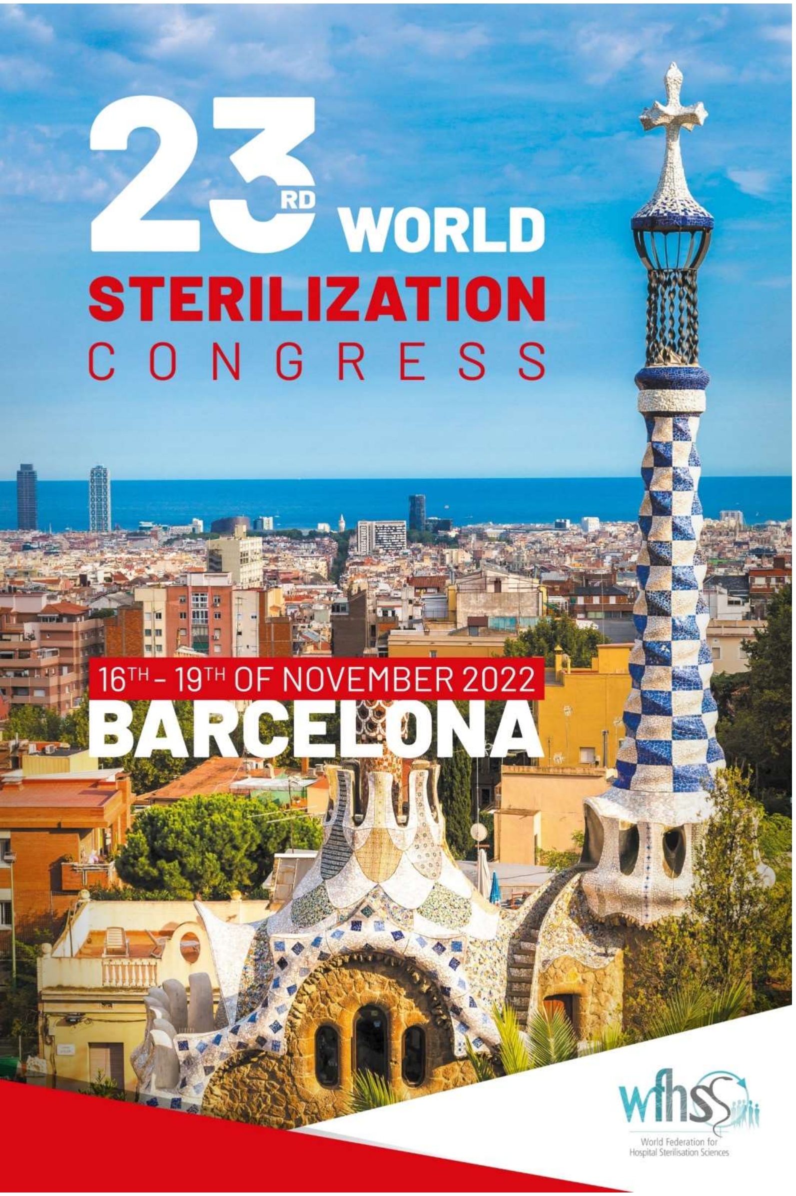

World Federation for Hospital Sterilisation Sciences

The physics of sterilization

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The point of view of physics

Physics looks for general laws

Biology has to deal with specificities

« generic » vs « specific »

Generalities on sterilization processes

- Pressure
- Temperature
- Water vap. relative humidity
- Concentration of the sterilizing agent

- Inactivation of µ-organisms on all surfaces of medical devices
- Surface phenomena: condensation / adsorption

Agenda

1. Physics of adsorption and condensation

2. Review and discussion of the main sterilization processes (steam, ethylene oxide, formaldehyde, hydrogen peroxyde)

3. A case study: H_2O_2 (microzoom, microbalance and microbiological control) *

* In partnership with ASP (2012)

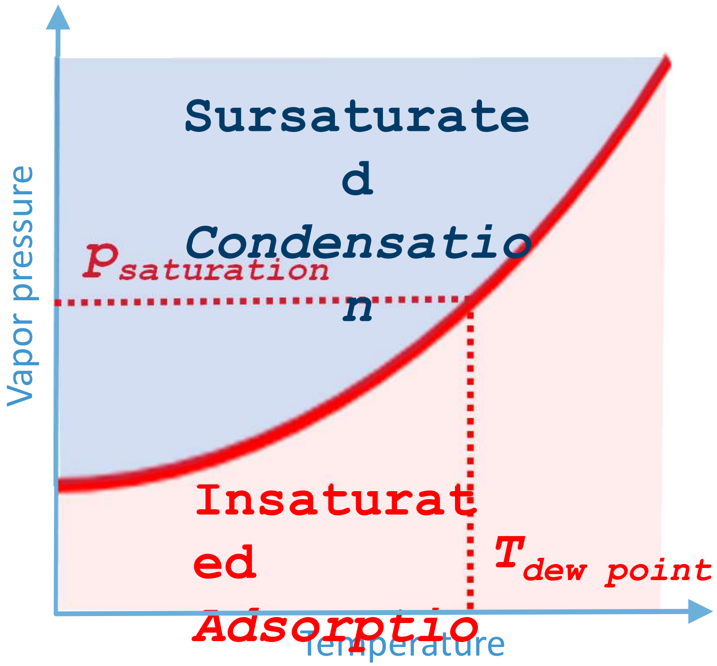
1. Physics of adsorption and condensation

