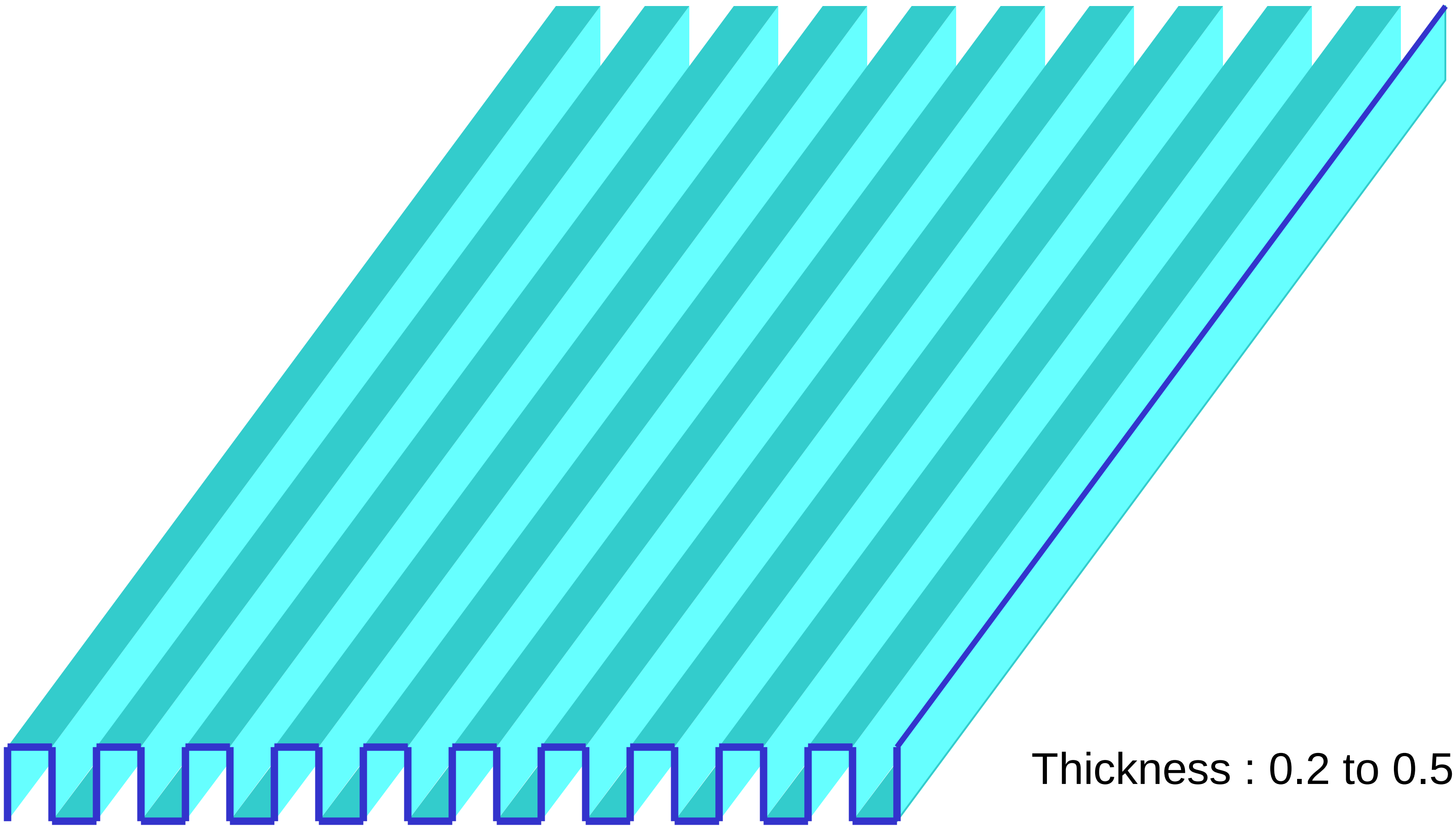
THE BASIC ELEMENTS OF A PLATE AND FIN HEAT EXCHANGER

1. THE PARTING SHEET



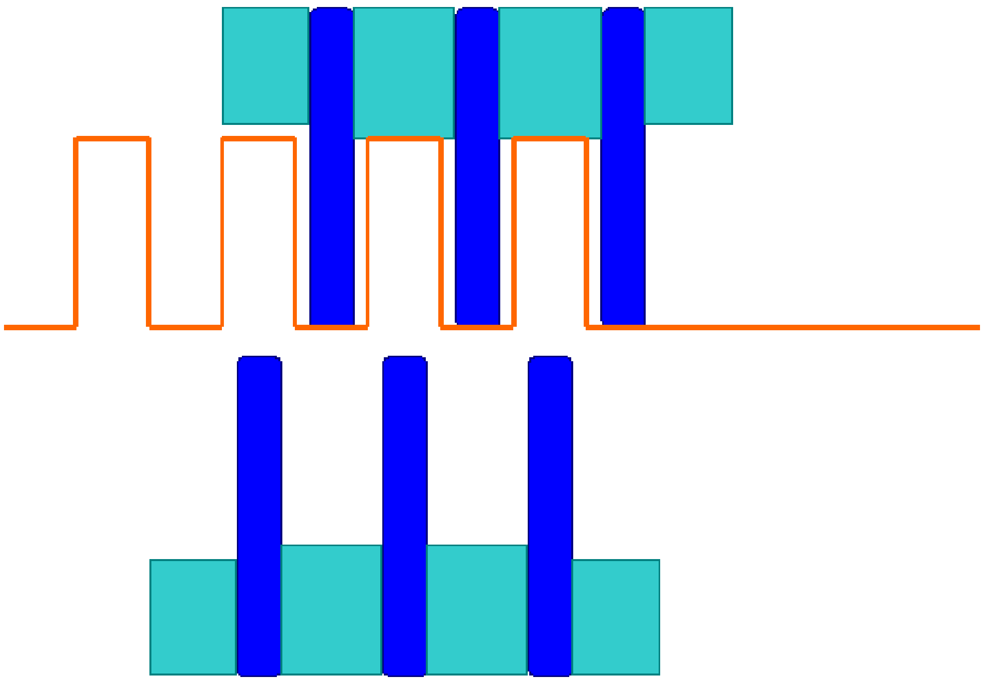
THE BASIC ELEMENTS

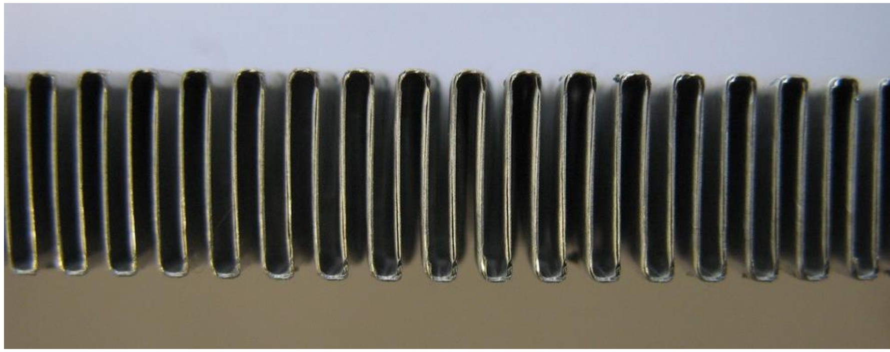
THE FINS

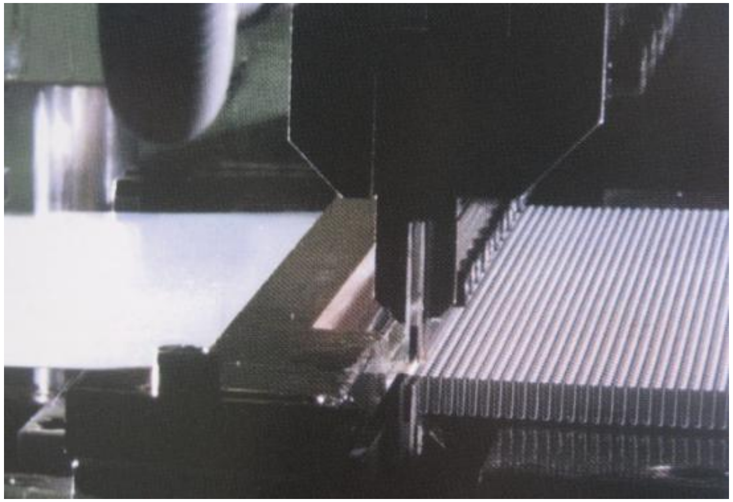


Thickness : 0.2 to 0.5 mm

FIN MACHINING







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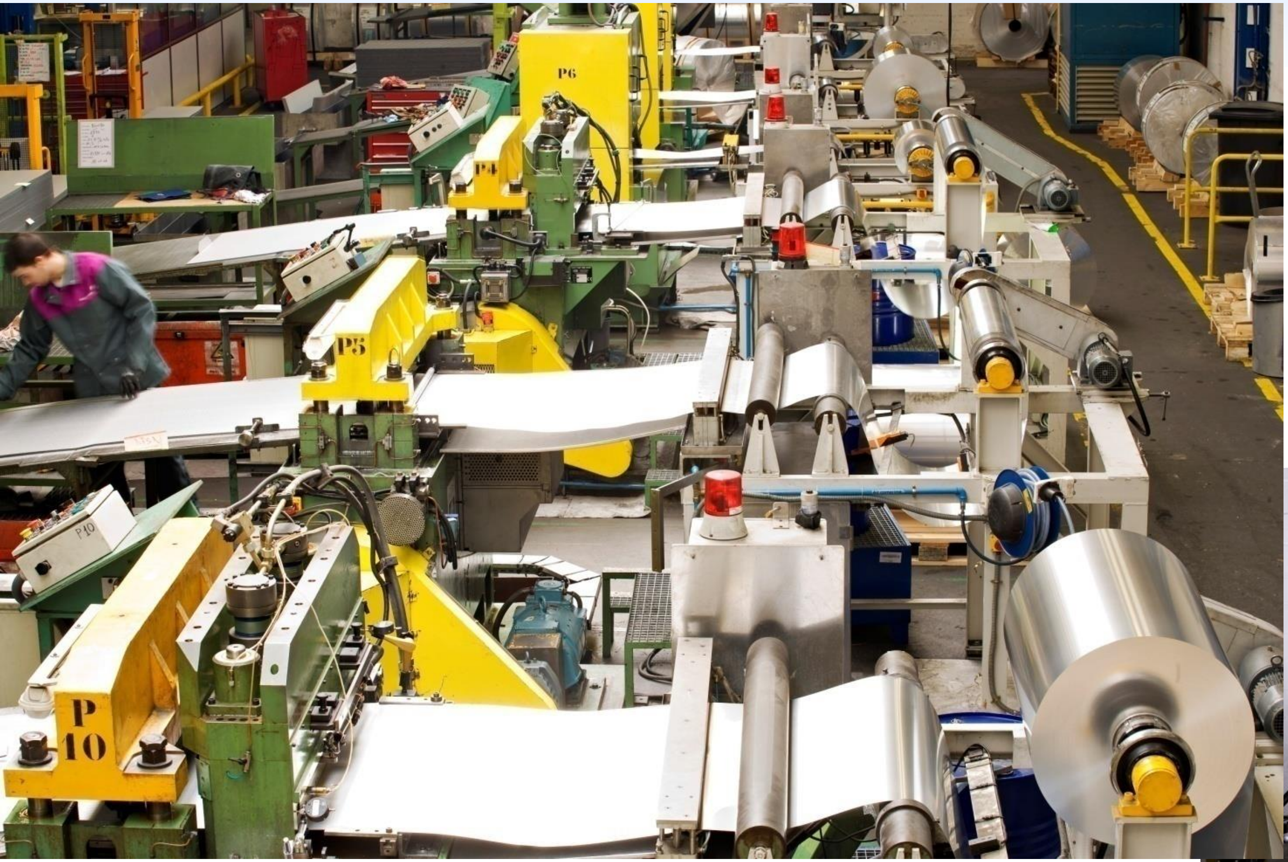
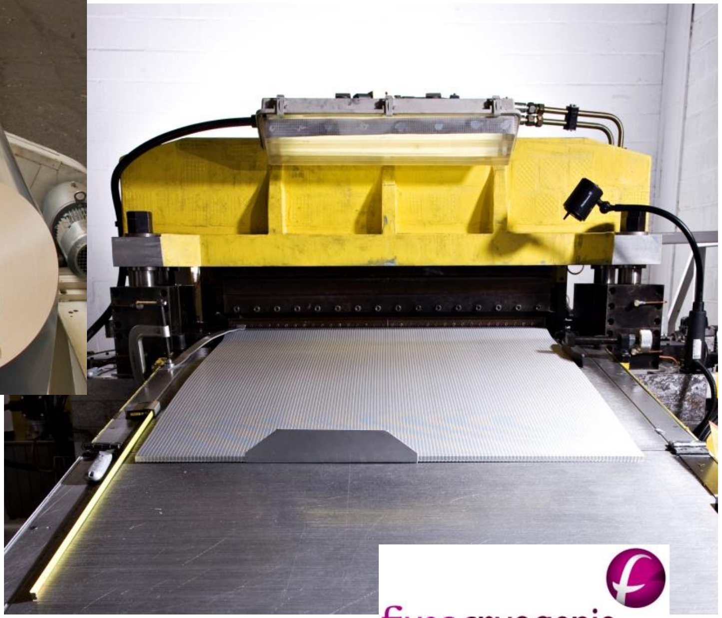
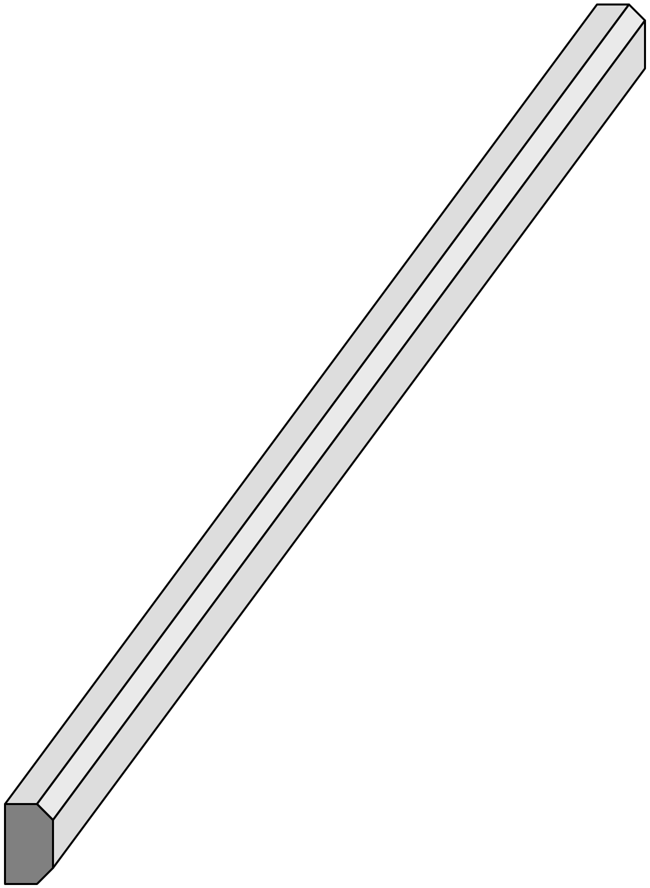
FIN MACHINING

