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Abatement and bio-digestion of airborne contamination in precision mechanics: the case study of Beretta firearms



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Outline of the work



- **Objective of the study:** verifying the effectiveness of a novel biotechnological air treatment system on improving air quality inside a modern and regulation compliant precision mechanic facility
- **Time span:** 4 months testing period (October 2013 – February 2014)
- **Monitoring method:** Oil mist and polycyclic aromatic hydrocarbons (PAHs) checked in indoor air, heavy metals content measured in process water
- **Air treatment technology:** stand-alone Immobilized cell Bioreactors' system (AIRcel)





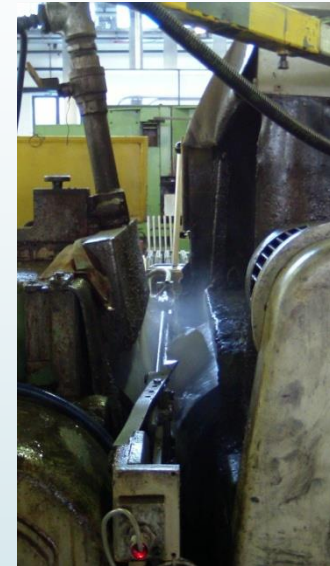
Case study



BERETTA

500 YEARS. ONE PASSION.

- The experimental application of AIRcel biotechnology in the Gardone Valtrompia (Italy) Beretta facility involved the department of gun barrels reaming
- Contamination issues involved:
 - **oil mist**
 - **metal dust**
- Past air quality tests were verified and they showed that facility is consistently **compliant with the regulatory limits for safety of the working sites**



The sizing of the system has been calibrated as to treat only part of the plant building where the reaming process is performed, in order to contain the test to a pilot scale level, even if applied already on field conditions.

N.7 AIRcel bioreactors were placed in the area:

n. 5 Aircel 5000 around the reaming machines

n.2 Aircel 600 as sentinels on the main openings of the building

Containing the
contamination source

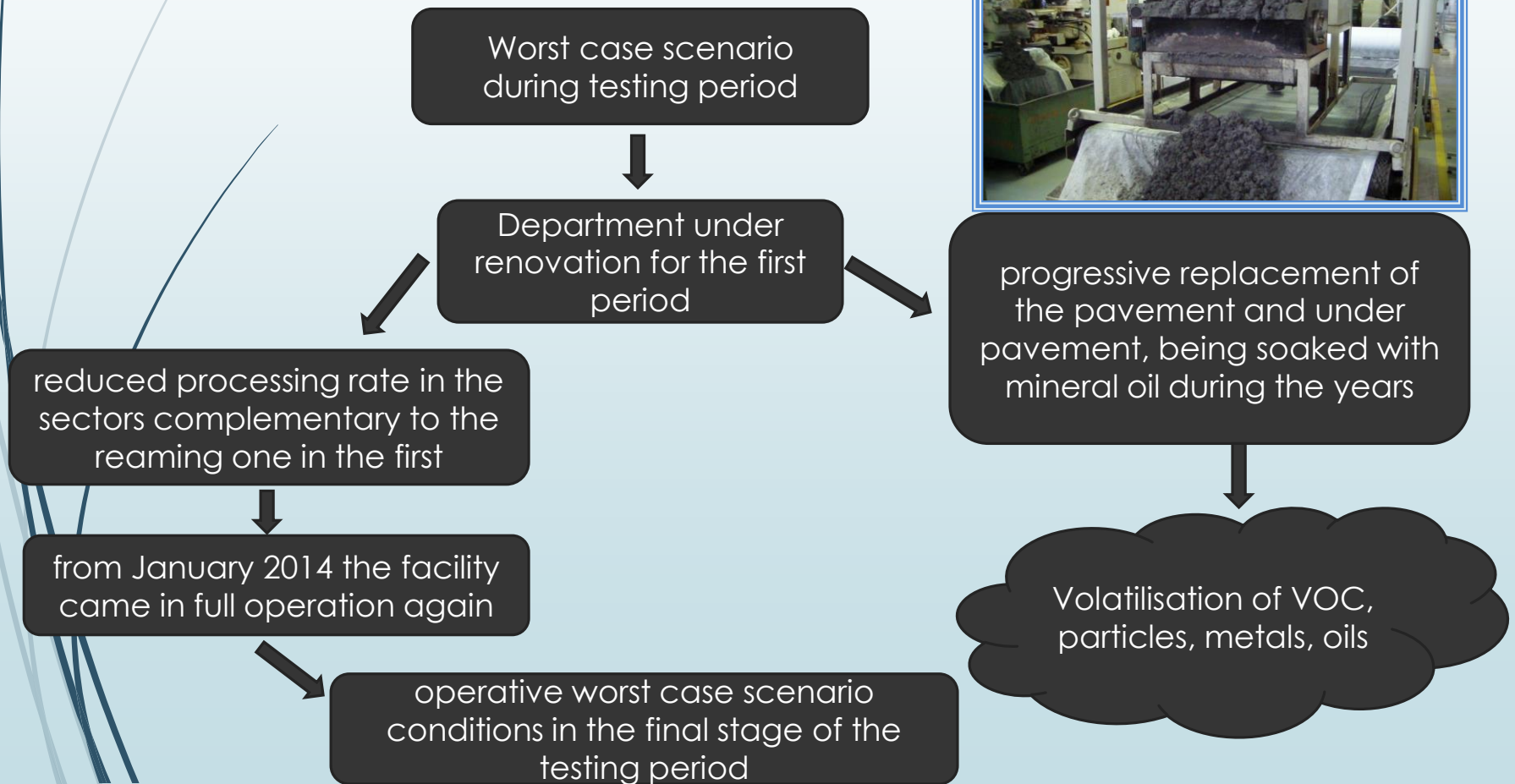
Preventing cross
contaminations



Case study



- The testing period has coincided with a period of renovation of the building in which the barrels reaming area is located (full implementation of the productive area only since January 2014)





Bio-Technology applied

The technology selected is constituted by **stand-alone bio-oxidizers** that provide **internal air-mixing within the facility** and **capture and digest** particulates and gases by attracting them to a clean air zone generated by its action (**BioHygienics_{TM}**). It presents three major working principles:



1.convection: a top fan moves large particulates and provides oxygen inside the bioreactor (vacuum principle)

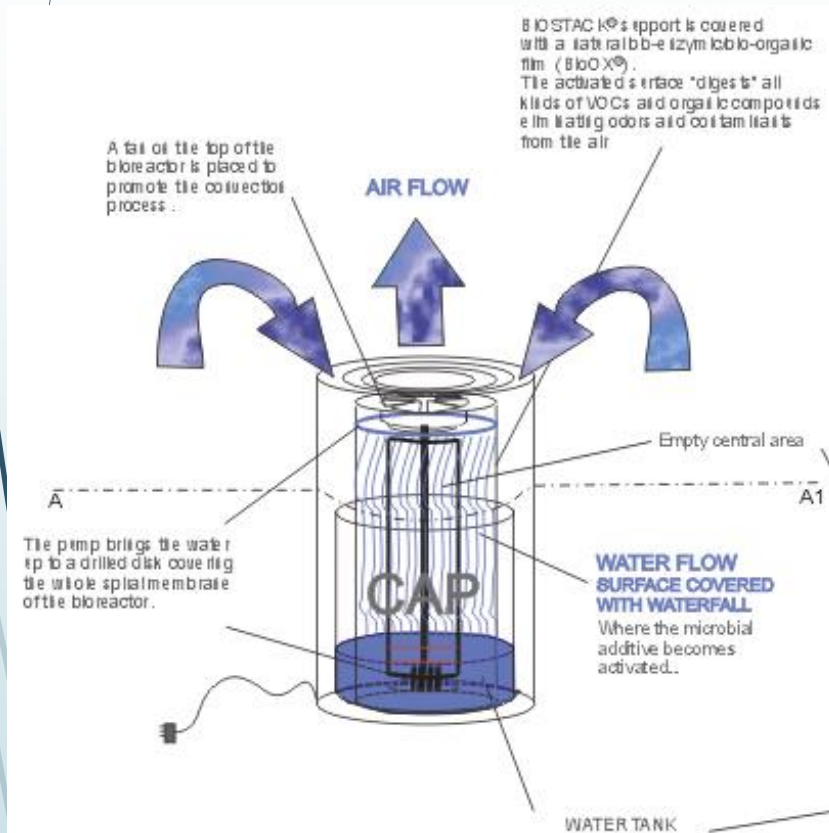
2.molecular charge attraction: grounded, neutral air generated by the bioreactors attracts airborne pollutants, especially fine and ultrafine ones, less affected by convection (volatile organic compounds-VOC)

