Anwendung von CFD-Analysen für die Risikoabschätzung von Maschinen in ATEX-Umgebungen: von der Identifizierung des Problems bis zur Designoptimierung

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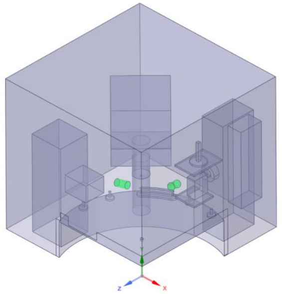

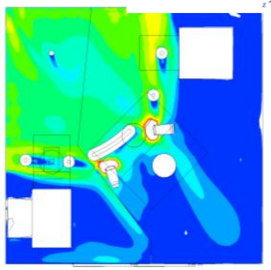

CADFEM CONFERENCE RAPPERSWIL 2024, 20.06.2024

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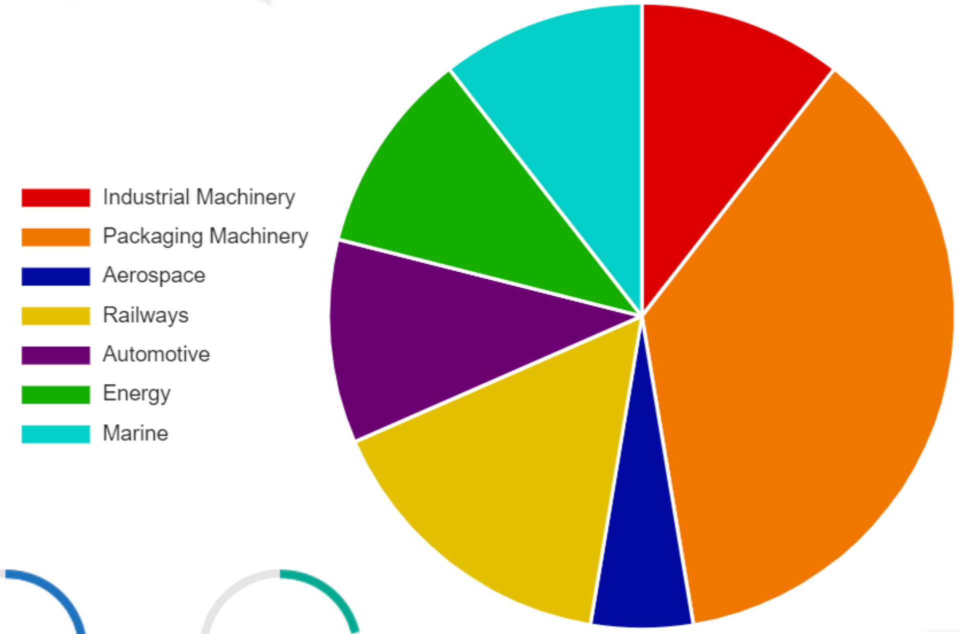

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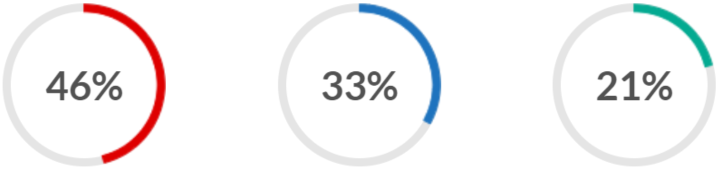

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INTRODUCTION

Analysis and reduction of explosion risk due to the presence of gas and dust, for example:

- Flammable gases such as isopropyl alcohol
- Powder/dust
- …

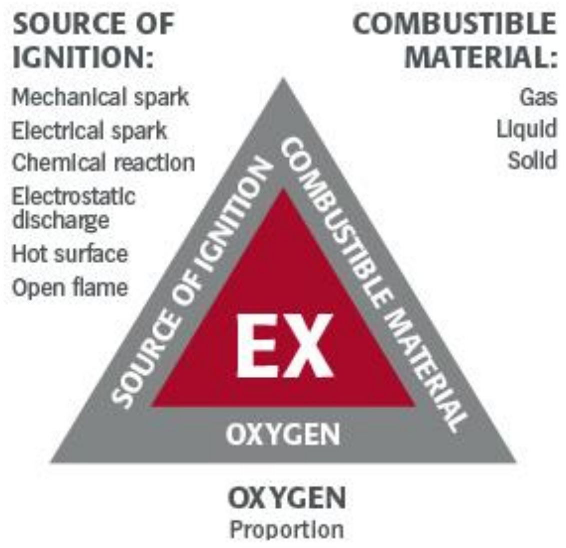
Legal framework:

- The machine must meet the essential health and safety requirements of **Annex I of Directive 2006/42/EC (Machinery Directive)**
- In particular, **requirement 1.5.7**, which sets out the requirements for machines with explosion hazards, must be complied with:

"Machinery must be designed and constructed in such a way as to avoid any risk of explosion posed by the machinery itself or by gases, liquids, dust, vapors or other substances produced or used by the machinery. Machinery must comply, as far as the risk of explosion due to its use in a potentially explosive atmosphere is concerned, with the provisions of the specific Community Directives."