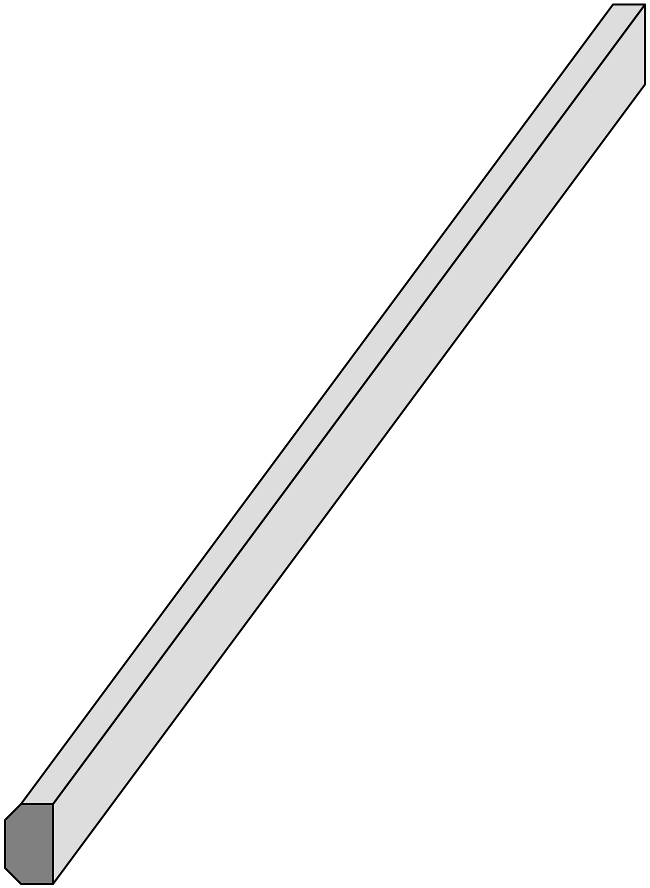




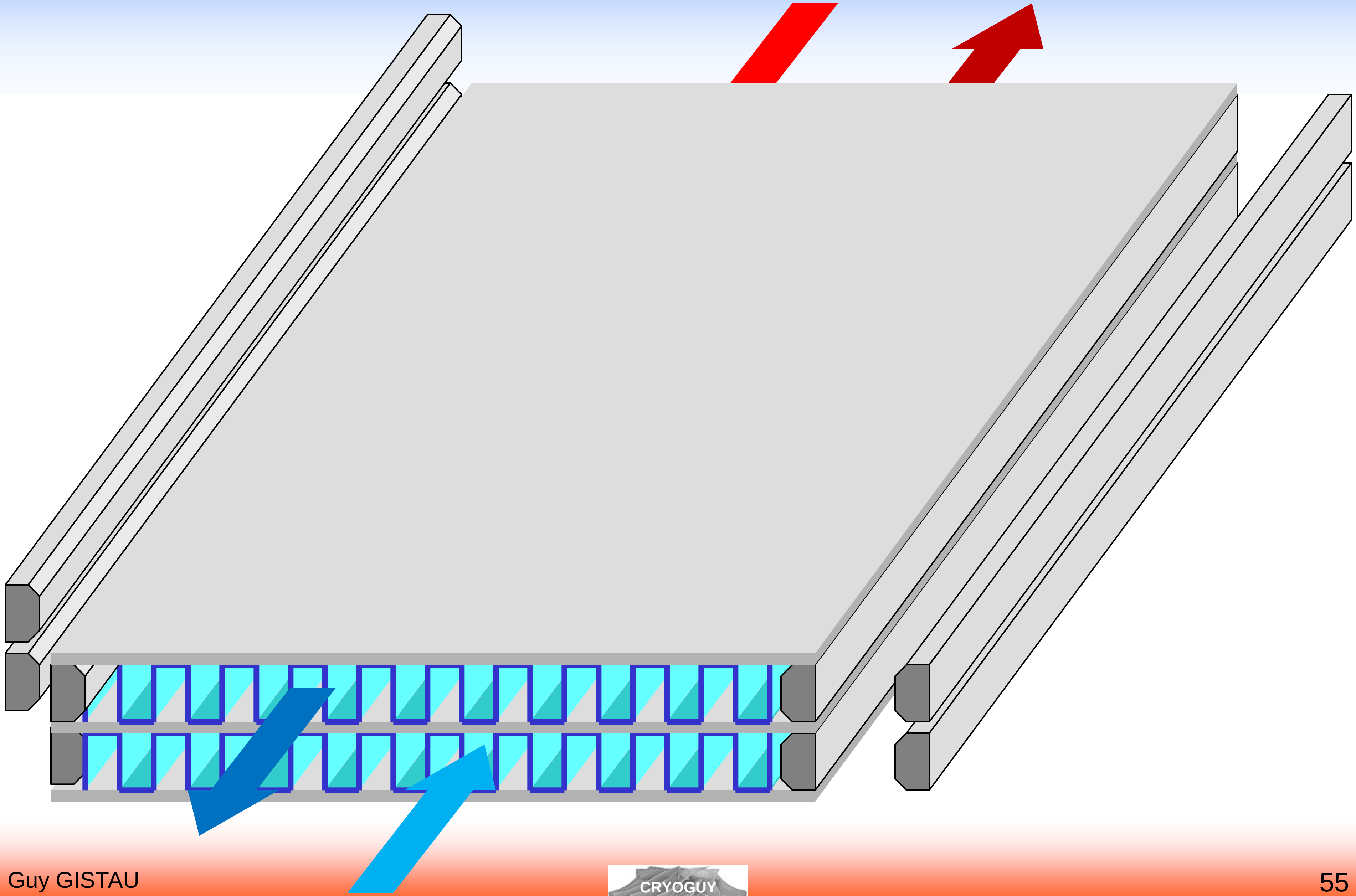
THE BASIC ELEMENTS

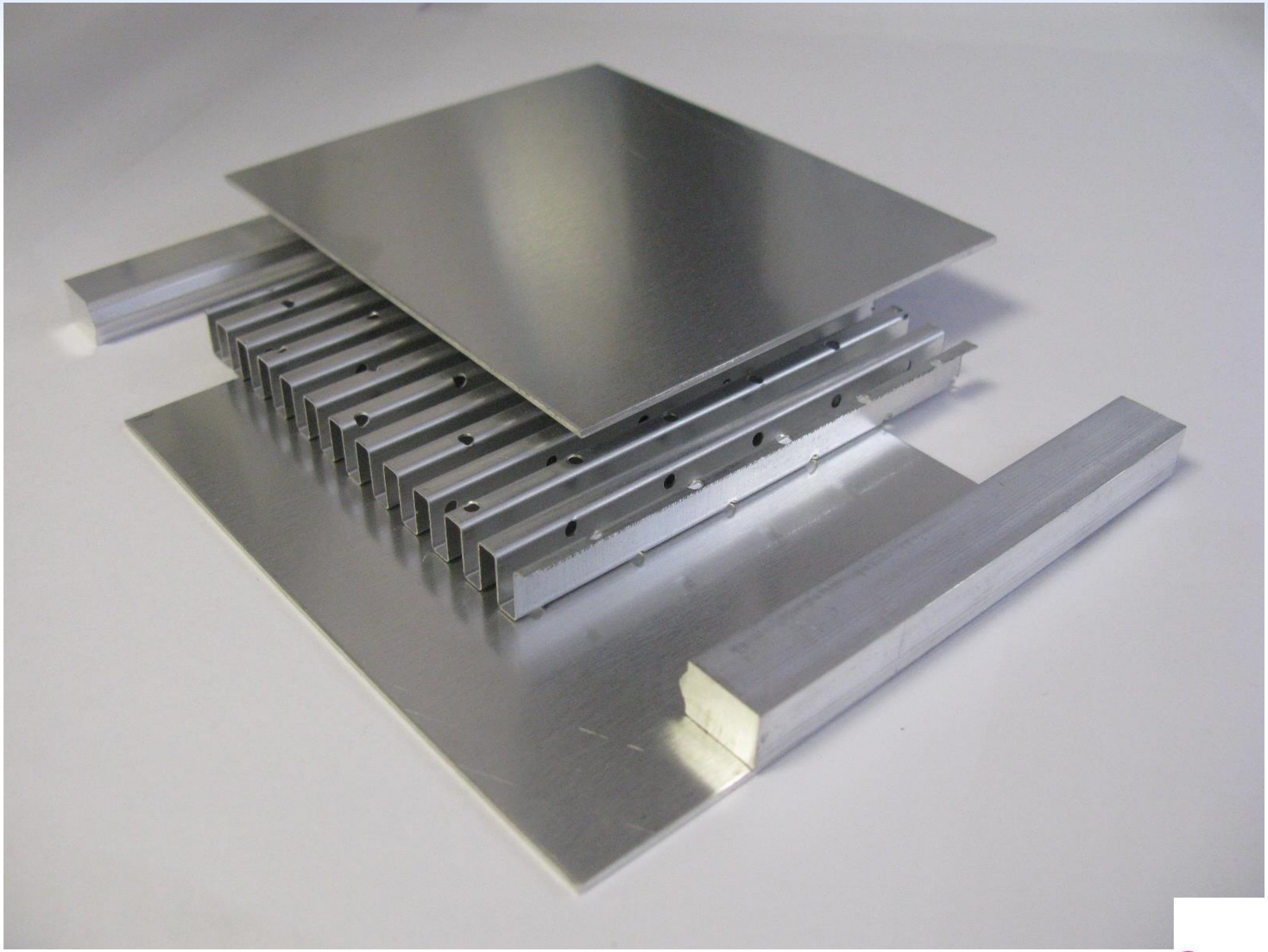
THE SIDE BARS





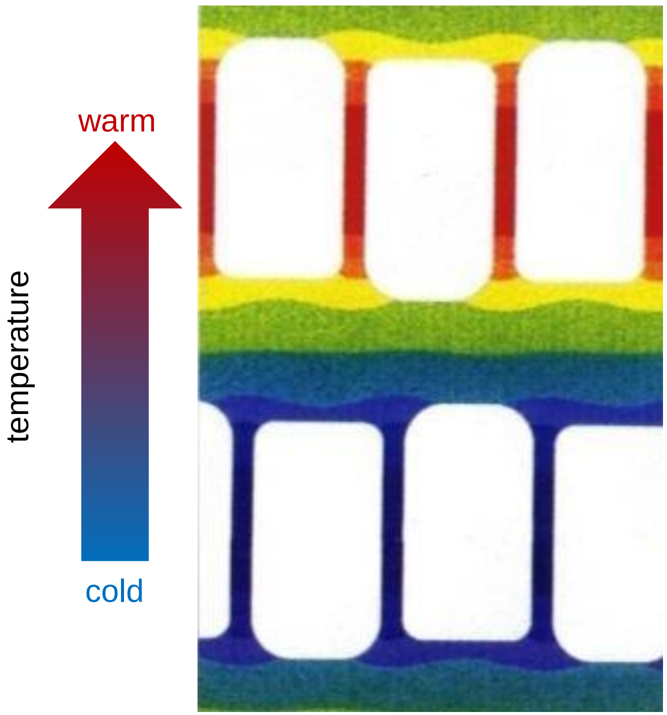
THE CONSTRUCTION





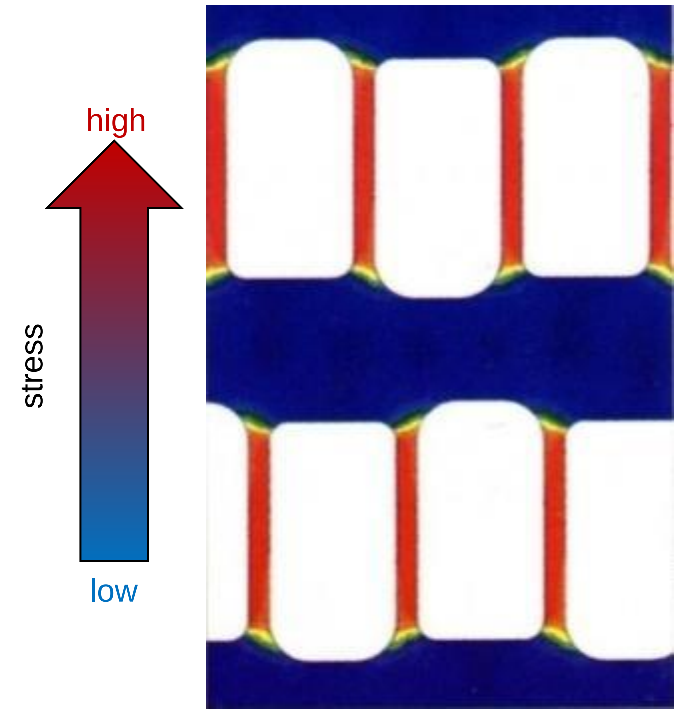
DUTIES OF THE FINS

Transfer heat



Isotherms of heat transfer from warm passage to cold passage

Withstand the pressure



Mechanical stresses under the effect of internal pressure

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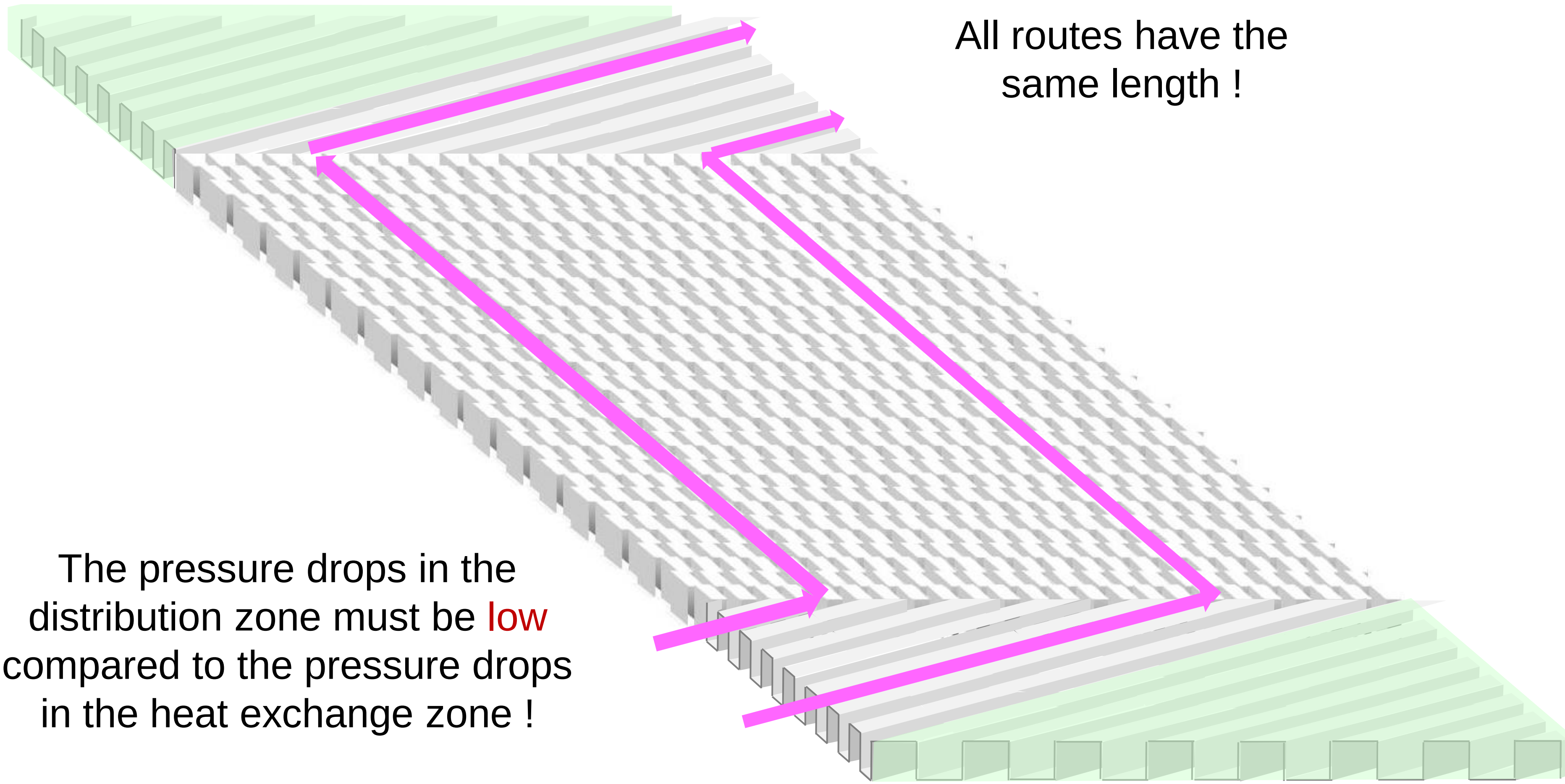
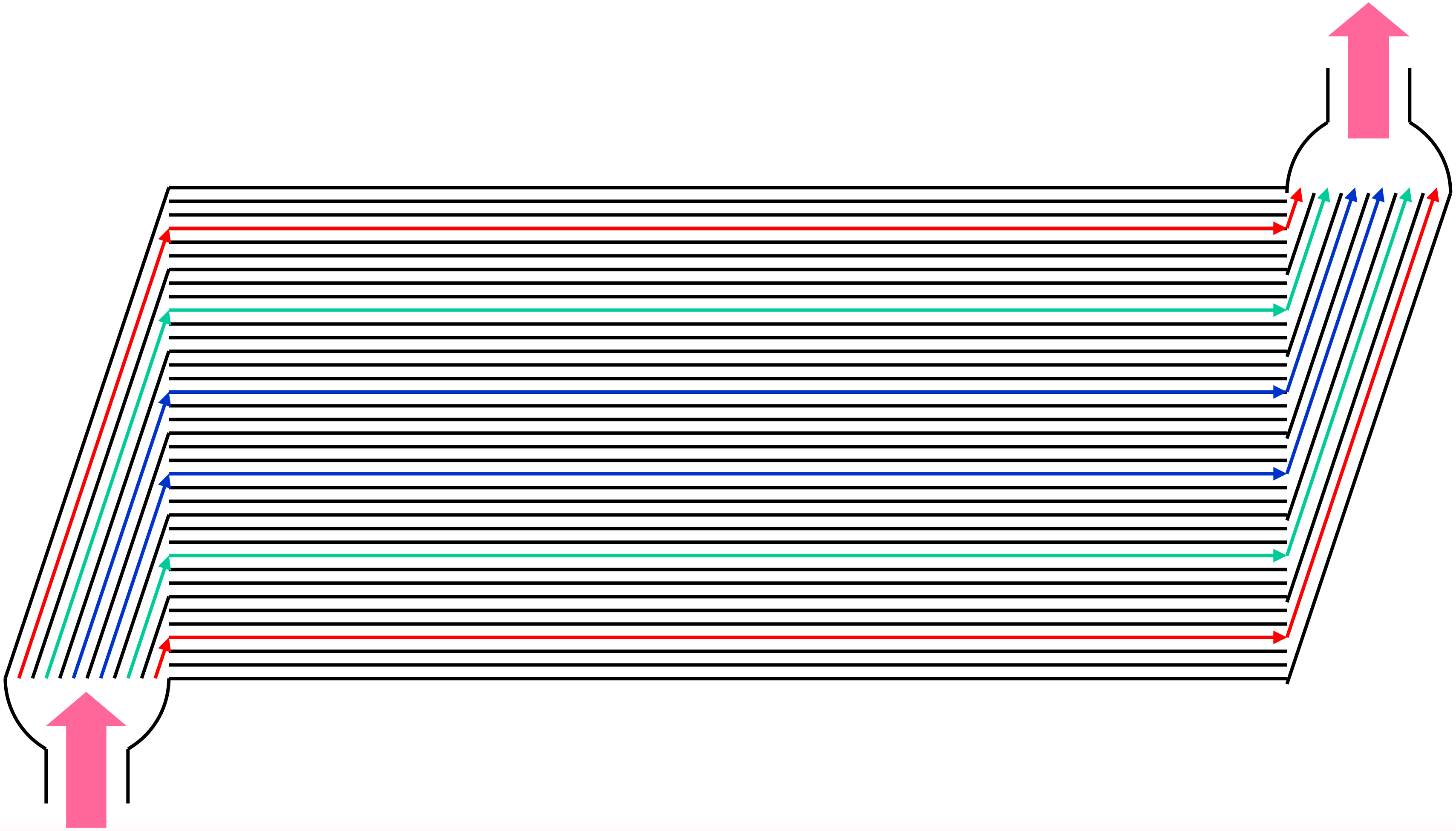
HOW TO EVENLY DISTRIBUTE THE FLUIDS THROUGH THE FINS ?



All routes have the same length !

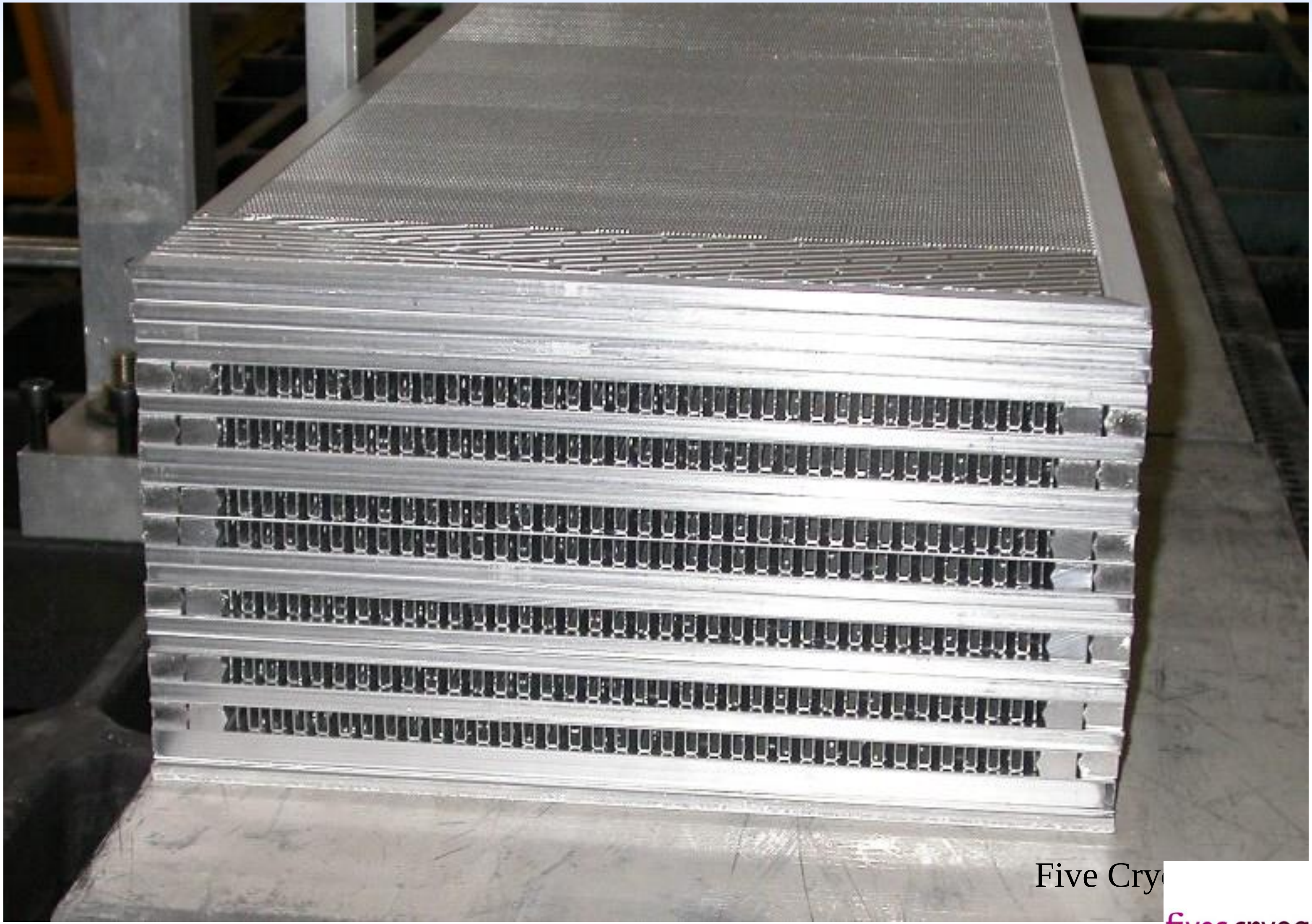
The pressure drops in the distribution zone must be low compared to the pressure drops in the heat exchange zone !