3.natural oxidation: the patented bioreactors provide correct control on the mixture of water, oxygen, enzymes and pollutants to achieve an effective degrading process





Bio-Technology applied



Gas-liquid mixing with electrically grounded water from the reservoir tank additionally grounds the clean air zone, attracting and capturing pollutants

Contaminants (along with the odors that they generate) are **attracted** to the clean air zone by **concentration gradients** (both with mass and electrical charge)

charged particles are removed by electrical grounding

organic compounds digested by the biomass



Bio-Technology applied: a sustainability issue

An indoor air treating system must be regarded as a **sustainable technology**, particularly when compared to standard air treatment systems, since it requires

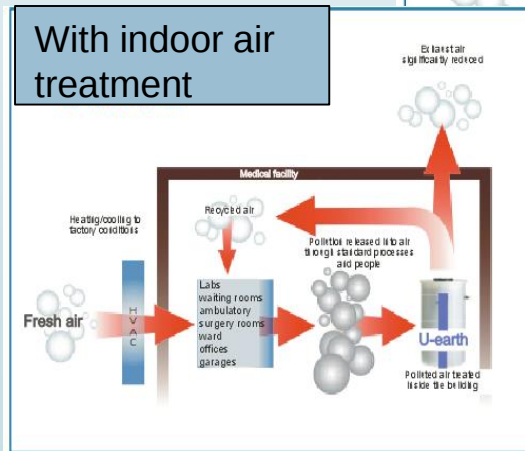
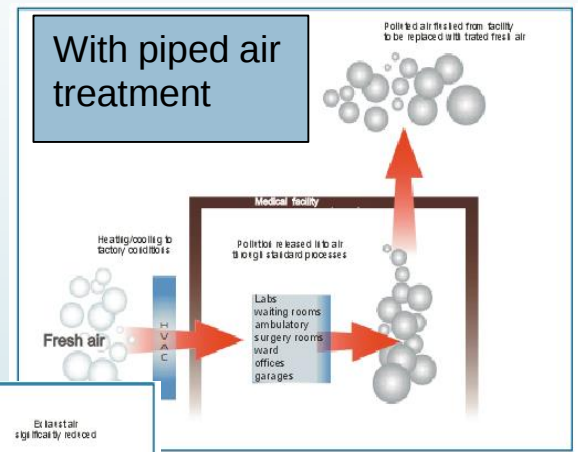
environmental temperatures

standard pressure

low energy

indoor air can be for a great part **recycled inside the facility** itself, reducing the need to bring in fresh air from the outside to balance the facility

By **lowering the air turnover rate** inside the facility, significant improvements in overall environmental sustainability and significant reductions in operating costs are possible





Target contaminants

- Numerous **Lubricant oils** are used for the reaming process, variously defined as synthetic base oils with
 - additives,
 - hydraulic fluid,
 - gear oil,
 - oil for machinery,
 - cutting fluid for machining,
 - highly refined mineral oil
- They are not classified as dangerous for UE regulation and non-carcinogenic.
- The regulatory limit for working environment for the oil mist generated by them is, therefore, set at 5 mg/l



Requirement already fulfilled by the case study
Company



Indoor air monitoring

- Sampling of air quality were made by **vacuum gauge** with subsequent **adsorption on inert support**



this technique that allows the detection of even small amounts of contaminants like oil mist (0.1 mg/L).

- The samples were
 - taken at different locations of the factory body,
 - kept identical in every subsequent monitoring
 - Taken for sufficient time to permit the analysis of more than 1000 L of air
- Sampling of VOC have been achieved through the use of a **portable Photo-Ionization Detector (PID)**, which provided instantaneous reading of the overall **VOC** concentration within the building.



particularly dangerous for operators' health and often carried by airborne particulate of breathable size



Indoor air monitoring

- the **baseline** for comparison was carried out during
 - *summertime*, that is, when natural ventilation is more favorable for the containment of the specific issue (on the contrary, a baseline performed in wintertime would have, presumably, provided higher data)
 - while processing within the factory was running at a reduced intensity
- the **final sampling**, was carried out, on the contrary,
 - during *wintertime*
 - with *machinery at full capacity*