Adsorption, absorption, sorption

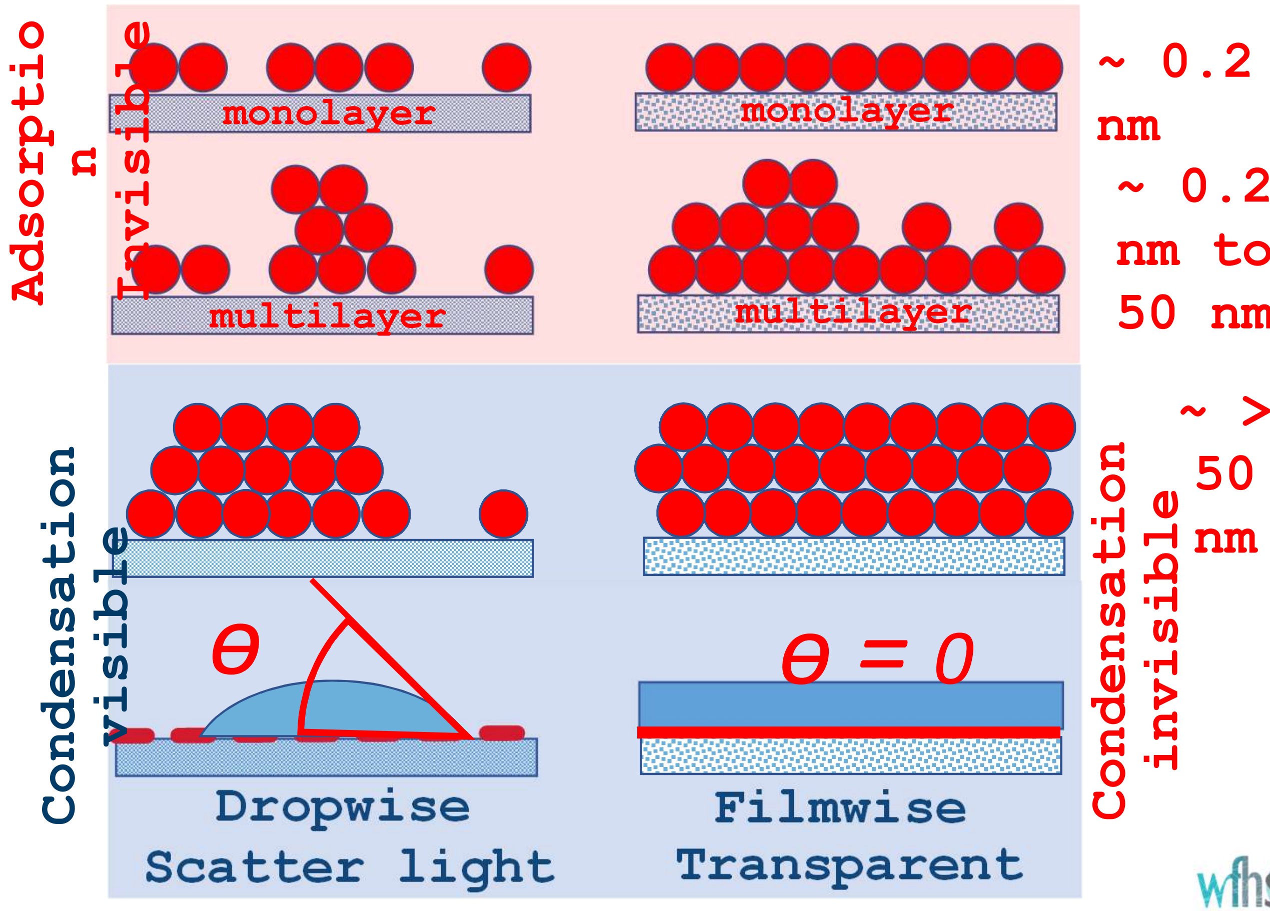
adsorption absorption

Sorption = adsorption + absorption

Adsorption/Condensation



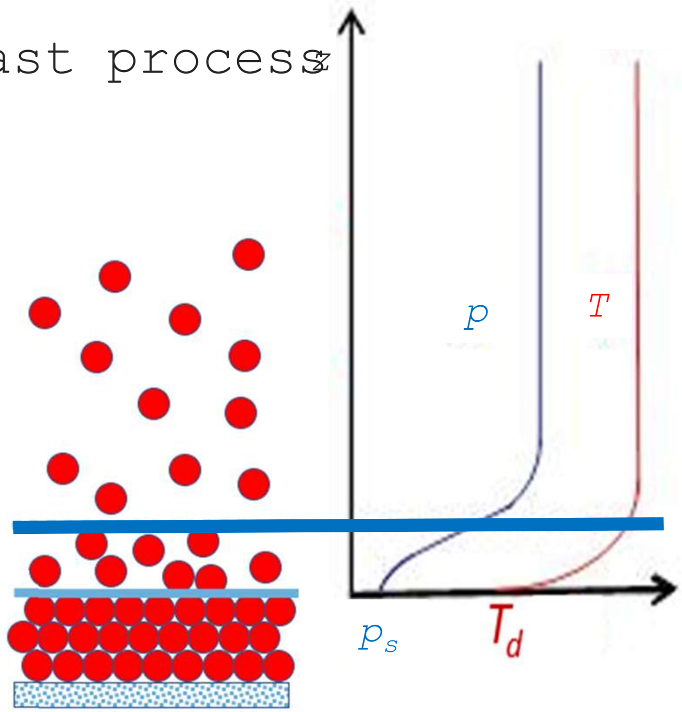
« Micro-condensation » = Invisible to human eye



Why eliminate non condensable gases ?

Vapor
Kinetic limited
(mean free path 100 nm)

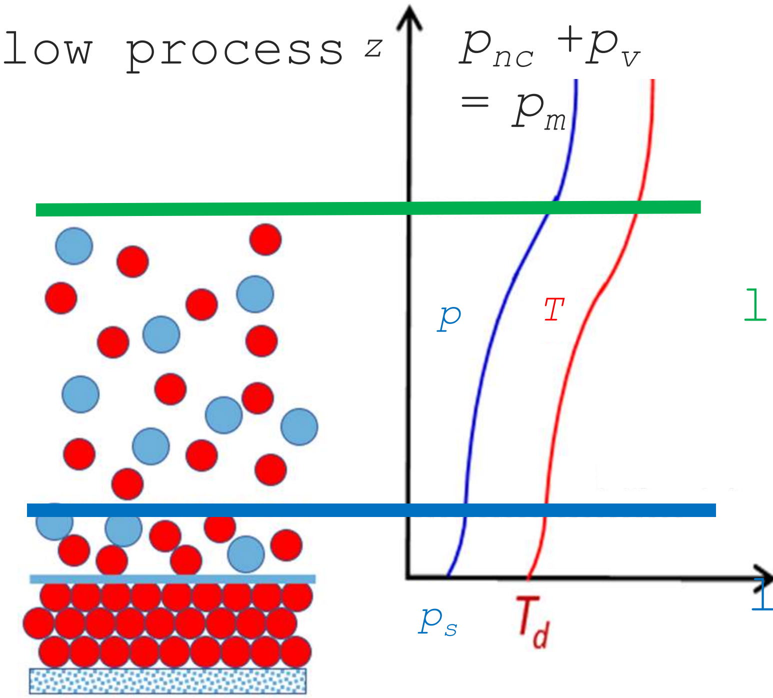
Fast process



Knudsen layer
Interface
Liquid

Vapor + non-condensable gases (e.g. air)
Limited by diffusions gradient
(boundary layer mm)