BALANCING THE GAS DISTRIBUTION (1)



PILING UP !

BEFORE BRAZING



Five Cry

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BRAZING PROCESS

The parting sheets have been covered with a brazing alloy (silicon).

Fins and parting sheets are perfectly cleaned

Fins and parting sheets are pressed together

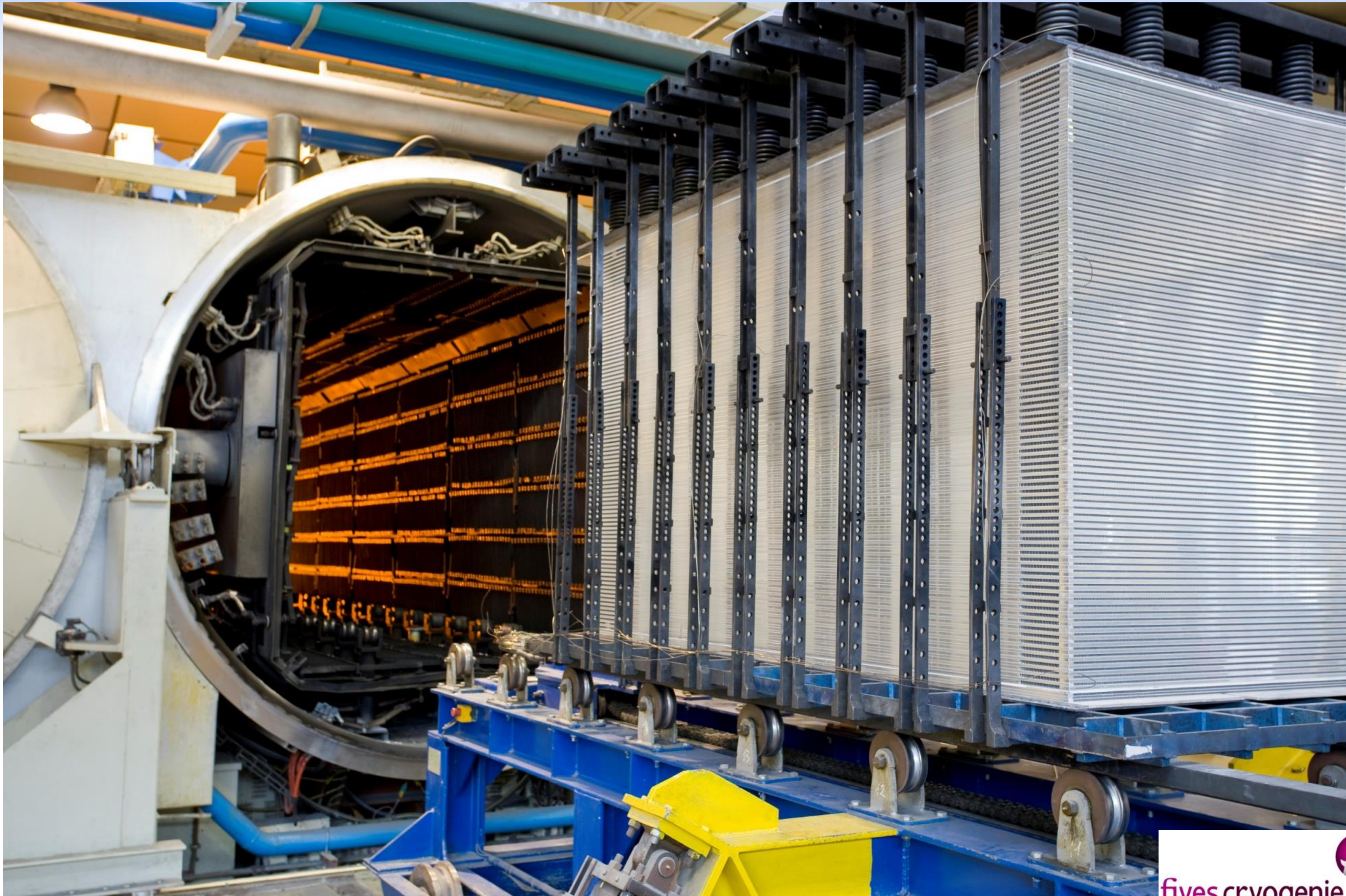
The core is inserted into a vacuum furnace heated at 620°C.

The aluminium alloy/silicon melts at a temperature that is 20°C lower than the aluminium alloy.

All contact points braze together to form a compact block.

The brazing process is monitored with thermocouples located inside the core to ensure an even temperature distribution.

THE VACUUM FURNACE



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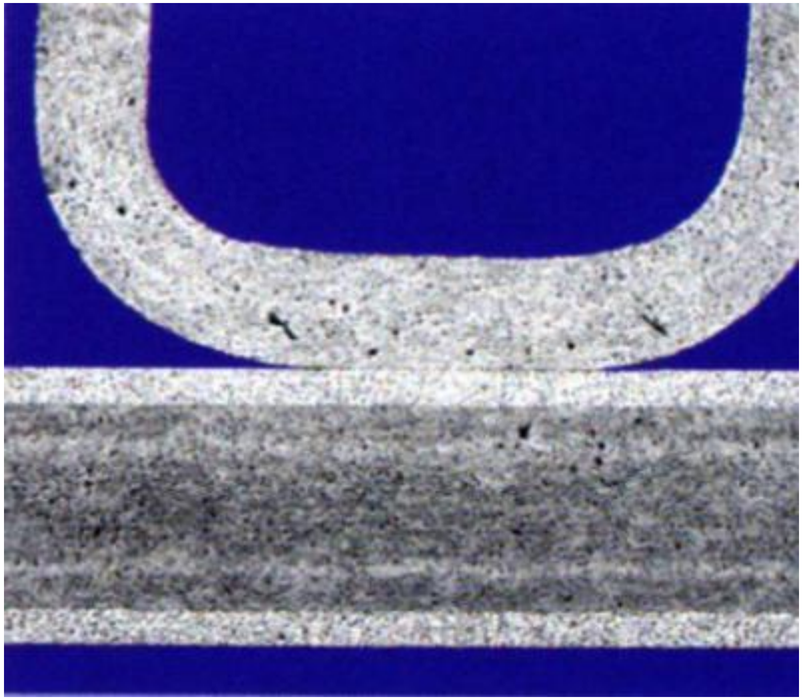
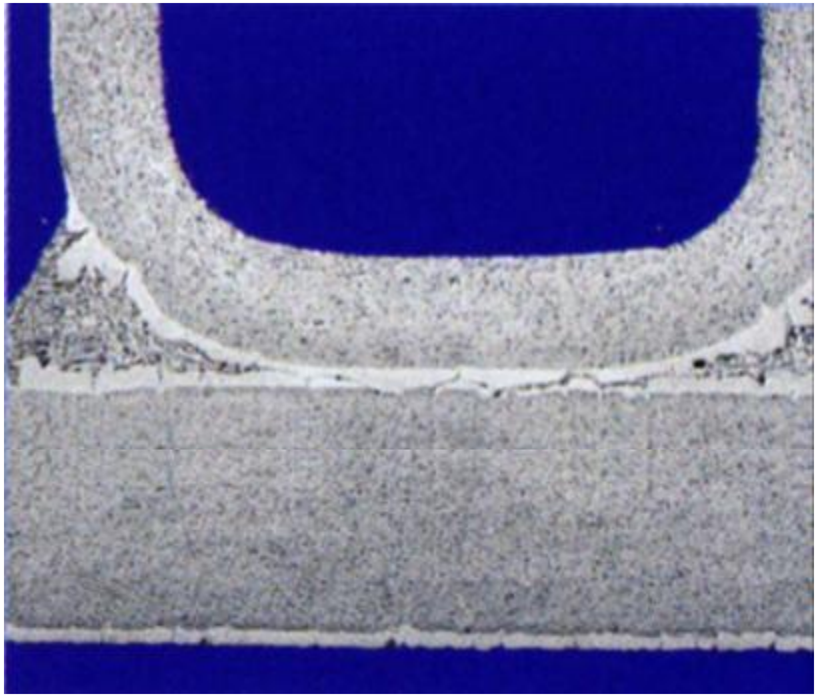
BRAZING PROCESS