The prevention of explosion hazards, as set out in EN 1127-1:2019 normative, involves a combination of the following measures:

1. avoiding the accumulation of explosive mixtures in or near the machine by avoiding flammable materials and substances or by permanently maintaining their concentration in air at values other than the minimum or maximum exposure limits;
2. avoiding the presence of ignition sources in hazardous areas;
3. reduce the concentration of oxygen in hazardous areas.



Zone classification:

1. Identification of hazardous substances, by analysis of:
   - Processes
   - Safety Datasheets
   - Chemical risk assessment

2. Identification of emission sources present in the machine where hazardous substances are present in significant quantities.

3. Identification of the characteristics of the environments in which hazardous substances are present, such as:
   - maximum statistical temperature
   - atmospheric pressure
   - natural ventilation due to wind thrust, chimney effect, infiltration
   - general artificial ventilation
   - local artificial ventilation
   - ambient decontamination systems

Zone classification:

4. Definition of the emission degree according to EN 60079-10-1:2021 (liquids and gases) and EN 60079-10-2:2016 (dusts).

5. Zone type classification according to EN 60079-10-1:2021 (liquids and gases) and EN 60079-10-2:2016 (dusts).

6. **Selection, study and implementation of risk reduction solutions.**

→ **CFD SIMULATIONS & EXPERIMENTAL VALIDATION**

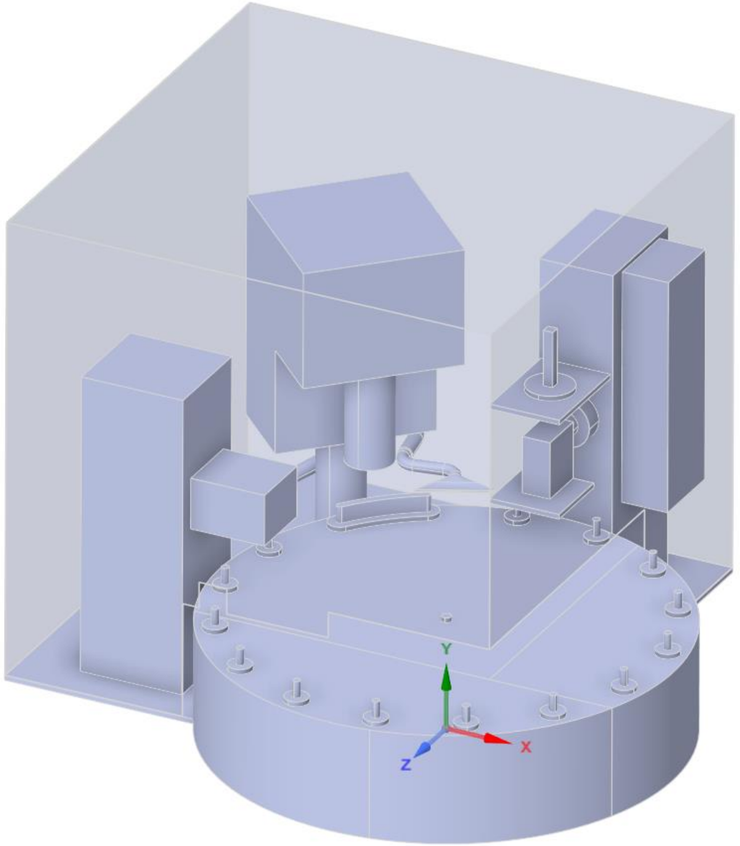
CASE STUDY: VIAL FILLING AND CAPPING MACHINE