Process water quality monitoring

- The sampling of process water were carried out after about
 1. 60 days of installation (01/02/2014)
 2. 90 days of installation (01/31/2014)
 3. 20 days of installation (at the end of the test 02/19/2014)
- Main purpose: to identify and quantify elements and compounds not degraded (or under degradation process, i.e. intermediate metabolites) by the biomass, especially metals
- The bioreactors' system was supplied with water from the public distribution network

contamination from **metals and oils** is supposed to be found occasionally and only in traces, not harmful for human health

- Chemical quality of supply water was known
- no chemical compounds are included into U-ox biomass

Contamination found in water samples is assumed to come from the capturing activity of the AIRcel system



Results obtained: air

Analytical results abatement of oil mist in

1. t_0 (baseline),
2. t_1 (about 90 days after installation)
3. t_2 (130 days after installation).

Where the concentrations observed were **below the detection limit**, two **different scenarios** have been outlined to define the abatement rate:

(¹) = the concentration value in t_2 has been assumed conservatively equal to **95% of the detection limit value**;

(²) = the concentration value in t_2 has been assumed equal to 50% of the detection limit value

Sampling point identification code	t_0 08/08/2013	t_1 01/31/2014	t_2 02/28/2014	abatement rate compared to t_0 ¹	abatement rate compared to t_1 ¹	abatement rate compared to t_0 ²	abatement rate compared to t_1 ²
A25	0,17	0,27	<0,1	44%	65%	71%	81%
A32	0,21	0,27	0,15	29%	44%	29%	44%
A12	0,13	0,15	0,1	23%	33%	23%	33%
A47	0,23	0,13	<0,1	59%	27%	78%	62%
average abatement rate				39%	42%	50%	55%



Results obtained: process water

- The samples showed a remarkable presence of the following:
 - **metal dust** from processing of gun barrels,
 - **suspended solids** presumably coming from **airborne particulates**,
 - **COD** (chemical oxygen demand) deriving from the presence of compounds captured by the system and in course of degradation ; at the same time also BOD (biological oxygen demand) is increasing,
 - **oils** deriving from lubricant oils used into reaming process.



Water quality	S. time	pH	Susp solids	BOD5	COD	Cd	Cr (tot)	Ni	Pb	Cu	Fe	Oils
Unit of measure		pH units	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
AIRcel 5000-SN 13070003	t ₁	8,3		<5	<10	<0,00 2	0,02	<0,02	0,02	0,02		0,9
	t ₃	8,1	52400		10200		0,3	0,19			45	0,8
AIRcel 5000-SN 13070004	t ₁	8,4		<5	<10	<0,00 2	0,02	<0,02	<0,02	0,01		0,2
	t ₃	9,2	39180		9000		1,8	0,9			300	0,9
AIRcel 5000-SN 13070005	t ₁	8,4		<5	<10	<0,00 2	0,02	<0,02	<0,02	0,01		<0,2
	t ₃	7,9	108800		14800		2,5	1,1			1728	1
AIRcel 600-SN 13070007	t ₁	8,3		15	39	<0,00 2	0,02	<0,02	<0,02	0,02		0,3
	t ₃	8,2	32560		13100		3	2,2			468	0,9
AIRcel 600-SN 13070008	t ₁	8,5		<5	23	<0,00 2	0,03	0,02	<0,02	0,02		1
	t ₃	8,9	53760		8200		1,8	0,8			456	1
AIRcel 5000-SN 13070001	t ₁	8,4		12	32	<0,00 2	0,02	<0,02	<0,02	0,01		0,1
	t ₃	8,1	48560		10400		0,6	0,3			99	0,7
AIRcel 5000-SN 13070002	t ₁	8,1		<5	<10	<0,00 2	<0,02	<0,02	<0,02	<0,01		0,2
	t ₃	7,9	39020		12900		4,2	3,1			1050	0,6



Results obtained: process water

- evaluation on the amount of the compounds of interest related to the specific working environment, in particular **heavy metals** and **oils**



Inferences have been made on the **total content of contaminants captured by the system**, calculated on the basis of the concentration detected into the samples.

The **quantified amount of pollutants** have been projected to the **minimum water content** inside the bioreactor (below which they stop, since the activity of capture and digestion is compromised).