Before brazing


After brazing

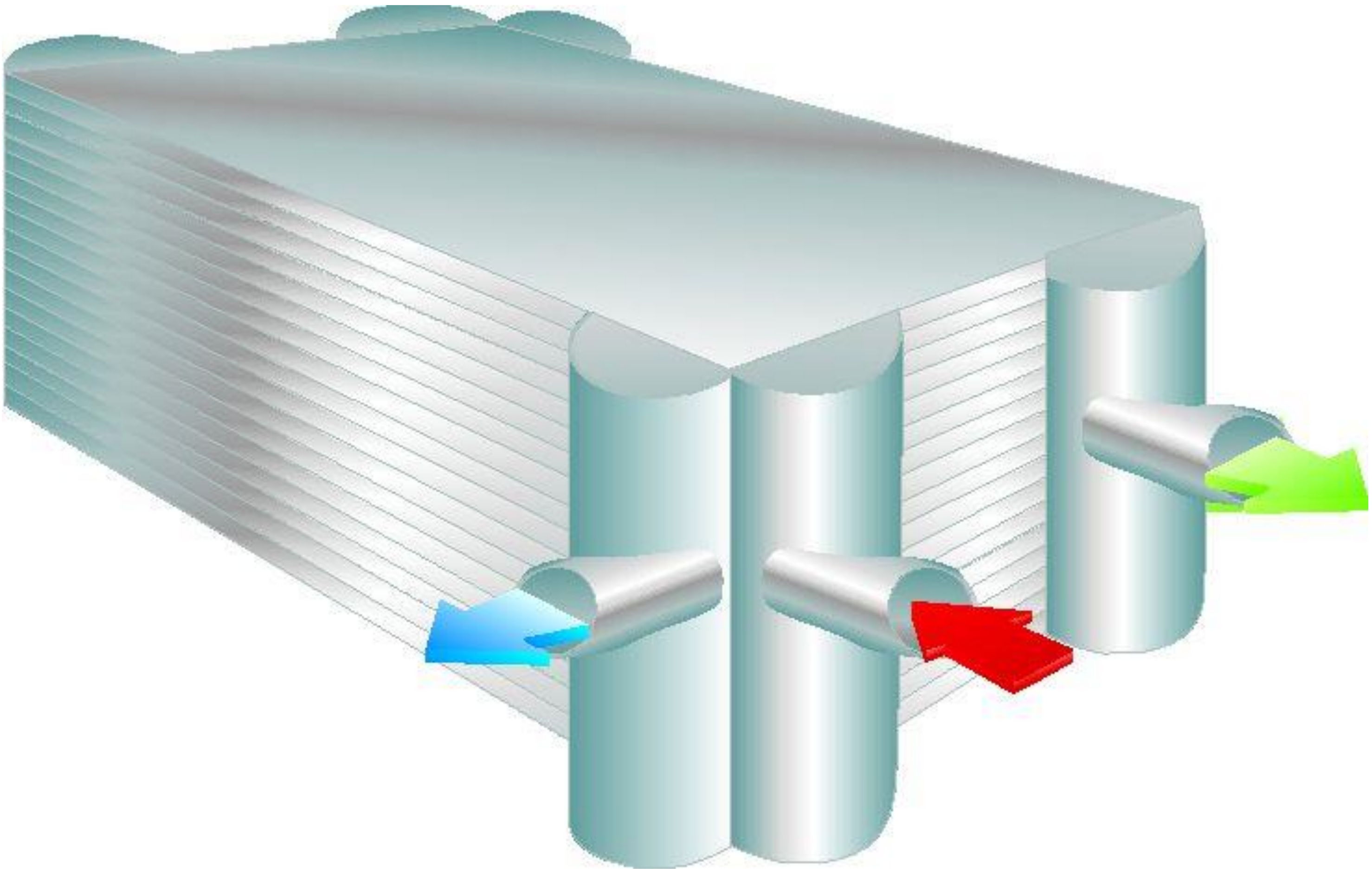
POST-BRAZING MANUFACTURING PROCESS

Welding of headers

Hydraulic or Pneumatic Strength Test

Helium Leak Testing (Internal and External)

Welding of aluminium to stainless steel transition joints



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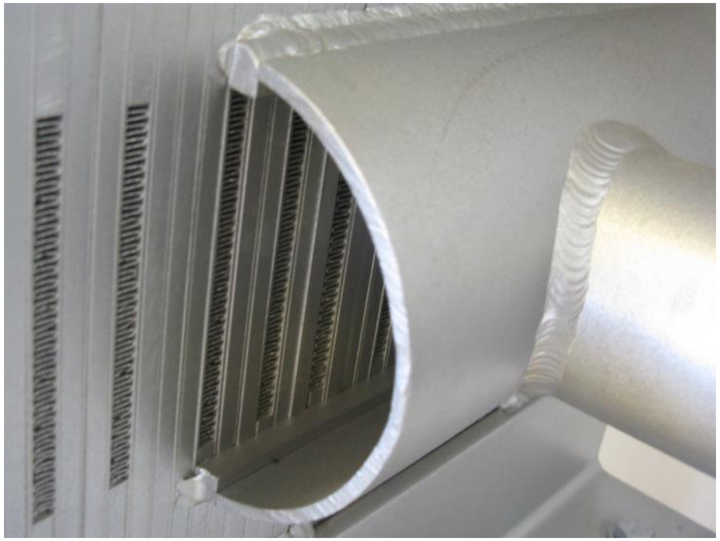
WELDING HEADERS



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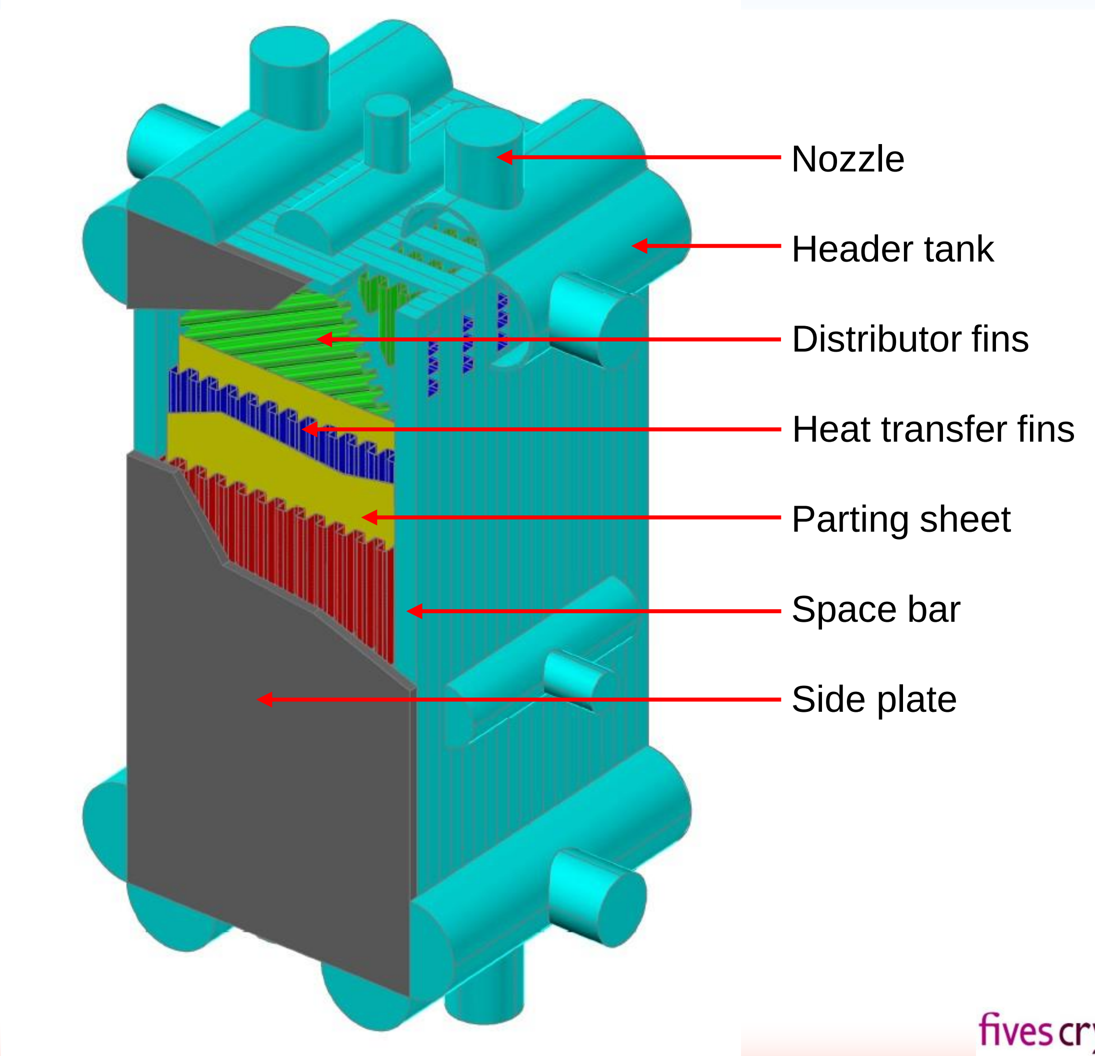
A HEAT EXCHANGER BLOCK



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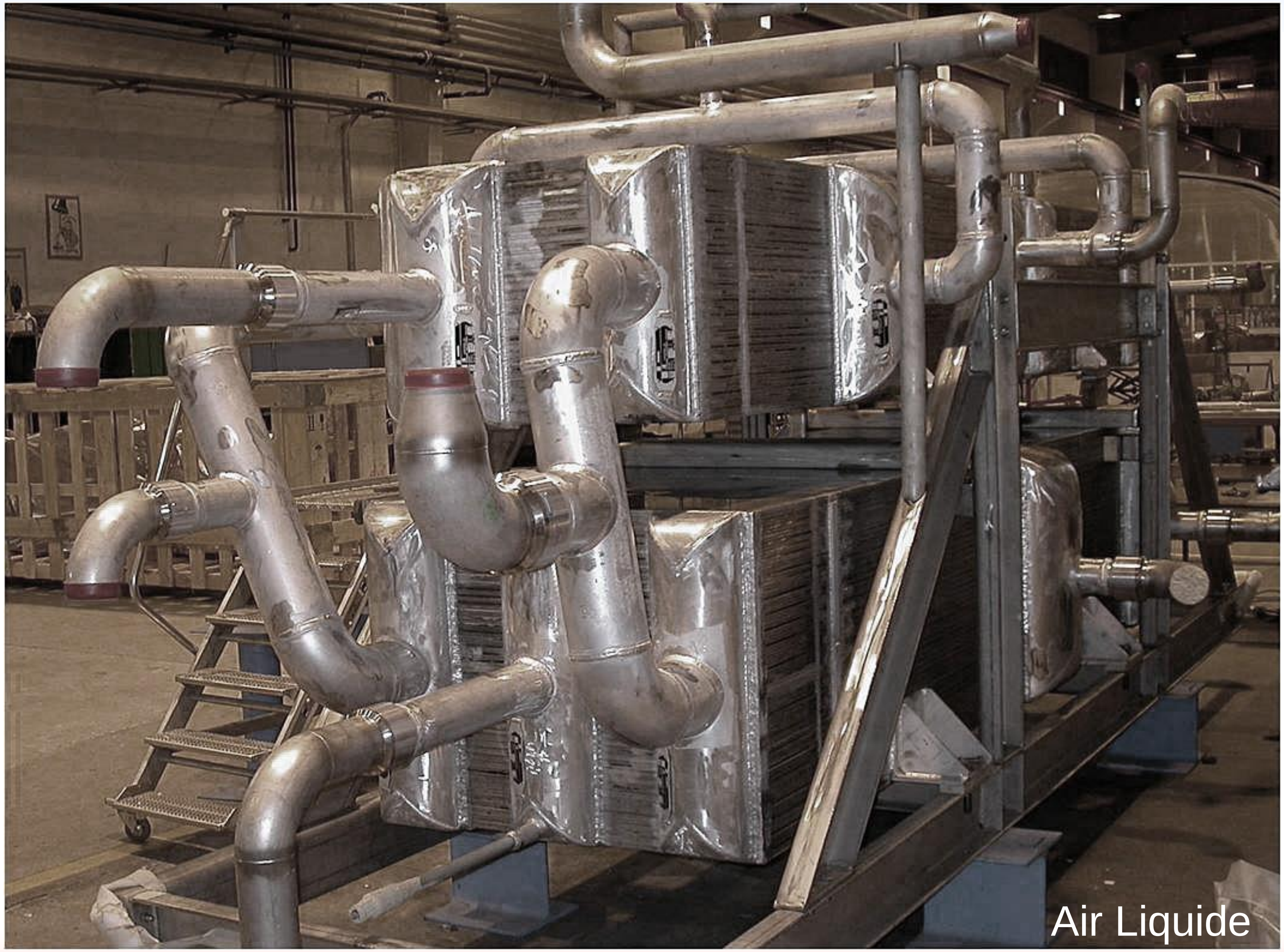
CRYOGUY

THE HEAT EXCHANGERS OF A LARGE HELIUM LIQUEFIER



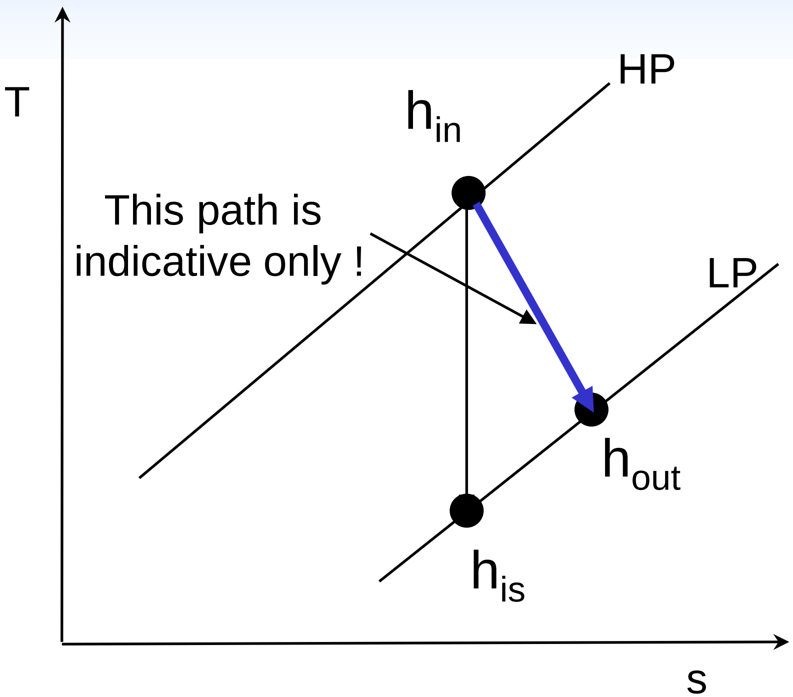
THE CRYOGENIC EXPANSION TURBINE

SPECIFICITIES OF A CRYOGENIC EXPANSION TURBINE

A cryogenic expansion turbine must be considered according to various issues :

- It must rotate at very high speeds (a few thousands rps),
- It is designed for nominal (or near to) operation, but it must also operate at any temperature between room temperature and the nominal operating temperature.
- It is sensitive to impurities that are diluted into the processed gas..