1. Identification of hazardous substances

Polvere

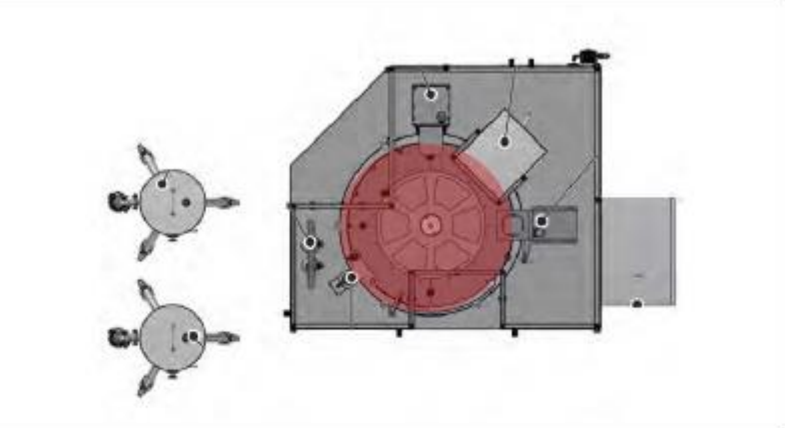
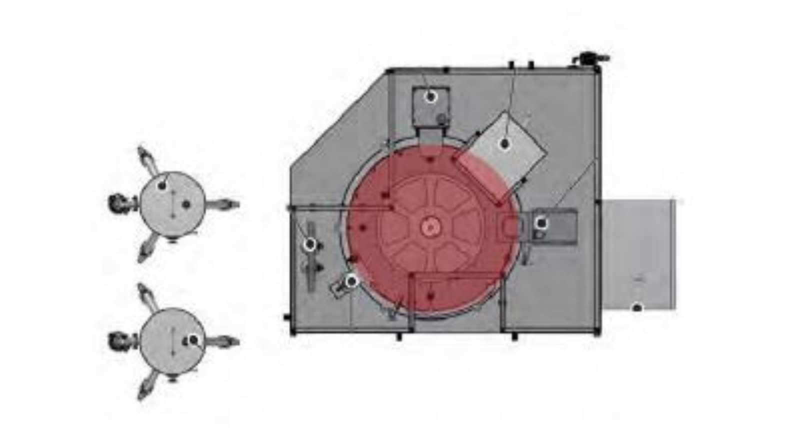
	Nome	Grandezza media particelle [µm]	Umidità della polvere [%]	LEL [g/m³]	Temperatura di accensione della nube [°C]	Temperatura di accensione dello strato di spessore 5 mm [°C]	Conducibilità della polvere	Densità assoluta [kg/m³]
1	Polvere colorante alimentare	-	-	-	-	-	-	600
2	Fecola di patate	65	-	125	490	450	NC	-

Note: potato starch was considered having similar physical characteristics, as there is no specific literature data for the food colouring powder.

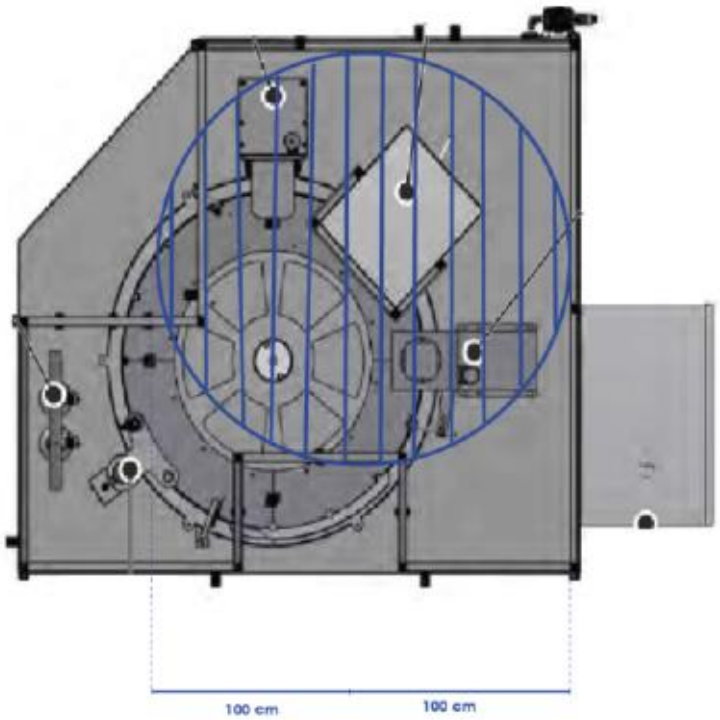


FOOD COLOURING POWDER

2. Identification of emission sources present in the machine where hazardous substances are present in significant quantities

SE1P GIOSTRA-RIEMPIMENTO	
SE2P GIOSTRA-RIEMPIMENTO (GUASTO)	

Estensione della zona



3. Identification of the characteristics of the environments in which hazardous substances are present

Caratteristiche dell'emissione:

Polvere infiammabile:	Polvere colorante alimentare
Grandezza media delle particelle	≈65 µm
Limite inferiore di esplodibilità (LEL):	125 g/m³=0,125 kg/m³
Densità assoluta della polvere:	≈500 kg/m³
Sorgente dell'emissione:	Rilascio puntuale polvere infiammabile
Grado di emissione:	Primo
Portata di emissione Q_d:	1.98*10⁻⁶ kg/s

Caratteristiche del luogo:

Situazione al chiuso	Ventilazione artificiale generale (VAG)
Pressione ambiente P_a	101325 Pa
Temperatura ambiente T_a	293 K
Velocità dell'aria di ventilazione w (come nota velocità del vento)	0.05 m/s
Grado della captazione e asportazione della polvere	Alta
Disponibilità della captazione e asportazione della polvere	Scarsa