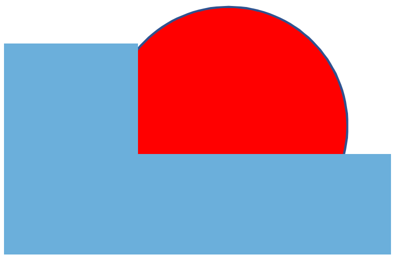
Slow process

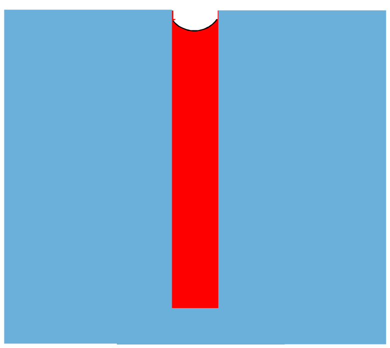


b-layer

K-layer

Role of surface geometry





Enhanced nucleation

Surface energy is lowered

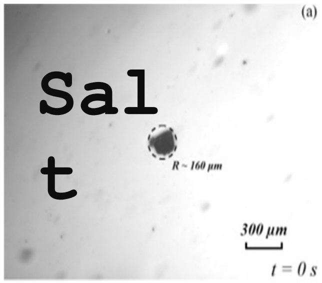
$p_c = p_s$, $T = T_d$

μ-pores; Kelvin

condensation at

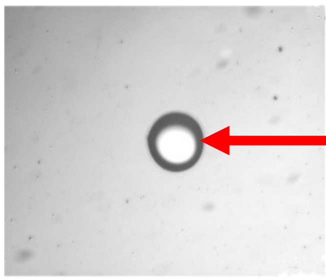
$p_c < p_s$, $T > T_d$

Hygroscopic materials

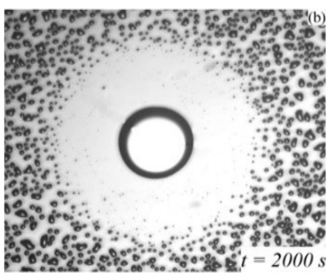


p_s (vap.+materials) < p_s (vapor)

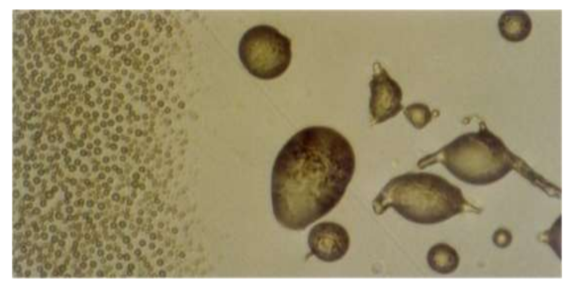
T_d (vap.+materials) > T_d (vapor)



Condensation



The materials "pumps" molecules around & dry the surrounding, preventing condensation



Salty water drop on silanized glass; from Guadarrama-Cetina et al., Phys. Rev. E 90 (2014)

Lyophilized spores of Bacillus macerans on silanized glass; from Marcos-Martin et al., Pharm. Techn. Eur. 8 (1996)

Vapor mixtures

Adsorption

Condensation

- Different component concentrations (analogy with liquid solutions)
- Using Raoult’s law and pure components isotherm

- Different component concentrations
- Using Raoult’s law and pure components saturation pressures

2. Main sterilization processes

Generalities in sterilization

- Vacuum to eliminate non-condensable gas
- Gas phase to penetrate in load and instruments
- Condensation:
  - Allow penetration of sterilization agent in spores
  - Release of latent heat
  - Concentration of sterilizing agent in condensate phase >> concentration in vapor phase (x 1000 – 10000)
  - Liquid water + sterilizing agent: Modify dew point temp. to obtain high adsorption / condensation at sterilizer chamber temperature (new phase diagram)

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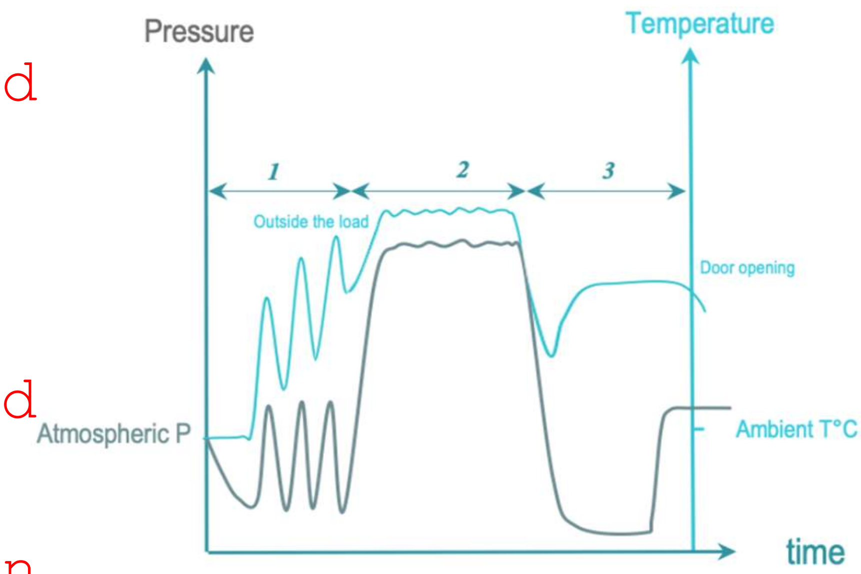
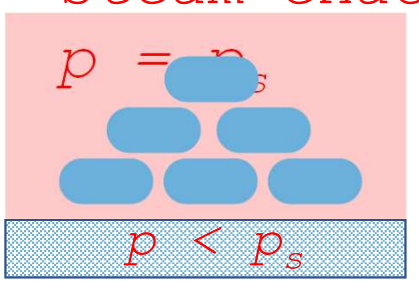
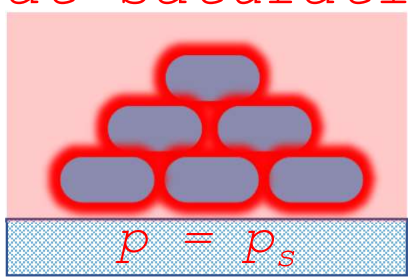
Saturated steam H_20