EXPANSION WITH EXTERNAL WORK



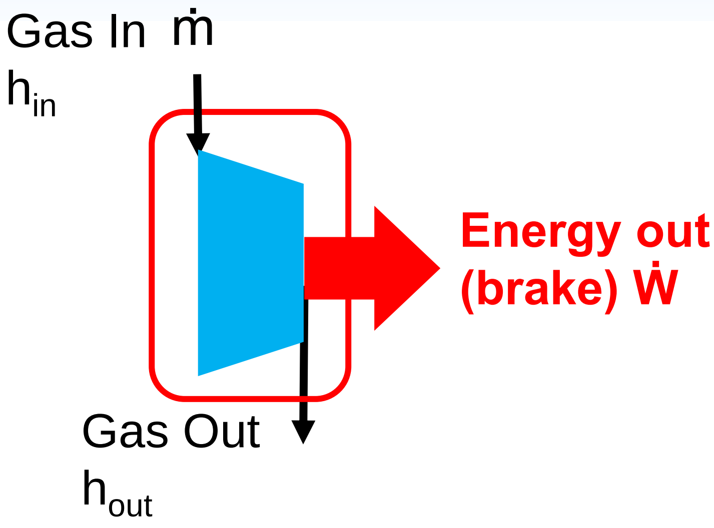
T-s CHART

Isentropic effectiveness : $\eta_{is} = \dfrac{h_{in} - h_{out}}{h_{in} - h_{is}}$

AN EVERYDAY PRACTICAL TOOL

P	T	h	ṁ		Dh real	Dh isent
(bar)	(K)	(J/g)	(g/s)	(W)	(J/g)	(J/g)
		TURBINE				
11,00	25,00	142,0154	50,00			
0,75						
1,20	13,74	85,3601		-2832,77	-56,66	-75,54

ENERGY BALANCE



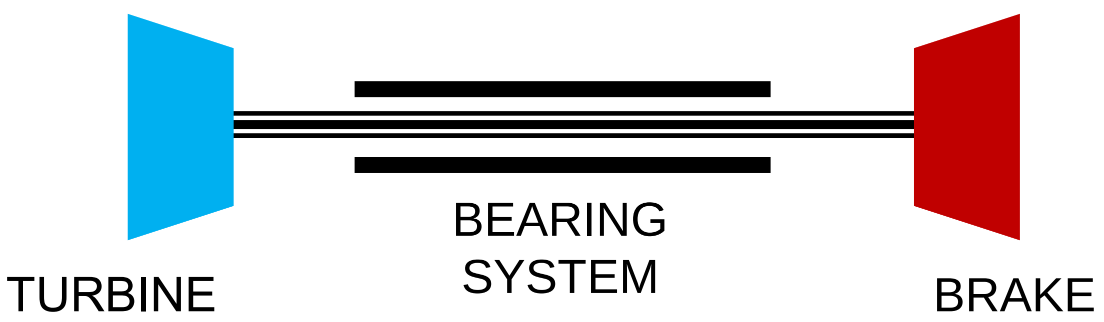
The refrigeration power of a turbine is the power that is withdrawn from the processed gas:

$$\dot{W} = \dot{m} \times (h_{in} - h_{out})$$

$$\dot{W} = \eta \times \dot{m} \times (h_{in} - h_{is})$$

Assuming no losses on the bearing system

GENERAL STRUCTURE

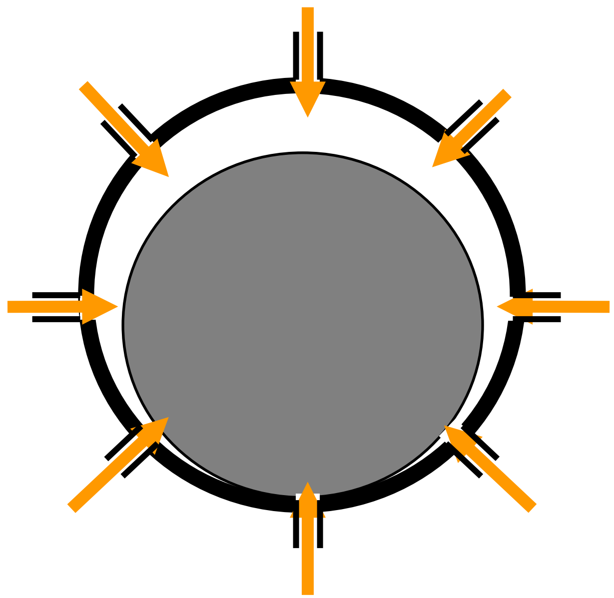


GAS BEARING SYSTEMS

Cryogenic expansion turbine rotate at very high speeds (up to 5000 rps)

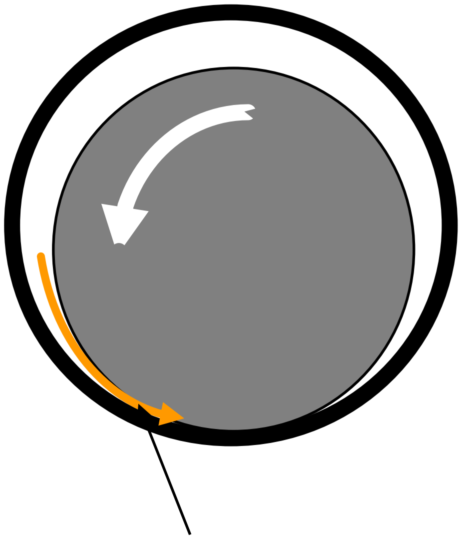
Any contact between shaft and bushing must be avoided !