Conservative assumption, since the minimum level value corresponds to about 40% of the maximum potential content of water



Results obtained: process water

- Total quantity of main contaminants found in the residual process water at the end of the test period

Contaminant	Chromium (tot)	Nickel	Iron	Oils
Aircel 5000 - SN 13070003	0,0765 g/l	0,0485 g/l	11,4750 g/l	0,2040 g/l
Aircel 5000 - SN 13070004	0,4590 g/l	0,2295 g/l	76,5000 g/l	0,2295 g/l
Aircel 5000 - SN 13070005	0,6375 g/l	0,2805 g/l	440,6400 g/l	0,2550 g/l
Aircel 5000 - SN 13070001	0,1530 g/l	0,0765 g/l	25,2450 g/l	0,1785 g/l
Aircel 5000 - SN 13070002	1,0710 g/l	0,7905 g/l	267,7500 g/l	0,1530 g/l
Aircel 600 - SN 13070007	0,2040 g/l	0,1496 g/l	31,8240 g/l	0,0612 g/l
Aircel 600 - SN 13070008	0,1224 g/l	0,0544 g/l	31,0080 g/l	0,0680 g/l
Content into the whole system	2,7234 g	1,6295 g	884,4420 g	1,1492 g
Avg. daily abatement	0,0227 g	0,0136 g	7,3704 g	0,0096 g



Results obtained: process water

for **metal dust** the air quality monitoring had proved not efficient, due to the low concentration



Confirmed by backward assessment performed on water results of the average pollutants concentration abated

In the perspective of a potential **recovery** of the **iron** possibly present in the residual material, it is possible to assume a quantity between **7 and 17 g per day** of fine and ultra-fine iron dust captured.

- Different treatment technologies available to remove metal ions from water (wastewater in particular)

membrane separation, ion exchange reverse osmosis, solvent extraction, evaporation and precipitation

- The application of a final stage of treatment for process water could involve a **magnetic filtration system** aimed to the removal of **both iron dust** and **possible residual oil** not yet digested by the biomass at the time of the required discharge



Conclusions

- For about four months, an **immobilized cell bioreactors** has been applied in the rifle barrel reaming area of the **Beretta** manufacturing plant of Gardone Valtrompia (Italy) for containment of the **airborne contamination** related to the specific processing involved.
- The removal of these contaminants (i.e. **oil mist** and **metal dust**) is important in order to **decrease the health risk for operators**, given the size of the particles, belonging to the breathable fraction.
- The airborne contamination proved to **comply with the regulations** for health protection and safety in working place already in the baseline.
- A **remarkable reduction** was found in the monitoring of **oil mist**, which is around 40% and in **Volatile Organic Compounds** content (brought below the detection limit of the photoionizator used).
- Contextual verification of **process water** has also highlighted the capture of **airborne oils and metal particles**, thus proving the system to have captured large quantities of airborne iron dust, even if it had not been detectable by sampling systems conventionally used in hygiene labor.



Conclusions

- **Monitoring of process water** quality inside the bioreactors became a **key element** to demonstrate technology effectiveness applied in the specific environment of precision mechanics:
 - a remarkable amount of **metal dust**, especially iron, was detected into the bioreactors at the end of the testing period
 - inferences have been made on a **backward assessment** of **airborne metal dust captured**, on the attempt of supplementing indoor air monitoring, which proved to be insufficient to characterize the specific working environment and, therefore, the effectiveness of the technology applied
 - in the **full-scale** application perspective, the **feasibility of metal dust recovery** from the process water must be addressed as an **opportunity**, rather than an issue and several studies prove its applicability in different contexts.



Outlook of the work

1. Establishing an **equilibrium state** for the bioreactors system, with a **stable containment** of air pollution and **predictable performance**
2. Defining a new state-of-the-art both for the AIRcel system, with a predictable **sizing-related performance** for this industrial sector, and for **indoor air quality standards** into **precision mechanics industry**
3. In relation to the production of firearms and in particular rifles for sport use, the **containment** of airborne contamination by **carcinogens**, such as **walnut wood** for the production of stocks
 - ✓ According to **IARC** (International Agency for Research on Cancer) available data and information are sufficient to relate the processing of **hardwood** with 'increased incidence of tumors in workers paranasal sinuses and, generally, the incidence is higher in the finishing process, where the dust generated is finer'
4. The obtained results suggest the opportunity of an in-depth analysis dedicated to the **possible recovery of metal dust from process water** and **residual material**, both to address the **final disposal issue** correctly and to verify the **feasibility of a recovery chain**, at least for iron.



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Thank you for your kind attention

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