- Heat (121-134°C) + repeated latent heat releases by condensation
- Coagulation and denaturation of enzymes and structural proteins
- Steam exactly at saturation



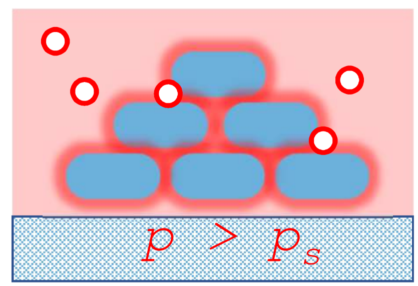


No condensation



Condensation

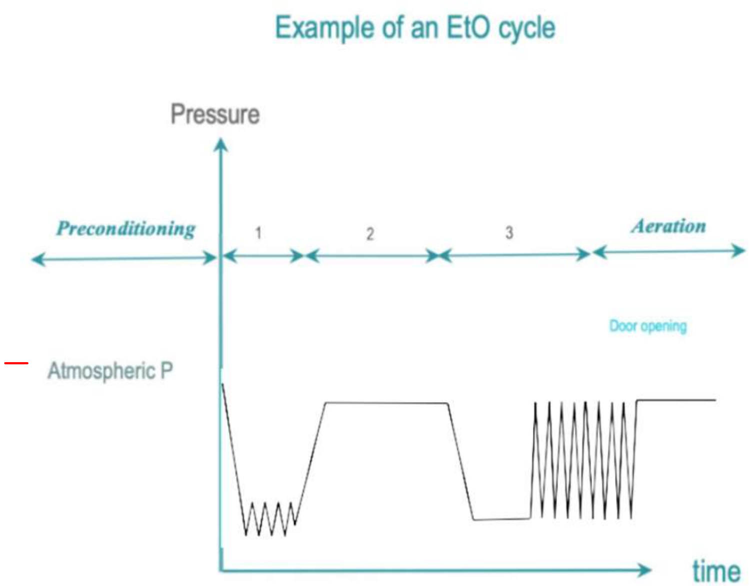
Latent heat

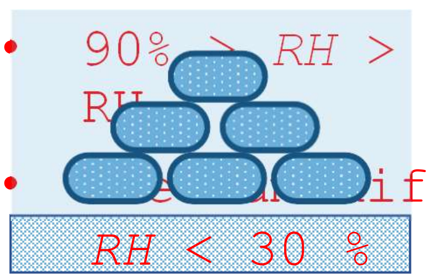


% of vapor already condensed

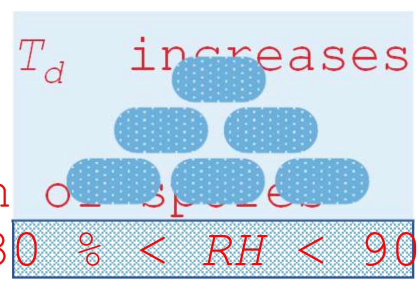
Ethylene Oxide C_2H_40

- EO: highly penetrative gas (absorption)
- Require aeration - carcinogenic
- Conc. 200-1200 mg/L
- Alkylation of protein, DNA and RNA – prion fixative
- Efficacy increases with *T* °C (typically 48°C)
- 90% > *RH* > 30% - T_d increases with RH
- ification of spores

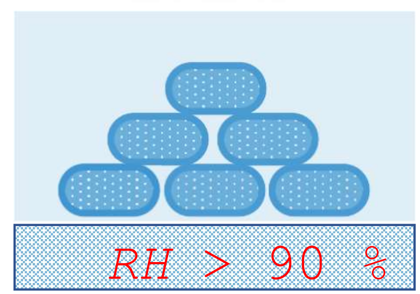




Not efficient on spores



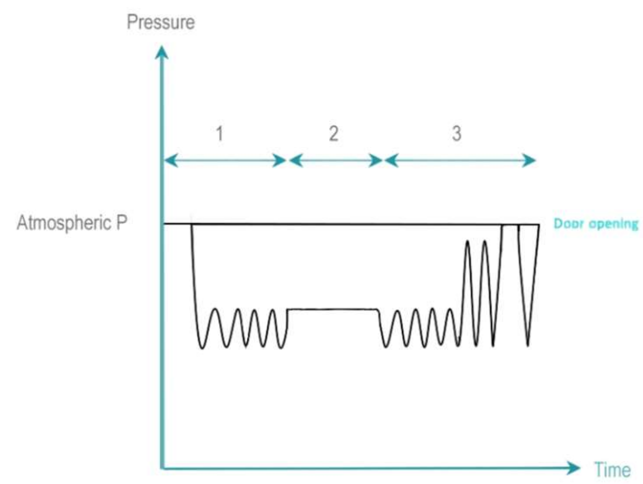
Penetration of EO in spores



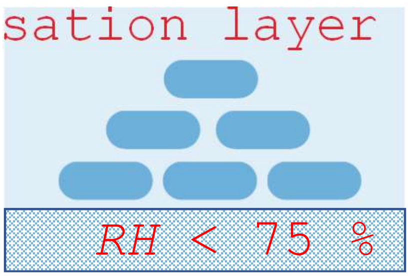
Efficacy vanishes

Steam formaldehyde CH_2O

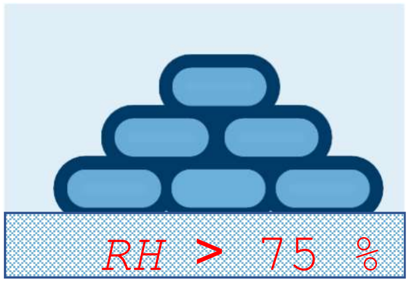
Example of an LTSF cycle



- Temperature: 50 - 80° C
- Potentially carcinogenic – aeration
- Concentration: 15-100 mg/L
- RH >75%
- Alkylation of amino and sulfhydral groups of proteins and ring nitrogen atoms of purine bases – prion fixative
- Condensation layer