STATIC



injection of helium

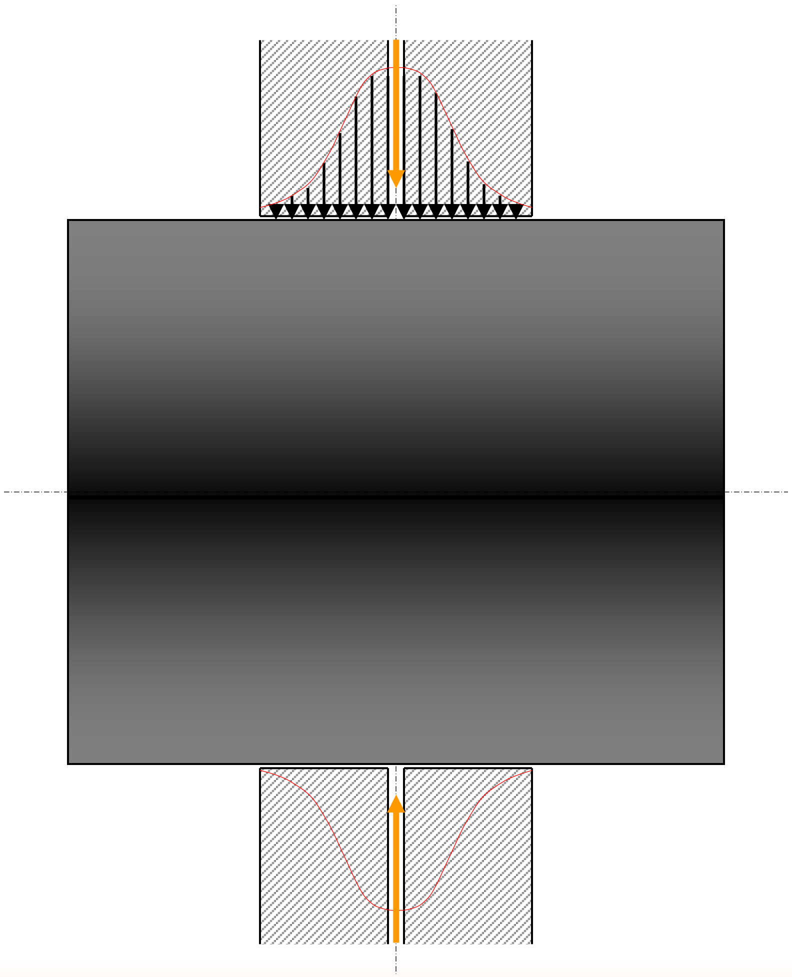
DYNAMIC

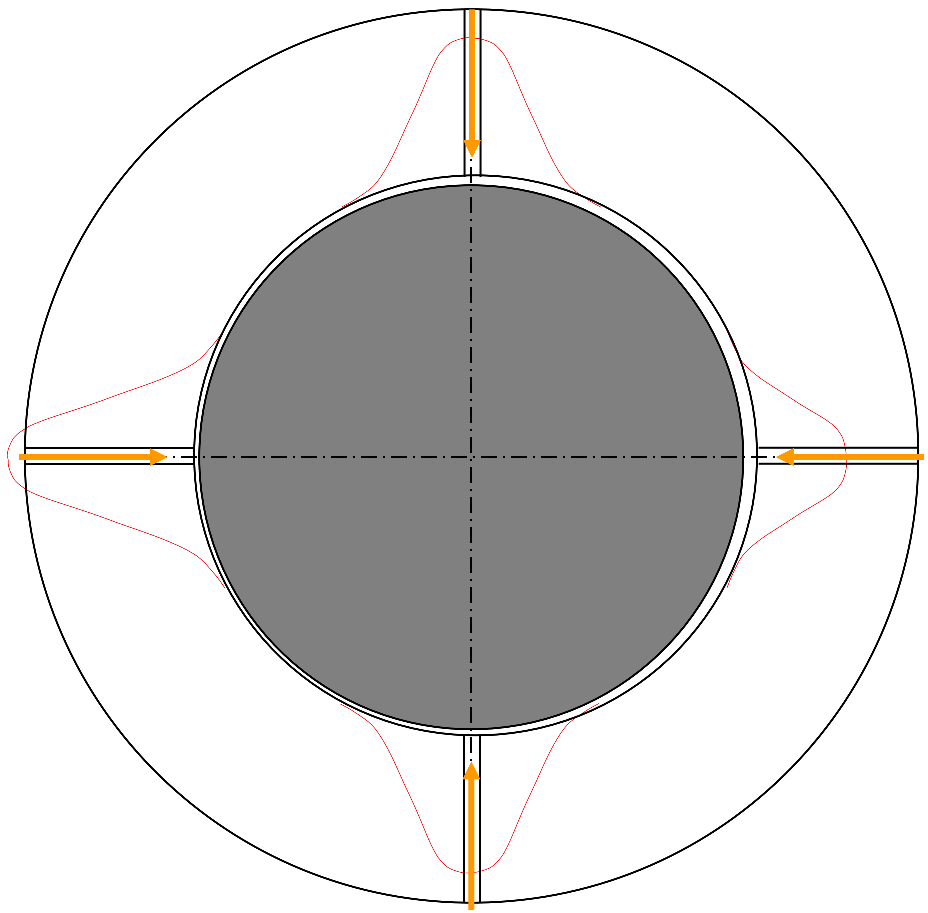


helium is pushed by viscosity

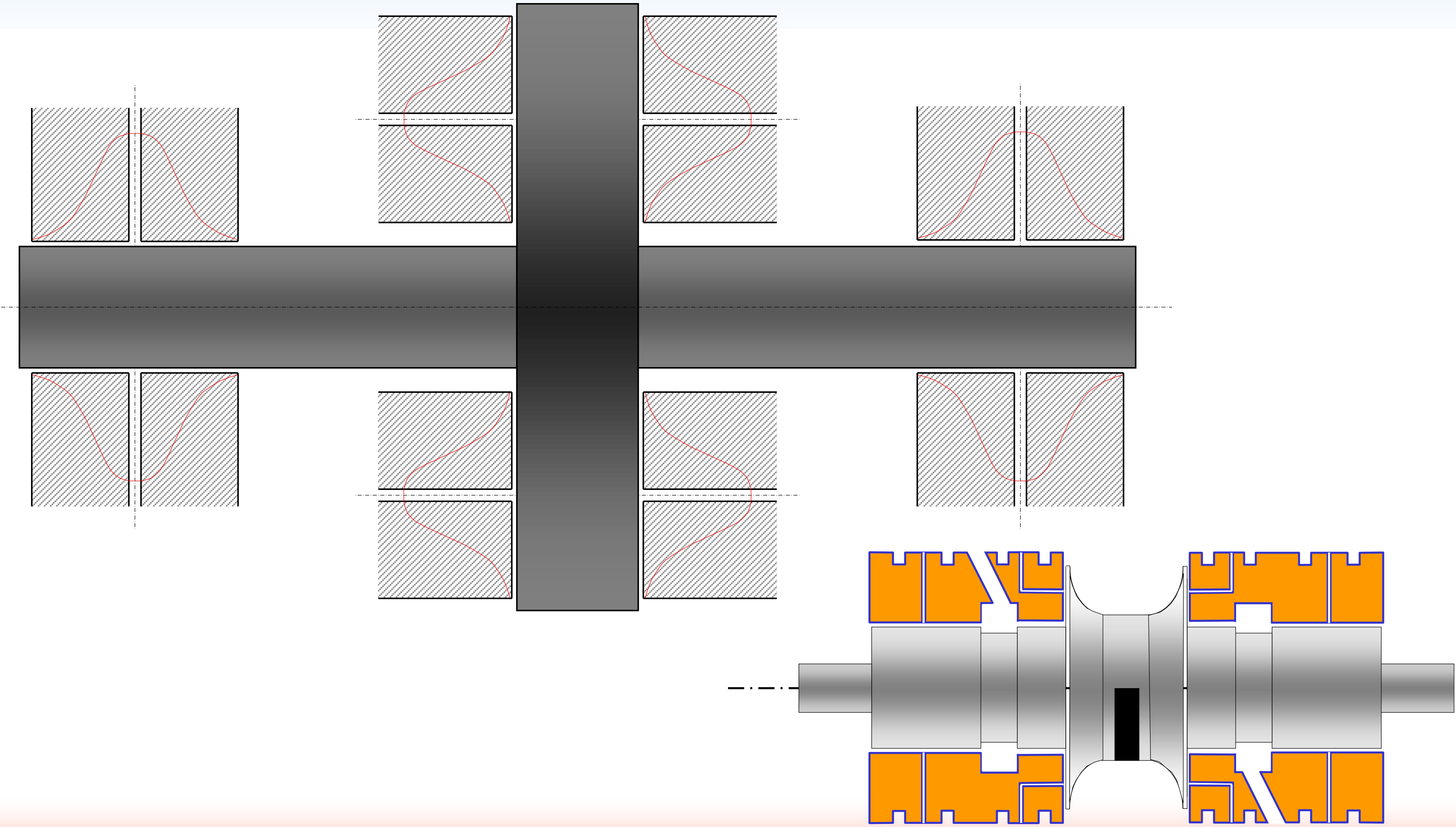
STATIC GAS BEARING

JOURNAL



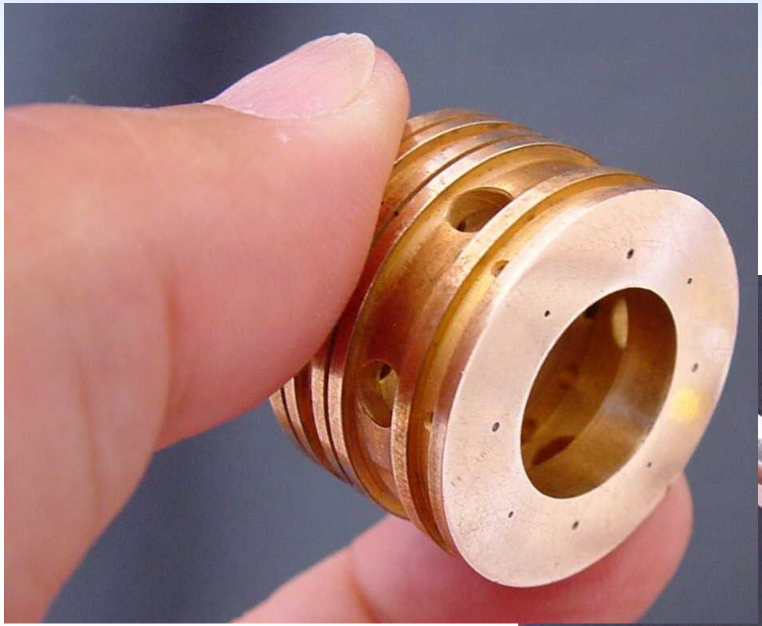


STATIC GAS BEARING



A STATIC GAS BEARING SYSTEM

SHAFT AND BEARING



A DYNAMIC GAS BEARING SYSTEM

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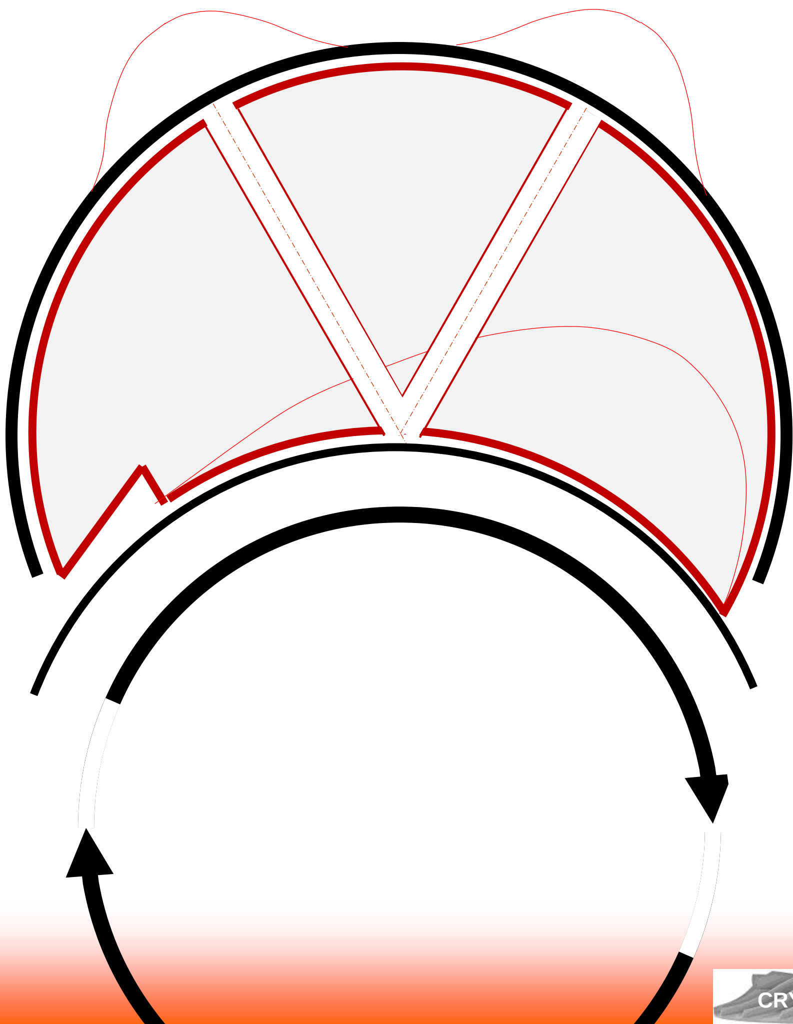
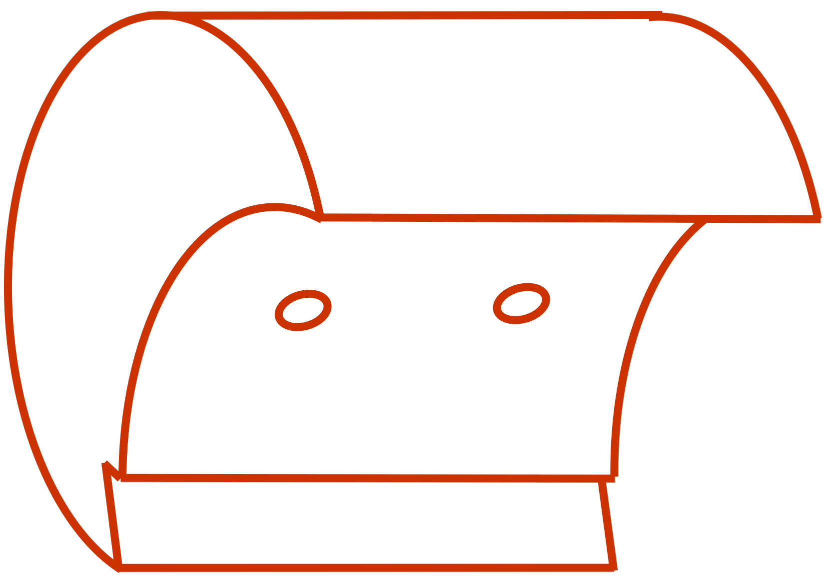
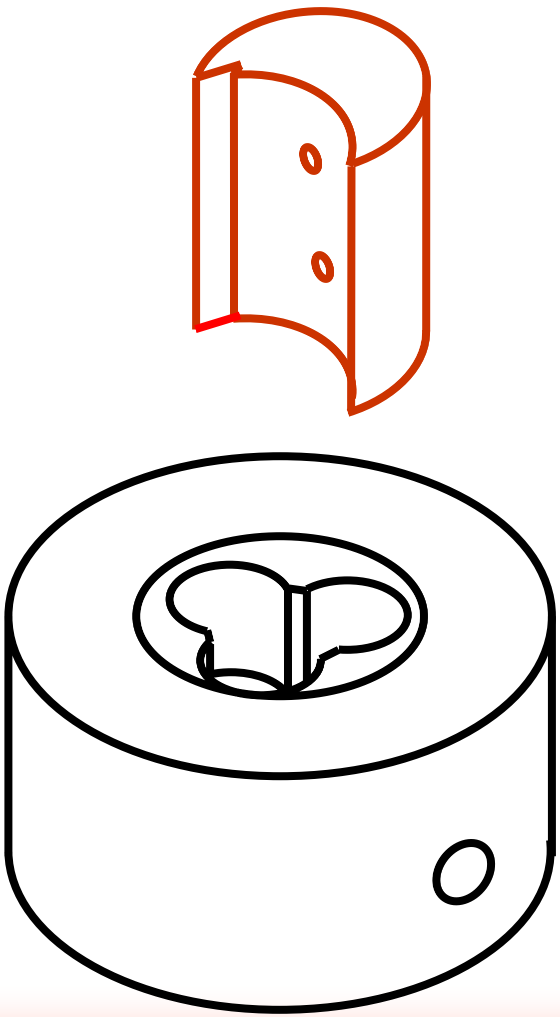
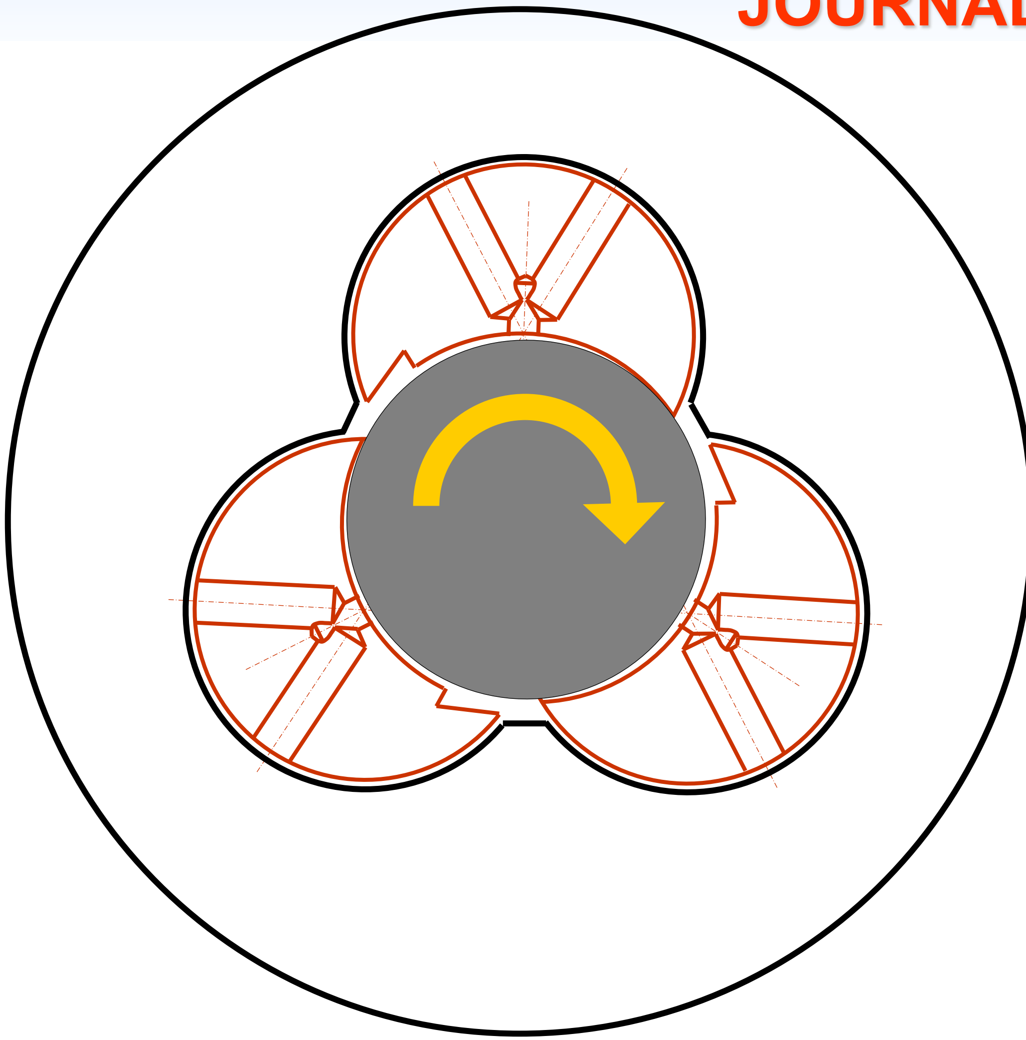