Grado della emissione	Grado della captazione e asportazione della polvere						
	Alto			Medio			Basso (2)
	Disponibilità della captazione e asportazione della polvere						
	Buona	Adeguata	Scarsa	Buona	Adeguata	Scarsa	Buona, Adeguata o Scarsa
Continuo	(Zona 20 NE) Zona non pericolosa (1)	(Zona 20 NE) Zona 22 (1) (3)	(Zona 20 NE) Zona 21 (1) (4)	Zona 20	Zona 20 + Zona 22 (3)	Zona 20 + Zona 21 (4)	Non considerato
Primo	(Zona 21 NE) Zona non pericolosa (1)	(Zona 21 NE) Zona 22 (1) (3)	(Zona 21 NE) Zona 22 (1) (4)	Zona 21	Zona 21 + Zona 22 (3)	Zona 21 + Zona 22 (4)	Non considerato
Secondo	(Zona 22 NE) Zona non pericolosa (1)	(Zona 22 NE) Zona non pericolosa (1) (3)	Zona 22 (4)	Zona 22	Zona 22 (3)	Zona 22 (4)	Non considerato

Example SE1:

- **Hazardous substance: food colouring powder**
- **Non continuous emission**
- **Poor natural ventilation**

→

4. Definition of the emission degree
5. Zone type classification

6. Selection, study and implementation of risk reduction solutions

a. Monitoring at start-up interlocked with the SRP/CS control circuit of the machine based on the two conditions:
   - Optimization of the existing ventilation system;
   - Switching on of the ventilation system.

b. Adaptation of Ex-certified components in the hazardous zone. All components (electrical and non-electrical) must be equipped with Ex string belonging to a defined category of protection level.

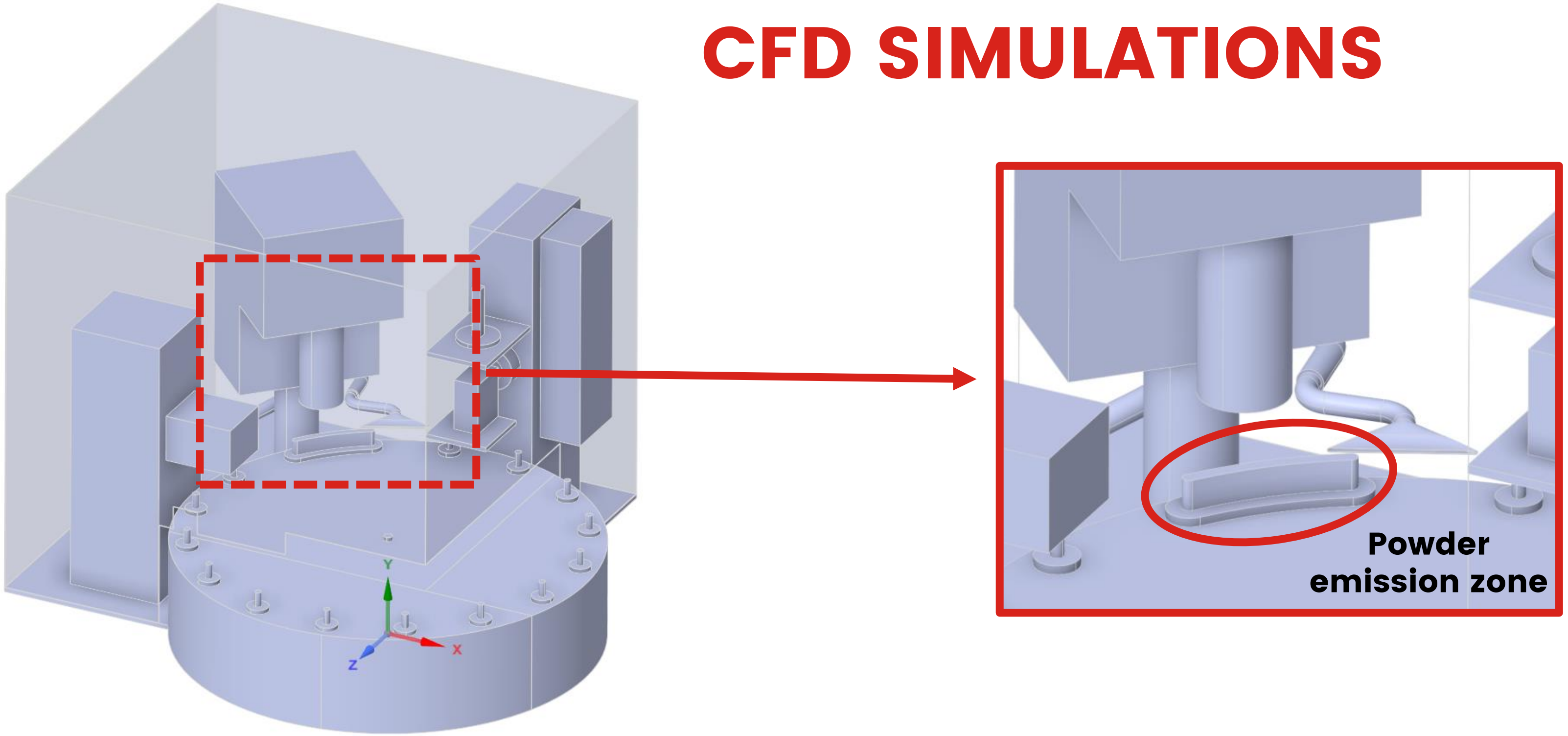
Solution a would ensure that the area would be reclassified as a **NON-DANGEROUS ZONE**, while **solution b** would imply that in the classified areas, the use of suitable components would render the **present ignition sources ineffective**.