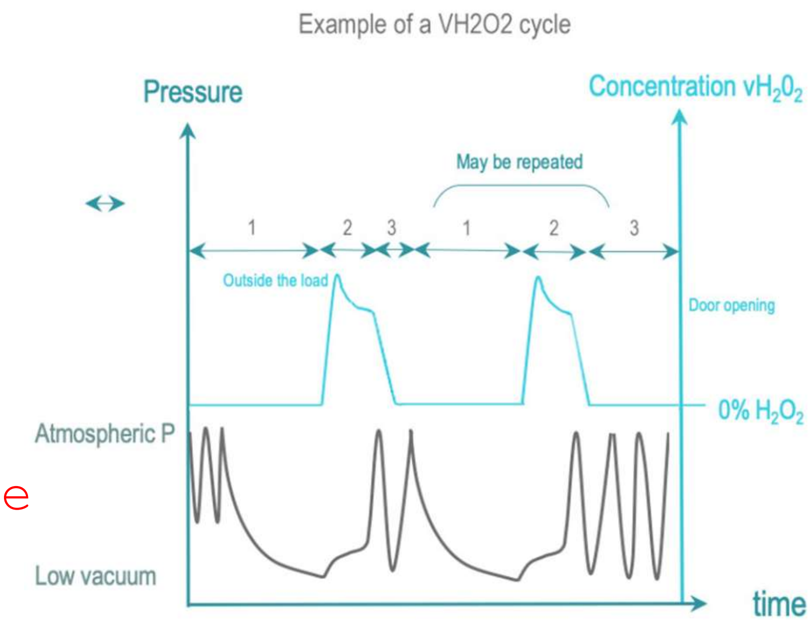
Not enough liquid around the spores

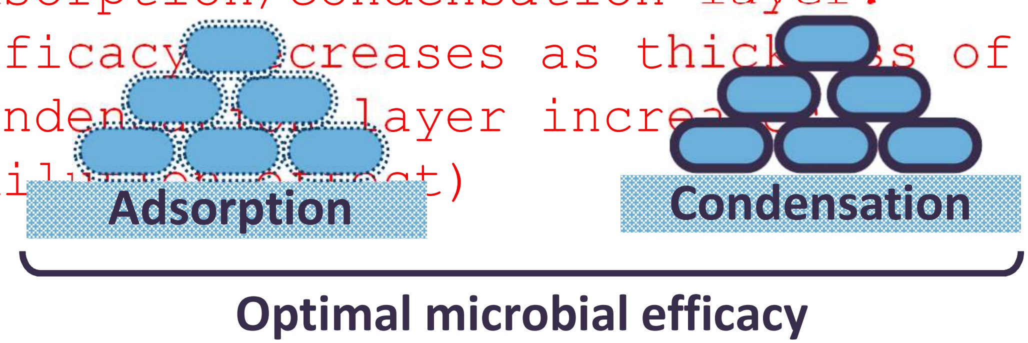


Condensation layer Liquid phase (ISO 11138-5)

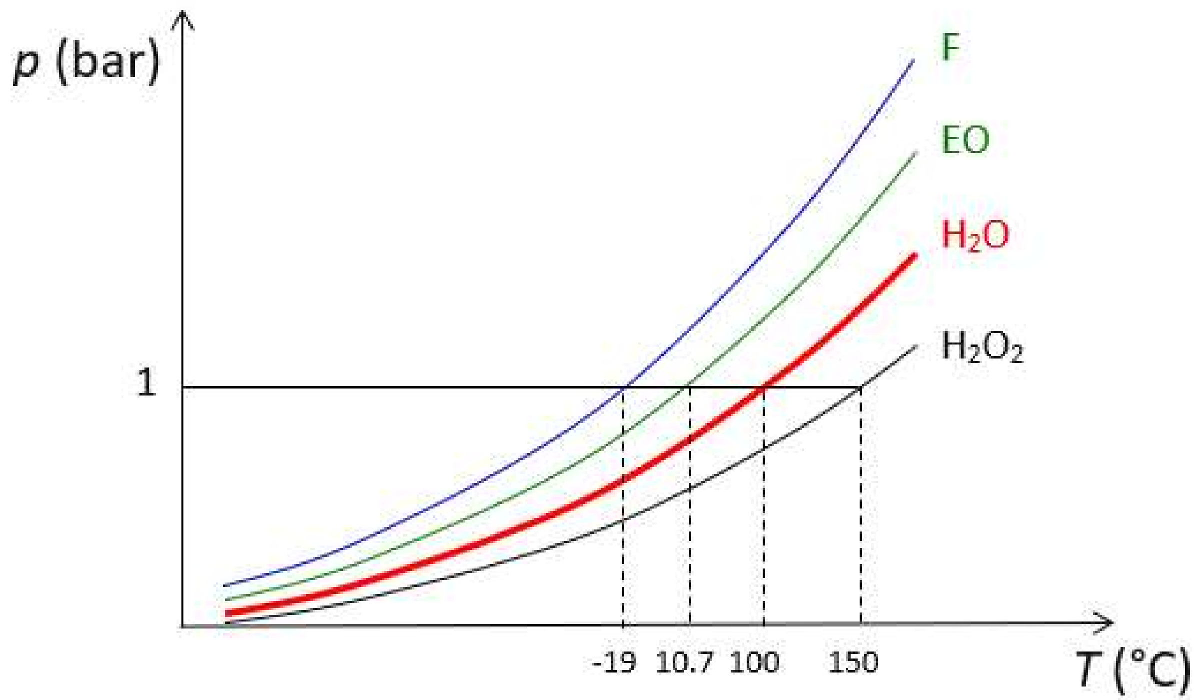
Hydrogen Peroxyde H_2O_2

- Injection of water + H_2O_2 after vacuum (≠ atmospheric pressure)
- Temperature < 60°C
- Hydroxyl free radicals attacking membrane lipids, DNA, and other essential cell structures. Effective on prion.
- Adsorption/condensation layer: Efficacy decreases as thickness of condensation layer increases (dilution effect)





Sterilizing agents – $T_{eb.}$



3. *Case study*:* $H_2O + H_2O_2$

- **Ambiant pressure and low cc. H_2O_2: Slow motion**
- **Influence of RH**
- **Micro-zoom, micro-balance and bio-controls**

* In partnership with ASP (2012)