A DYNAMIC GAS BEARING SYSTEM

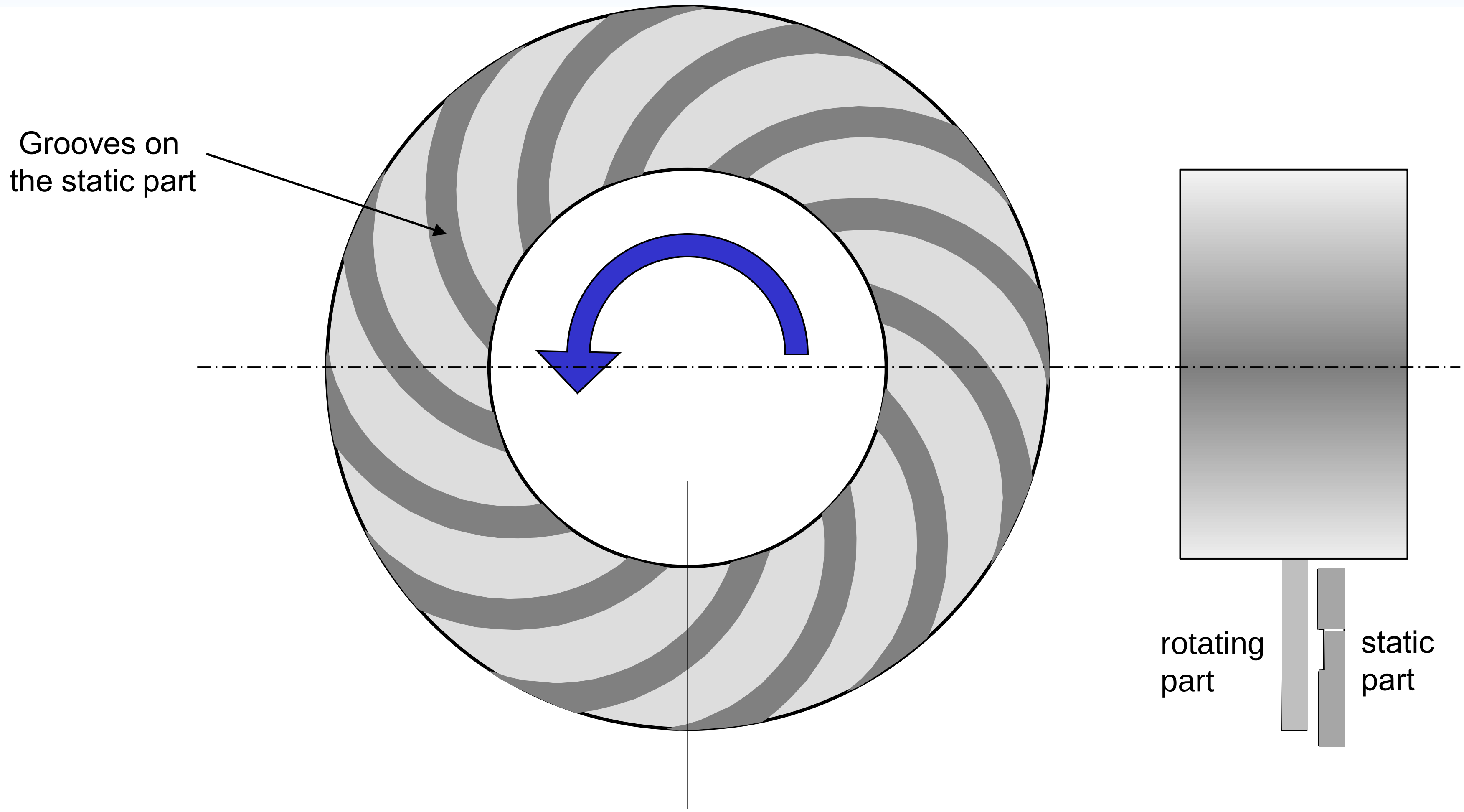
JOURNAL



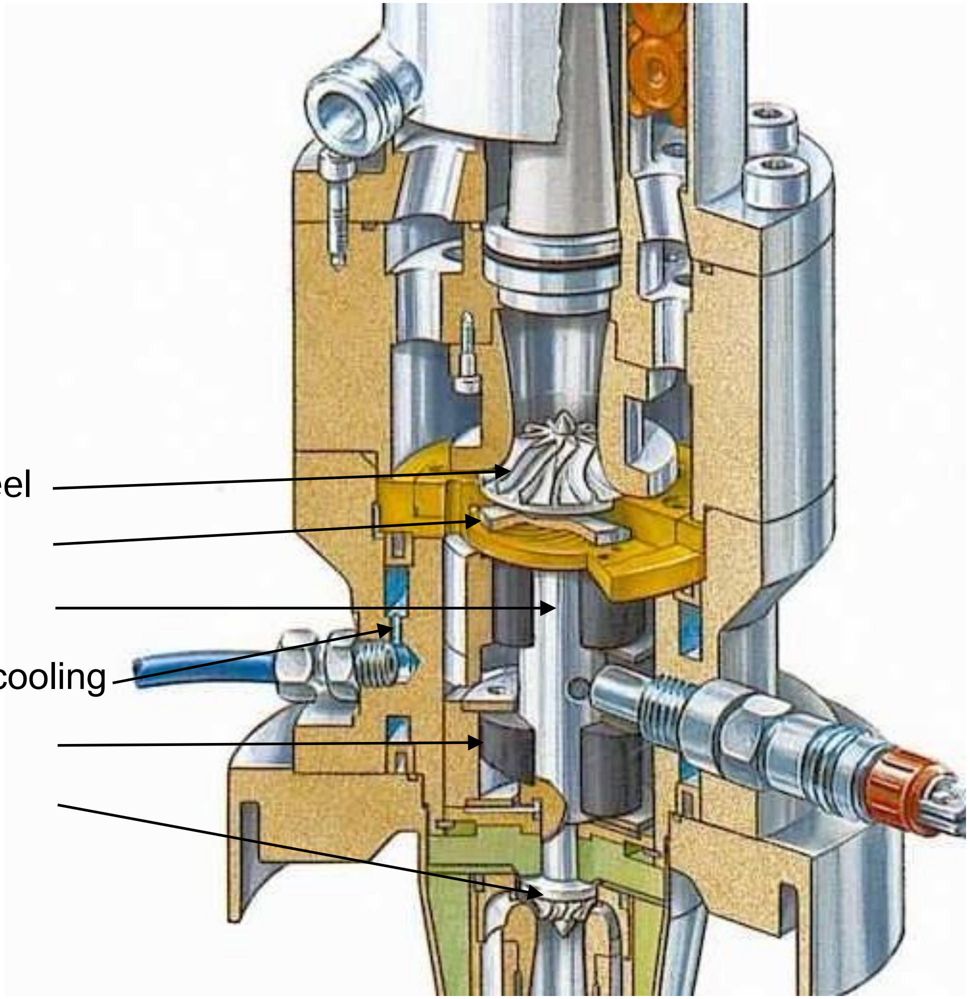


A DYNAMIC GAS BEARING SYSTEM

THRUST



A LINDE
DYNAMIC GAS BEARING SYSTEM



Compressor wheel
Thrust
Shaft
Bearing system cooling
Tilting pad
Turbine wheel

TURBINE OPERATING PRINCIPLE

1rst step

Conversion of most of the energy of pressure into kinetic energy:

Distributor duty

2nd step

Conversion of most of the kinetic energy into mechanical energy:

Wheel duty

3rd step

Conversion of the remaining kinetic energy into pressure:

Diffuser duty

THE DISTRIBUTOR DUTY

The distributor is a fixed nozzle.

1. Energy conservation:
enthalpy is converted into kinetic energy.

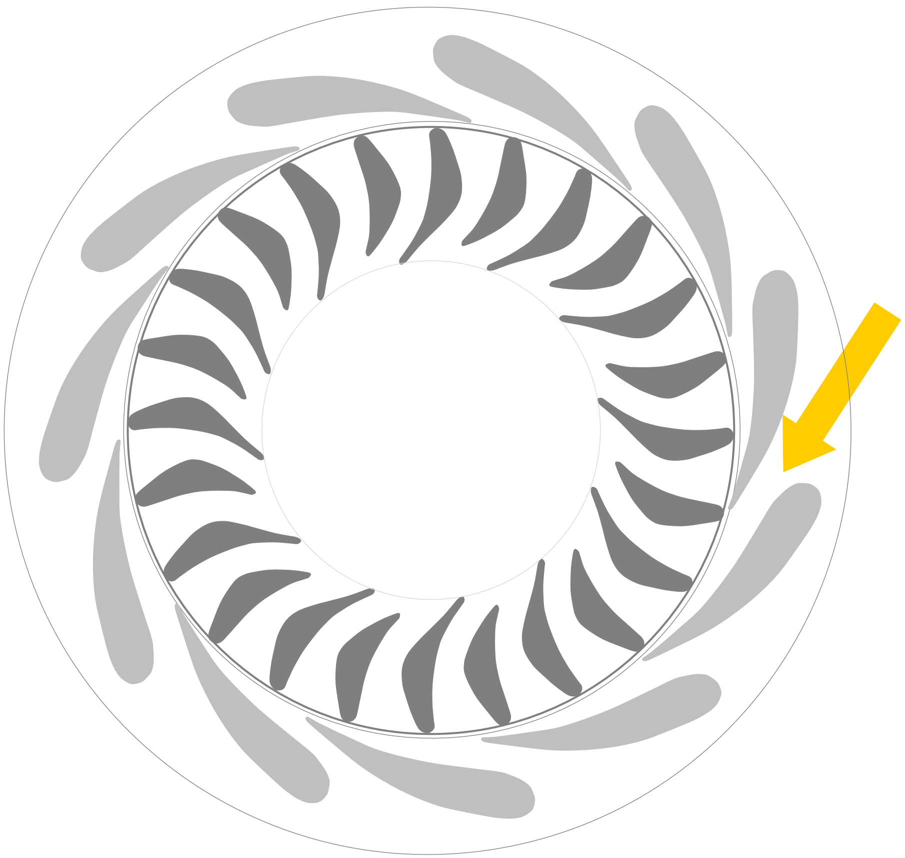
$$\Delta h_{dist} = ½ (C_{dis}^2 - C_{in}^2)$$

Part of expansion and cooling is done in the distributor.

2. Right orientation of the gas velocity
in order to enter correctly into the wheel.

3. Calibration of the gas flow by the cross section.

THE DISTRIBUTOR DUTY

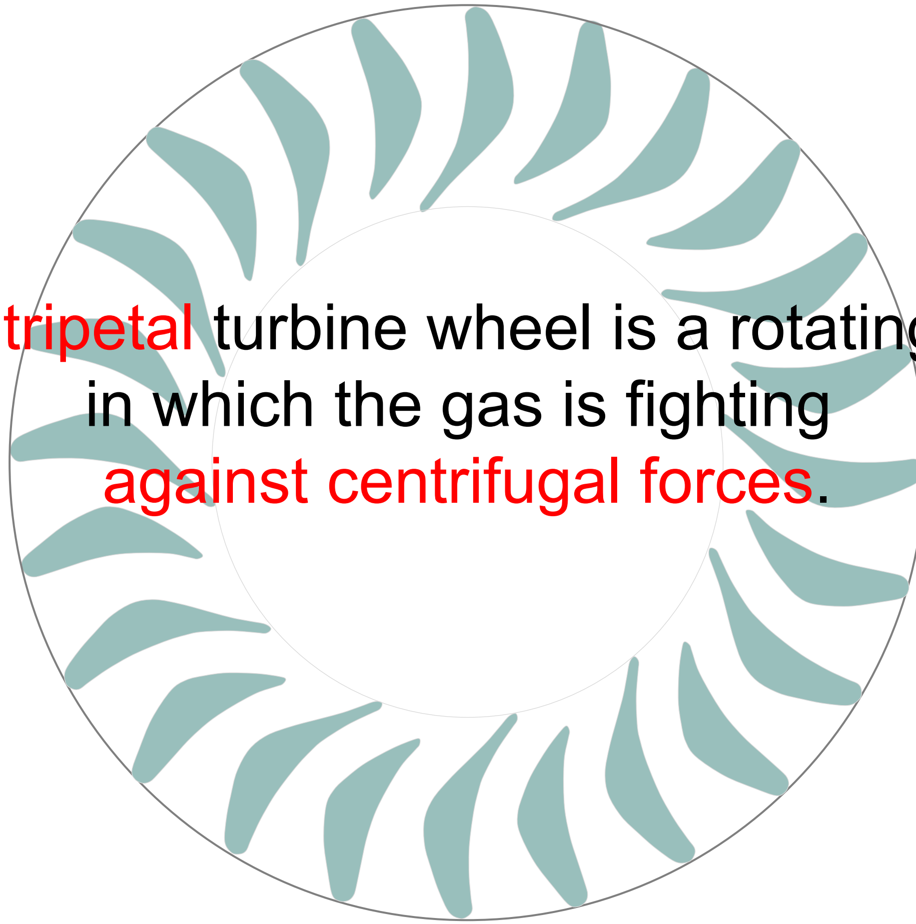


The cross section in which helium flows reduces in order to increase the velocity.

The distributor gives also a correct orientation of the gas velocity.

The cross section in which helium flows calibrates the gas flow.

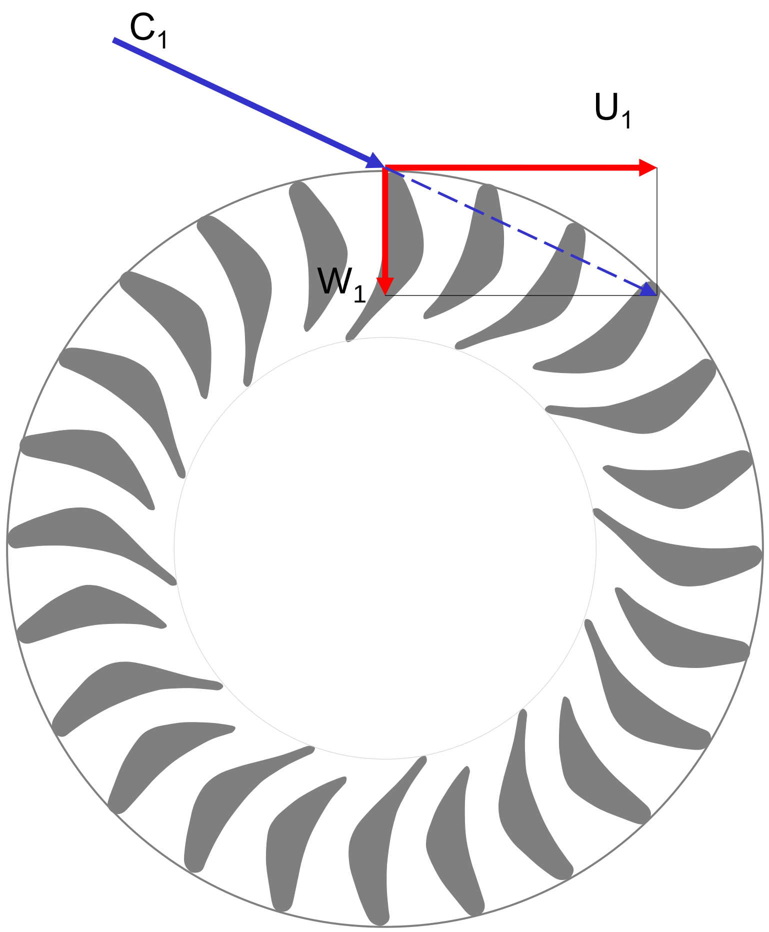
THE TURBINE WHEEL



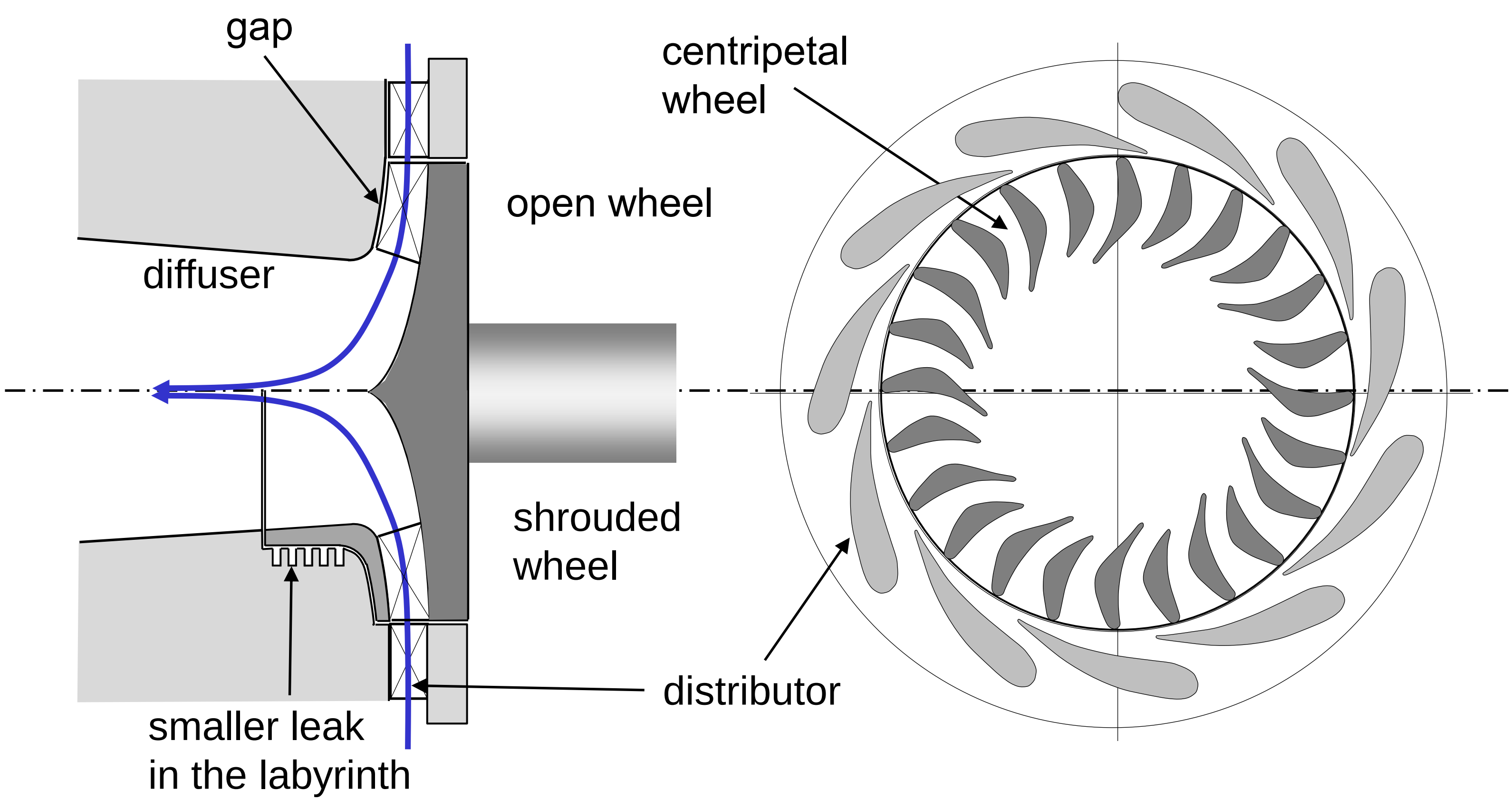
The centripetal turbine wheel is a rotating nozzle in which the gas is fighting against centrifugal forces.

VELOCITY COMPOSITION

RADIAL INLET



TYPES OF WHEELS



SOME TURBINE WHEELS...

radial-axial wheel

radial
shrouded
wheel

THE DIFFUSER

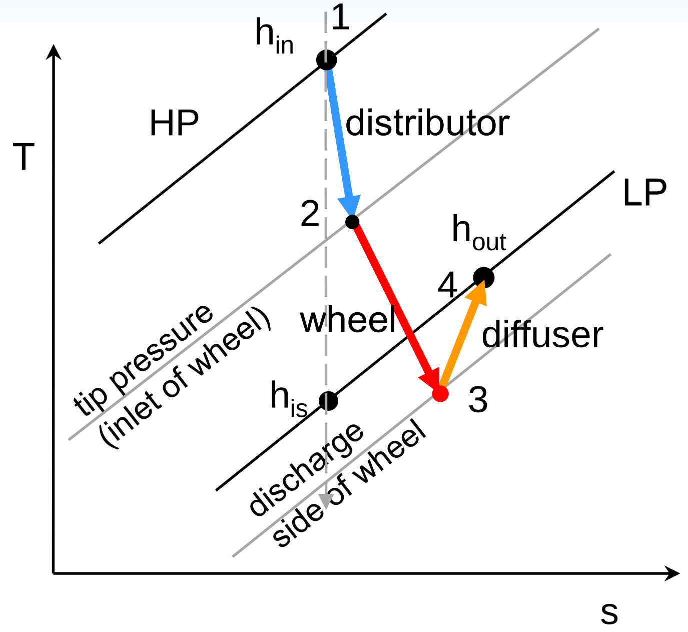
When the gas exits the wheel, its velocity is not zero.