Chosen solution a:
THE VENTILATION SYSTEM MUST BE EFFICIENT AND EFFECTIVE! => CFD SIMULATIONS

Design and optimization of the ventilation system

- **Analysis of the existing ventilation system:** performance and air distribution
- **Optimize ventilation system** to ensure hazardous powder concentration reduction
- **Ventilation system should not interfere with the vial filling process**
- Avoid hazardous powder losses to the external ambient → **avoid contamination**

CFD SIMULATIONS

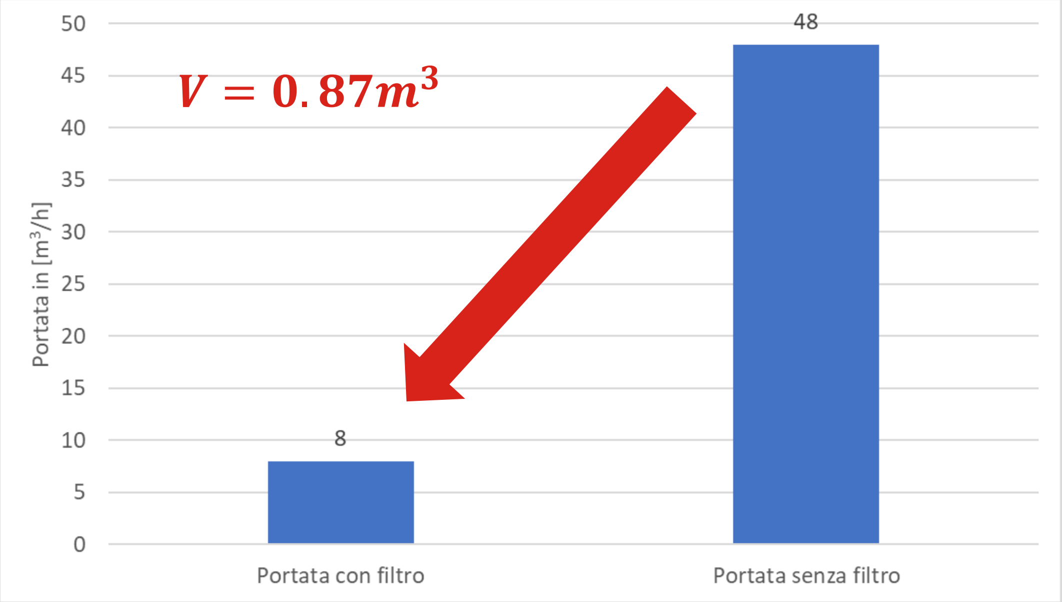


Design and optimization of the ventilation system

Experimental measurements on the existing ventilation system for CFD input:

- With dust filter $\Rightarrow 8\ \frac{m^3}{h} \Rightarrow 9$ ACH $\left(\text{Air Change per Hour } = \frac{\text{Flow rate}}{\text{Volume}}\right)$
- Without dust filter $\Rightarrow 48\ \frac{m^3}{h} \Rightarrow 50$ ACH

→ 83% performance reduction with filter!

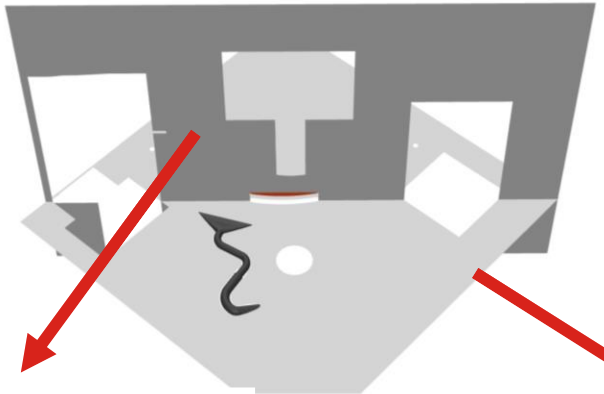


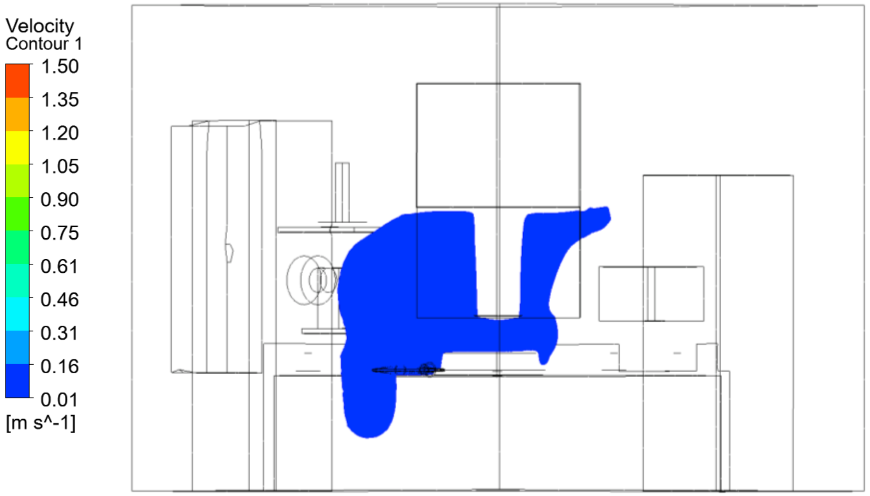
TSI 9565-P hot wire anemometer	Testo 410i vane anemometer
	