Test protocol

H_2O_2 sensors

Inactivation kinetic

Pre-conditioning: RH 30% to 80 %

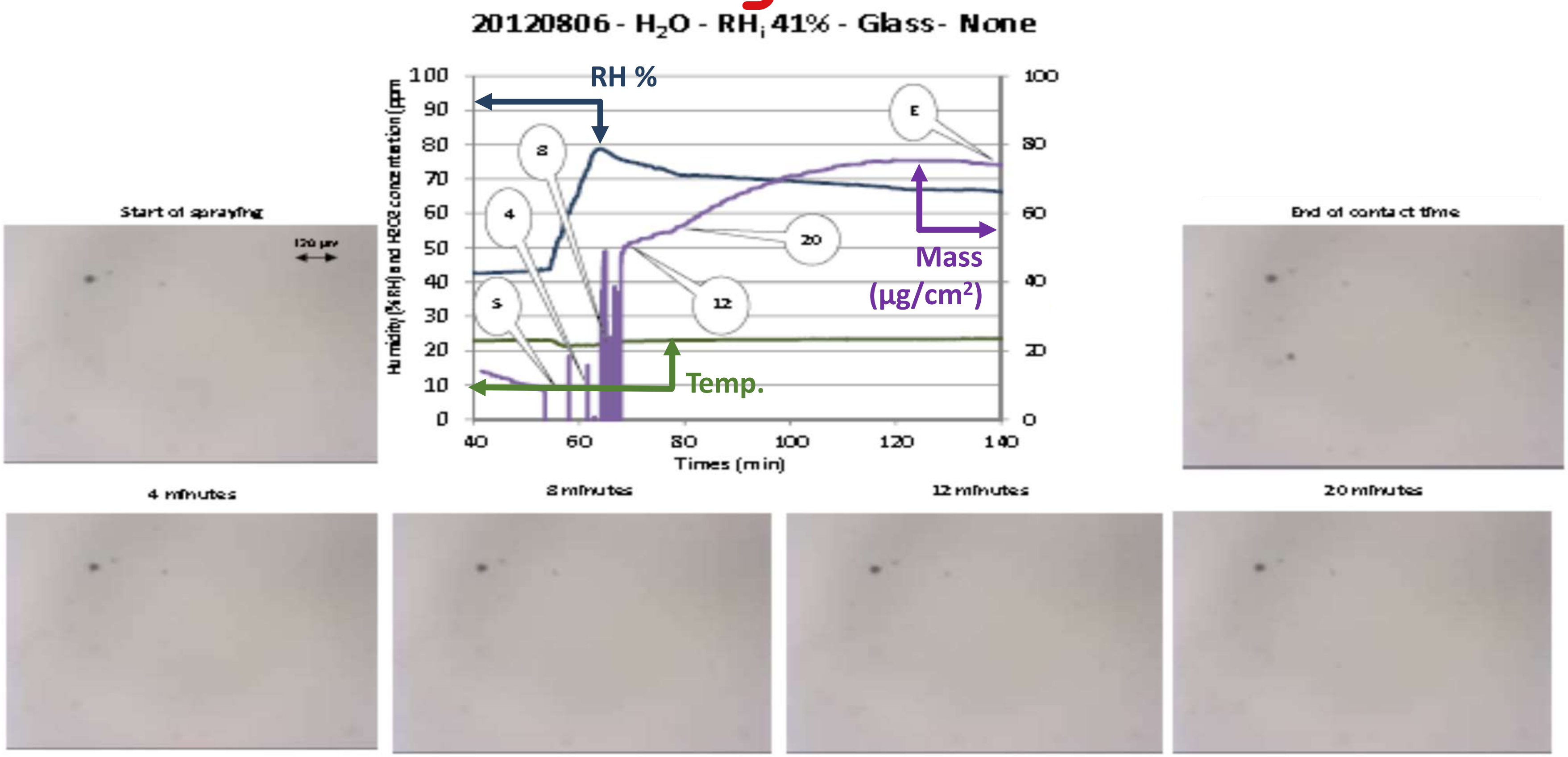
Injection of µ-droplets (evaporating)