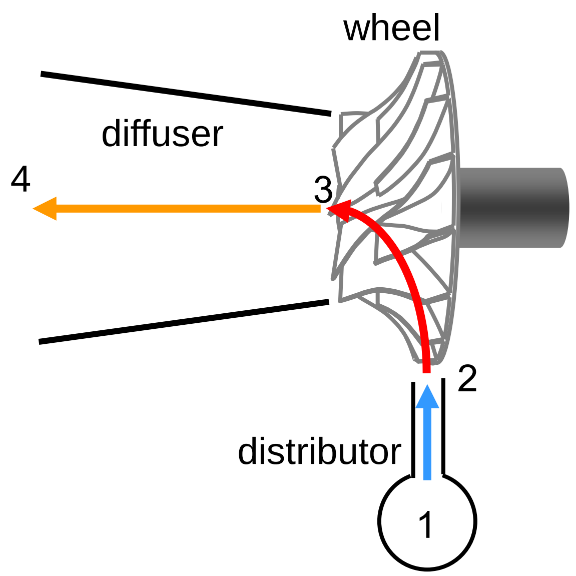
The velocity has to be reduced.

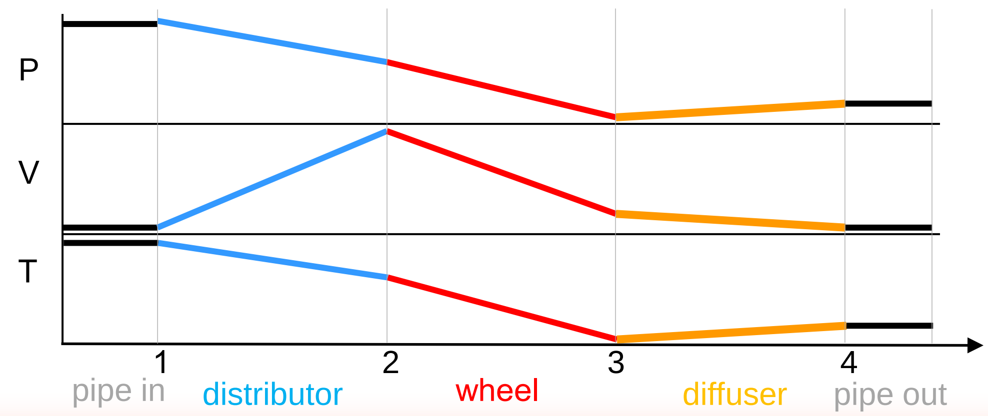
This is done by means of another nozzle : the diffuser.

As a consequence, both pressure and temperature increase slightly.

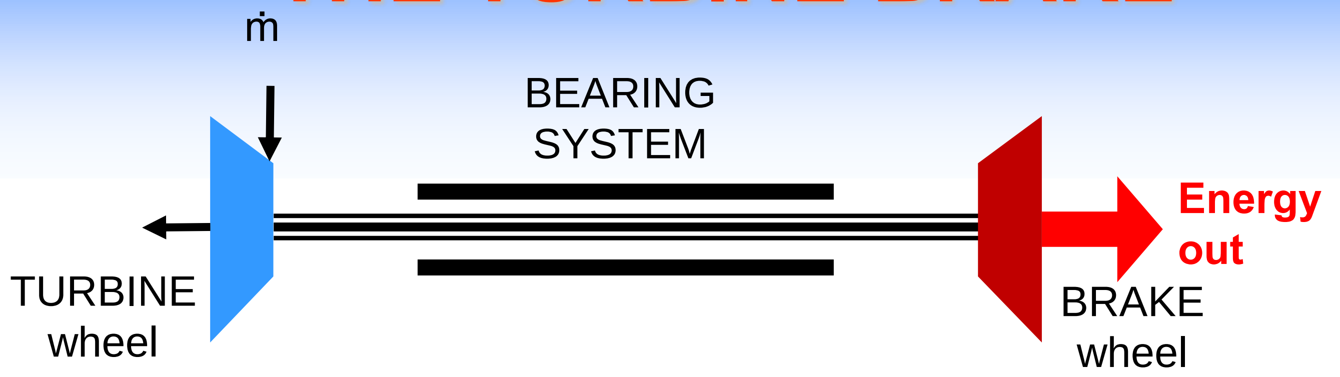
EVOLUTION OF GAS THROUGH THE TURBINE



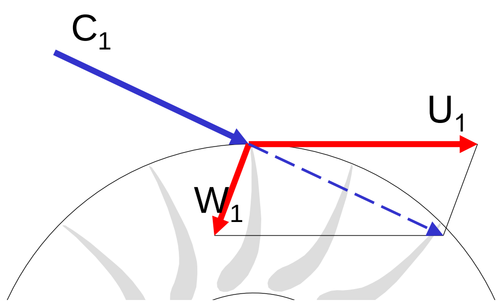




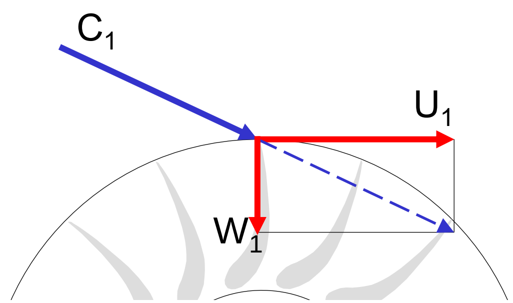
THE TURBINE BRAKE



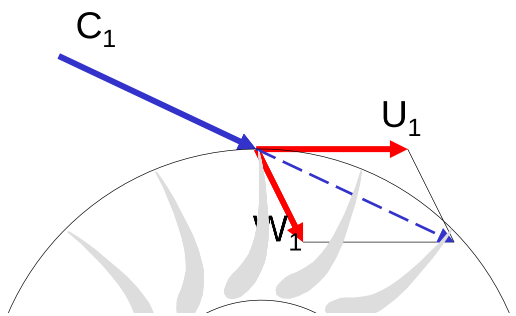
The brake dissipates the power that is extracted by the wheel, but it must fulfil this duty at the correct rotational speed !



speed is too high



speed is correct

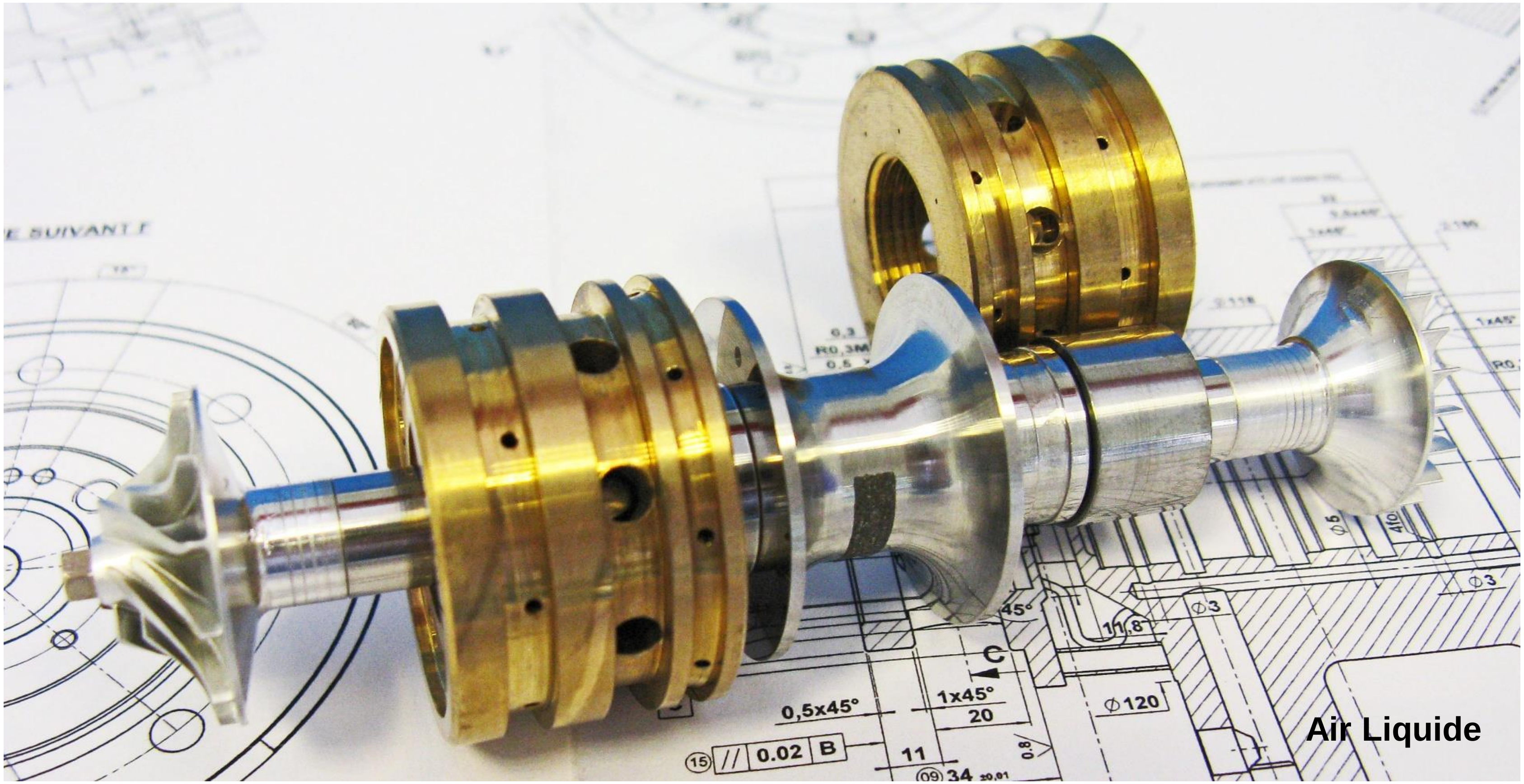


speed is too low

The main brake technologies are :

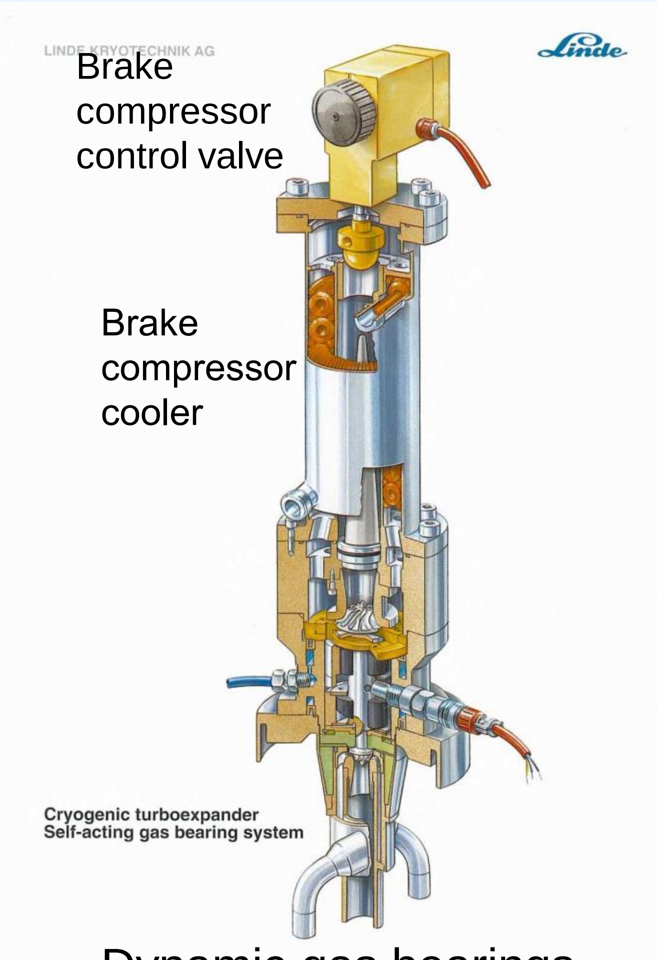
- a centrifugal compressor (most common)
- an eddy current system (for small powers).

SHAFT, BEARINGS AND WHEELS



STRUCTURE OF A TURBINE

A LINDE TURBINE



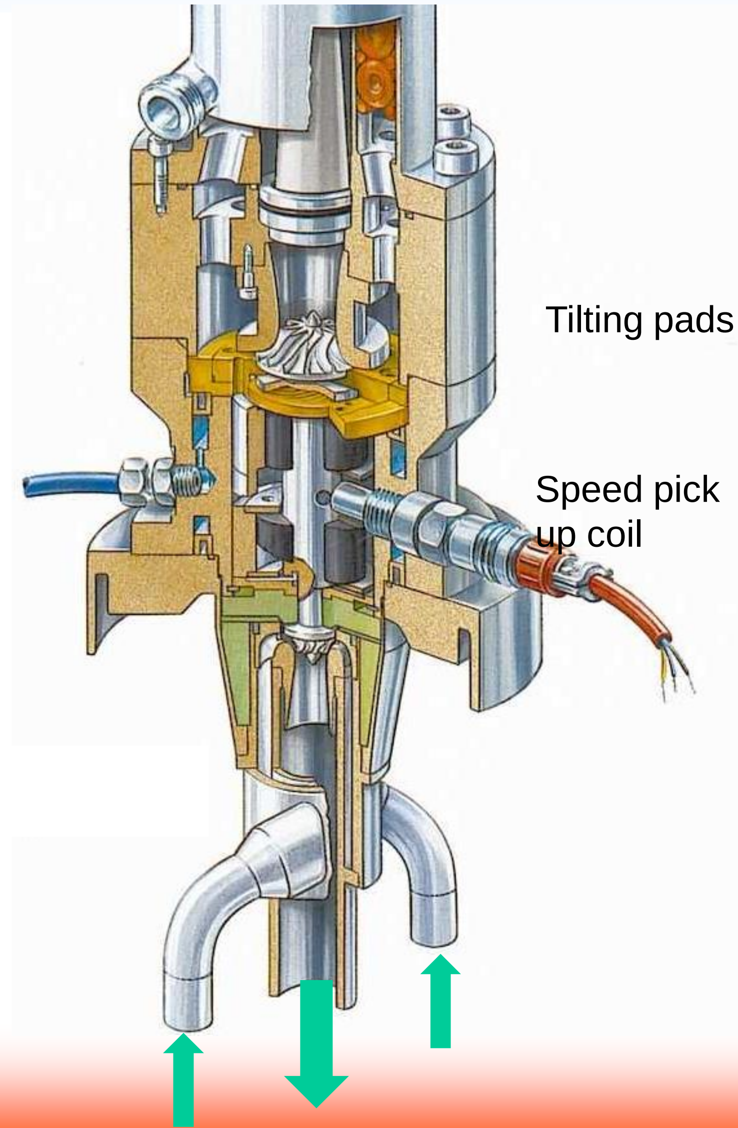
Brake compressor control valve

Brake compressor cooler

Compressor wheel

Bearing cooling water

Turbine wheel



Tilting pads

Speed pick up coil

Dynamic gas bearings

Non constant brake compressor pressure