Design and optimization of the ventilation system

CFD SIMULATIONS EXISTING VENTILATION SYSTEM

With filter: $8\ \frac{m^3}{h} \Rightarrow 9\ ACH$

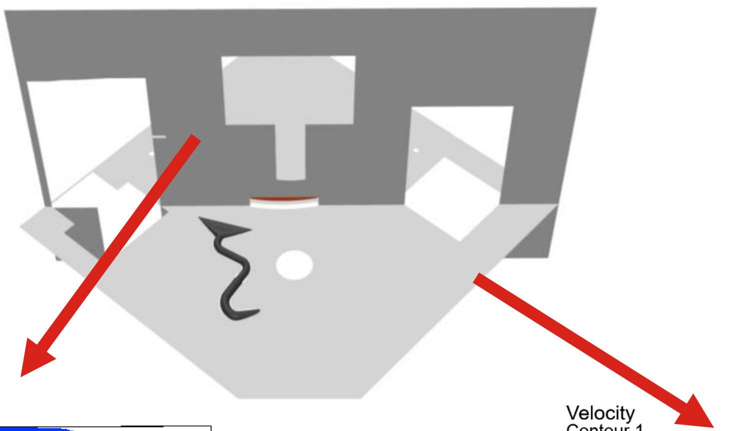


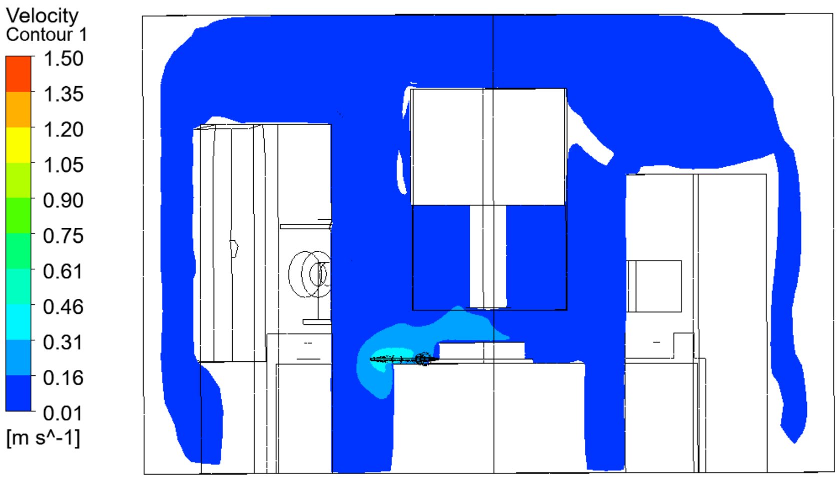


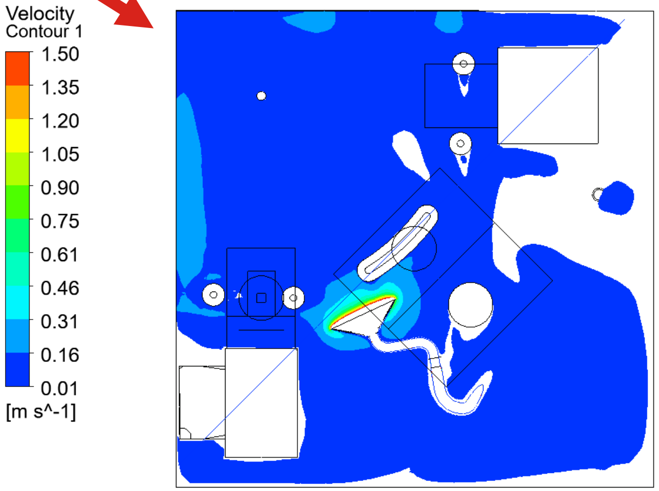
Design and optimization of the ventilation system