H_2O, H_2O_2 at 6% and 12 %

Macro-zoom

µ-balance

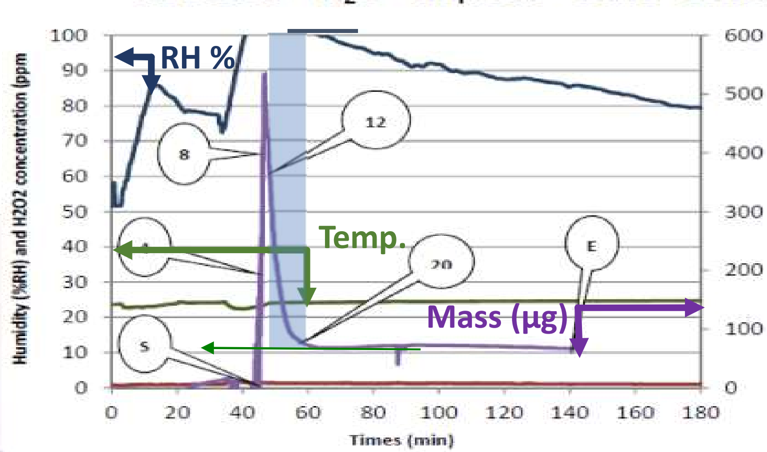
H_20 – Initial RH (41%) – glass



Adsorption and/or invisible condensation

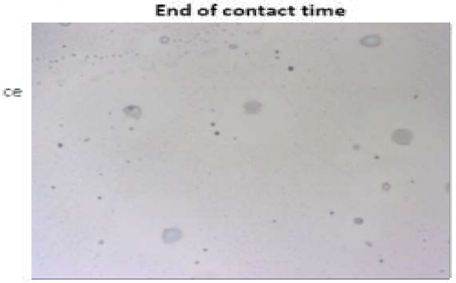
H_2O - Initial RH (72%) - glass

20120727 - H_2O - RH_i 72% - Glass - None



Start of spraying

End of contact time



4 minutes

8 minutes

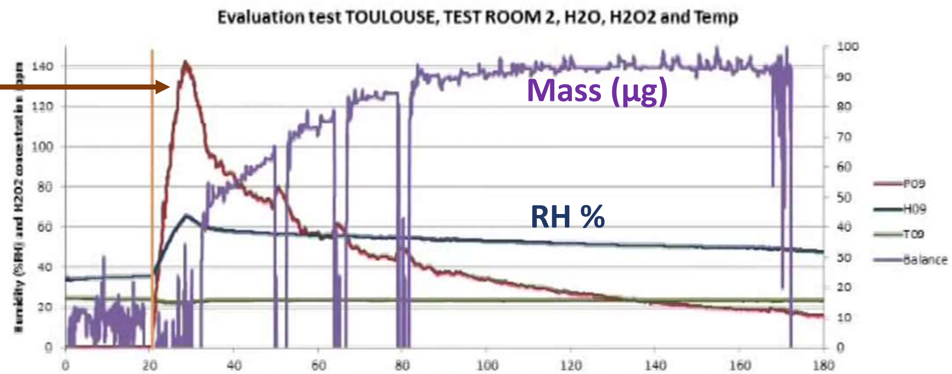
12 minutes

20 minutes

Visible dropwise condensation + rain

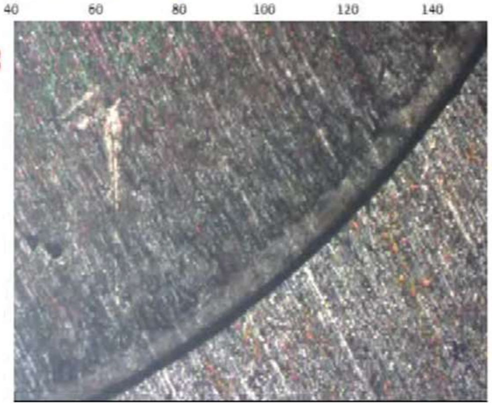
H_2O_2 6 % - RH_i (35 %) - Germs on steel

ppm H_2O_2



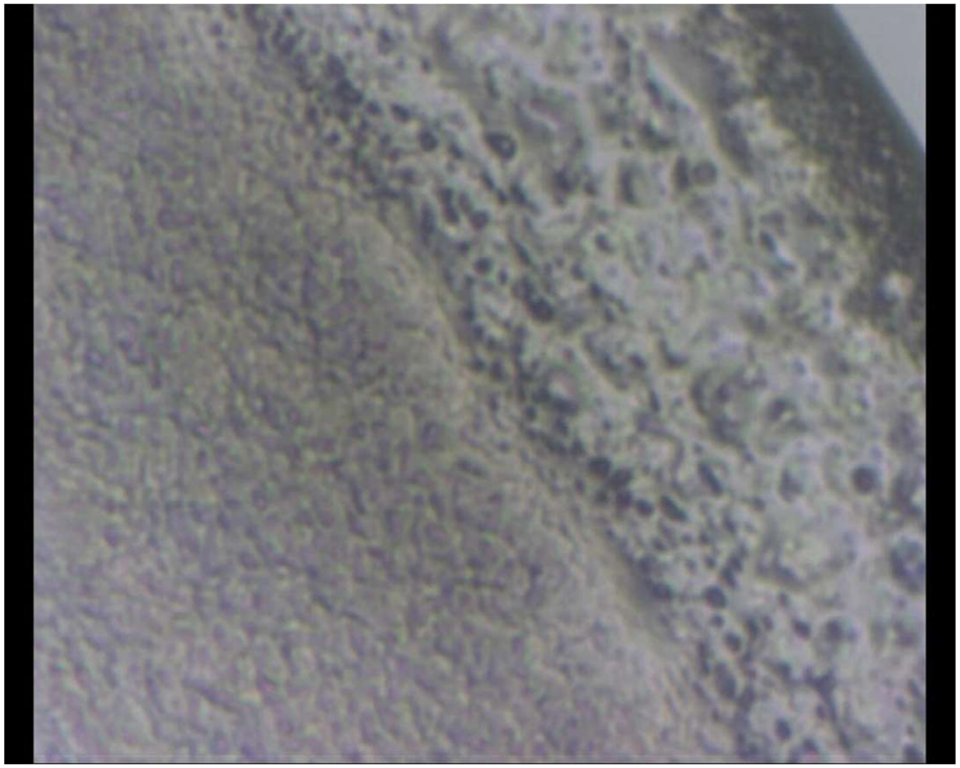
100µm

Start of Spraying



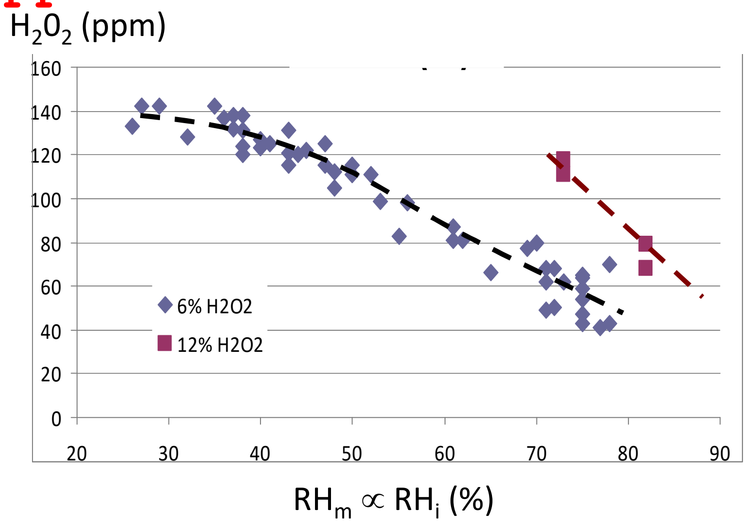
pseudomonas aeruginosa
6 log
Phosphate / Milk

H_2O_2 12 % - RH_i (51 %) - Germs on steel

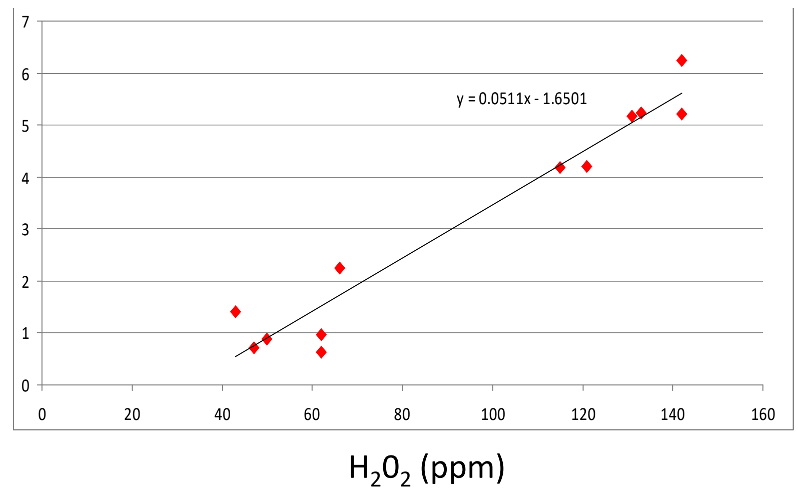


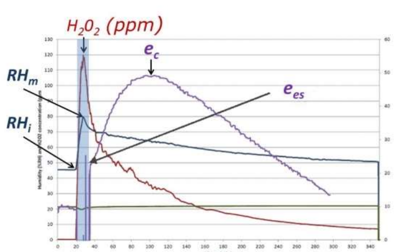
Case study - Analysis (1)