CFD SIMULATIONS EXISTING VENTILATION SYSTEM

With filter: $48 \frac{m^3}{h} \Rightarrow 50$ ACH

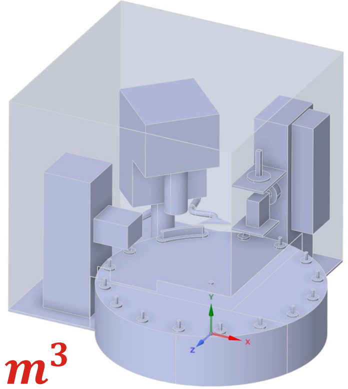






Design and optimization of the ventilation system

Ventilation system optimization: minimum flow rate estimation



$$\frac{dQ}{dt} = P - r(t) = P - r \cdot \frac{Q(t)}{V}$$

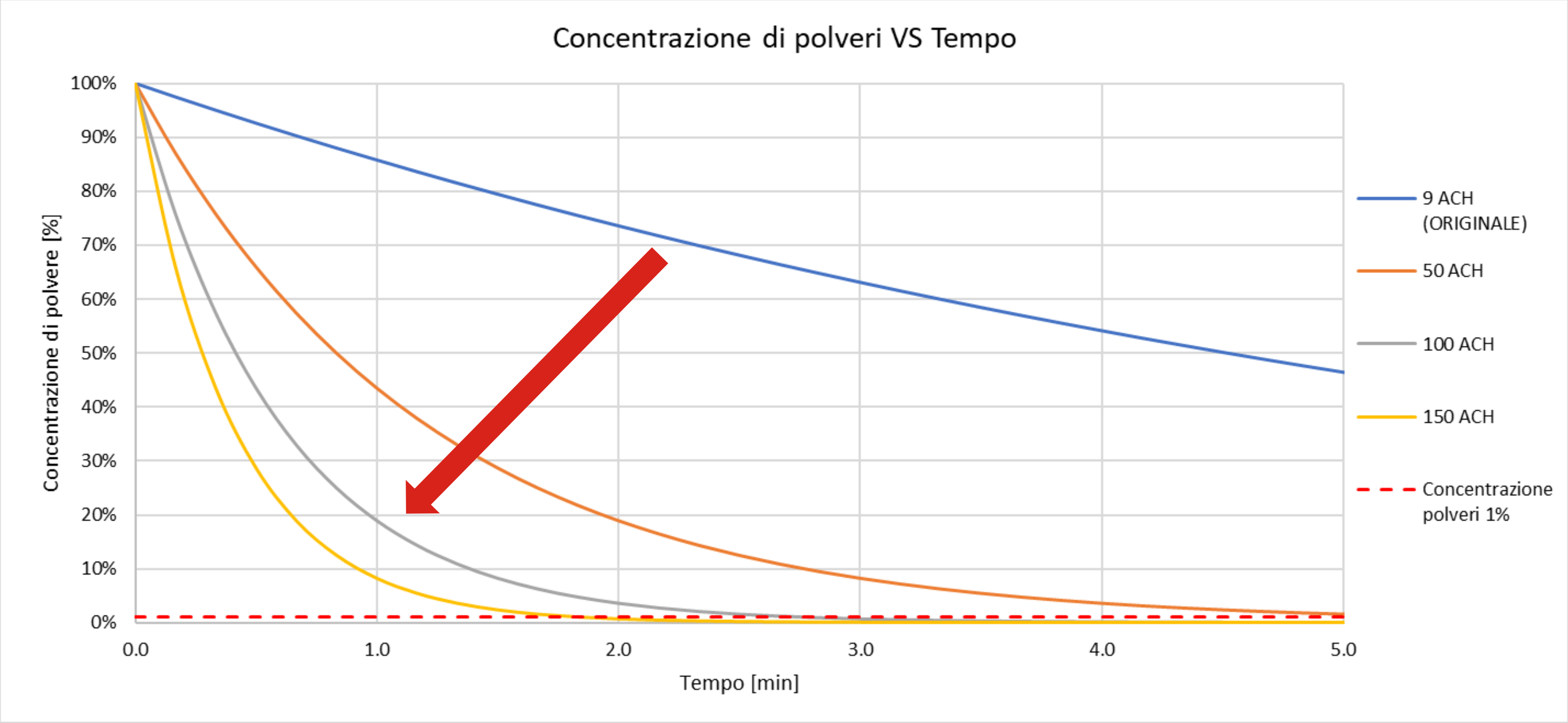
$$Q(t) = P \cdot \frac{V}{r} \cdot (c0 \cdot V - P) \cdot e^{\frac{-r \cdot t}{V}}$$

$$C(t) = \frac{Q(t)}{V}$$

Air flow rate [m³/h]	ACH [-]
8 (original)	9
43 (~original without filter)	50
87	100
130	150

Exponential decay model (ideal)

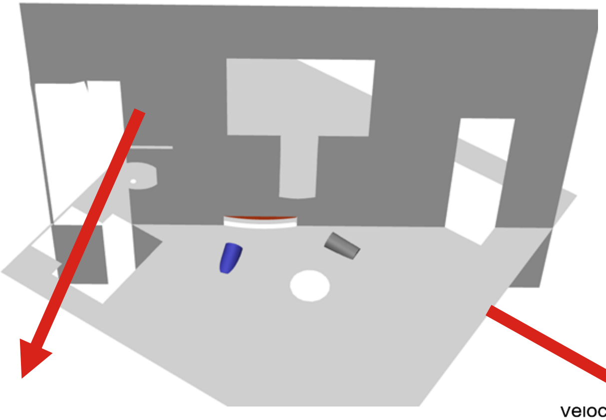
$V = 0.87\ m^3$

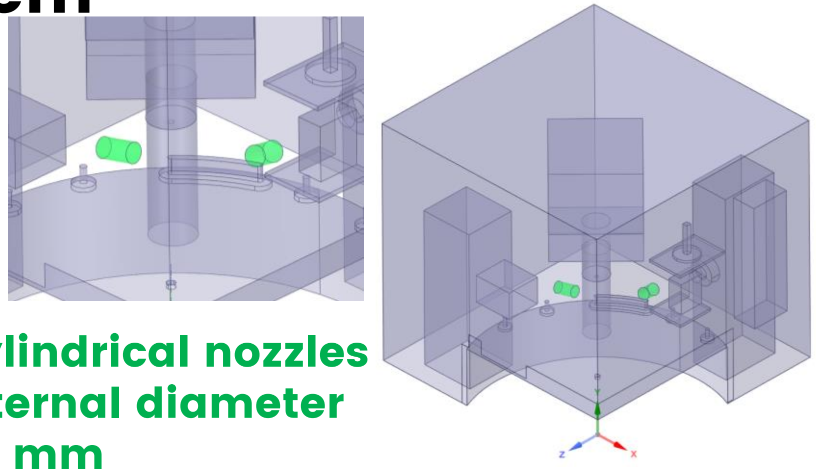


Design and optimization of the ventilation system

CFD SIMULATIONS OPTIMIZED SYSTEM

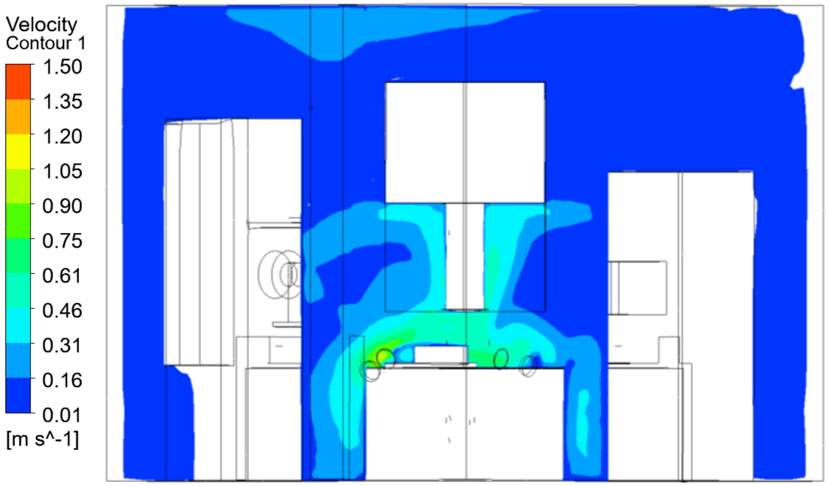
$$140\ \frac{m^3}{h} \Rightarrow 160\ \text{ACH}$$

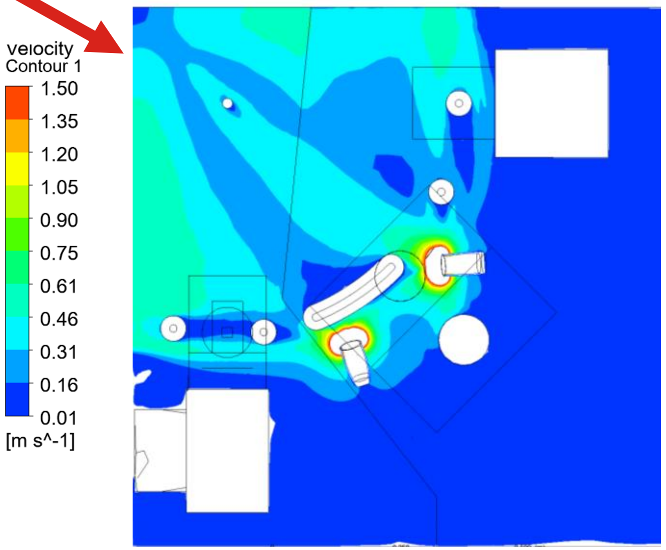




Cylindrical nozzles internal diameter 40 mm

$$V = 0.87\ m^3$$





CONCLUSIONS

From the problem identification to the design optimization in ATEX environments:

- Systematic methodology to identify the hazards and classify them;
- Identification of solutions to minimize the explosion risk:
  - Cost-optimized solutions for the customer
  - Minimize interference with the production process of a specific machine
  - Possibility to propose several action variants
- **CFD Simulations + Experimental measurements to allow identification of optimal solutions and simplify design processes**
- Final choice and implementation of the risk reduction actions in a reasonable time-frame.

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