RH_m (RH_i) determines H_2O_2 ppm



Efficacy ↑ when H_2O_2 ppm ↑ or RH_m (RH_i) ↓





H_2O_2 liquid phase cc >> vapor phase cc

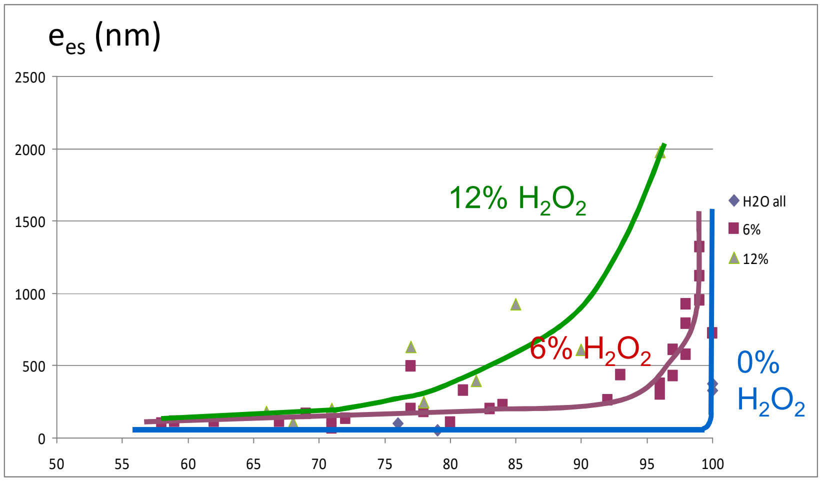
(Raoult and Henry's laws)

Case study - Analysis (2)

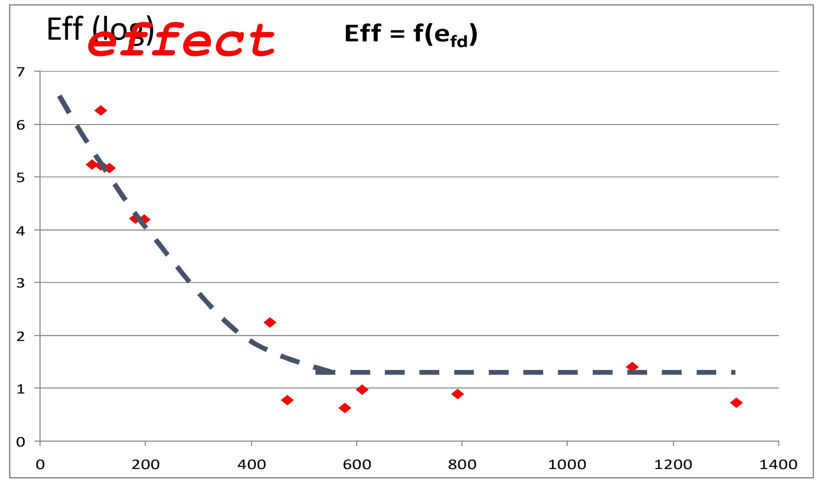
e_{es}↑ ***RH***↑ **or** H_2O_2 **ppm** ↑

e ↑ **(RHi** ↑ H_2O_2 **ppm** ↓ **Eff** ↓**)**

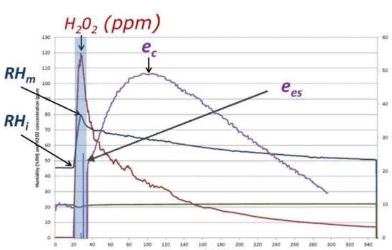
Dilution



RHm ∝ RHi (%)



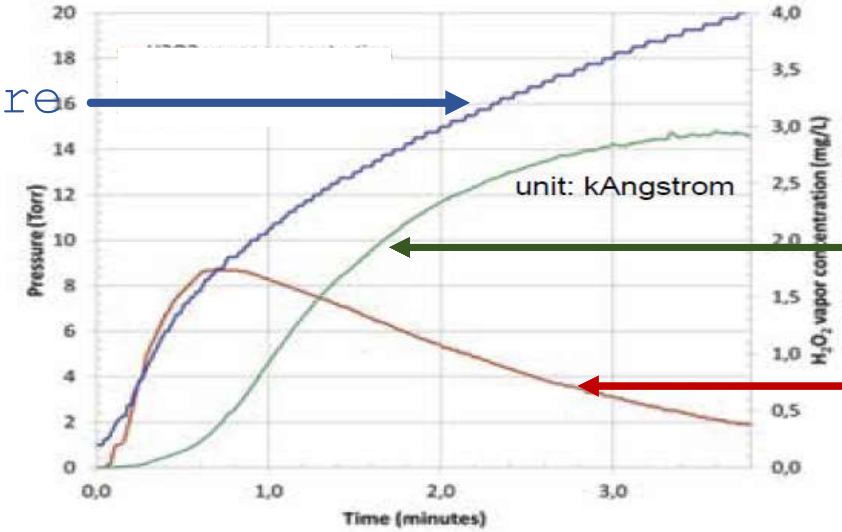
e_{es} (nm)



Adsorption / condensation

e_{es}=F(RH_i, H_2O_2 ppm)

Comparison with H_2O_2 sterilization in vacuum



pressure

Condensate
Layer thickness

H_2O_2 vapor conc

Timescale is
much shorter

Injection
(pulses of H_2O_2 to reach 19 Torr – specific to this process)

The first dual-sterilant low-temperature sterilization system; from Dufresne and Richards, Canad. J. of Infection Control (2016)

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Concluding remarks

- Vacuum to withdraw non-condensable gases
- Fast and efficient penetration in instruments of the sterilizing agent in vapor state
- Condensation/adsorption of water needed for various reasons for each sterilization modalities
- … But:
  - Condensation is a complex phenomenon, not to be reduced to *p*,*V*, *T* …
  - Growing complexity of medical devices

THANK YOU !