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A structured approach to support the definition of confined space entry and working procedures in the wine industry

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Abstract

The wine-production process involves several phases, during which the grape arriving at the winery in agricultural trailers becomes bottled wine. Equipment and machinery for wine production include hoppers with screws, stalk removers, and pumps. The products of the wine-production process are stored in different wine containers, e.g. wine tanks, autoclaves, and fermenting vats, depending on the production stage. The winery personnel are required to periodically access such confined spaces to perform ordinary and non-ordinary work activities, as cleaning, inspection, and maintenance. Particularly attention must be dedicated to define an efficient set of rescue procedures in case of emergency.

This paper provides a structured approach promoting safe work in confined spaces in the wine industry. The aim is to provide an effective methodology supporting employers and safety professionals dealing with work in confined spaces, in defining a proper procedure for their specific operational context, i.e. the confined space in which the winery personnel is required to access.

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Keywords: Wine-production; Confined space; work procedure; Confined space work.

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1. Introduction

Many workplaces comprehend spaces that are confined because of the restricted dimensions and the limited openings of entry or exit. Confinement may pose multiple hazards that are related to different characteristics of the confined space: the geometric features, the access, the internal configuration, and the atmosphere (Botti et al., 2017). Entrapment hazards are due to the geometric features and the internal configuration of the space. Such characteristics determine the proximity of the workers to hazard sources, such as moving parts of machinery or energy sources not correctly de-energized and made safe with a Lock-Out / Tag-Out procedure. Limited access and restricted airflow are additional characteristics of confined spaces that can result in hazardous conditions (Lv et al., 2021; Pritchard et al., 1996). The American Occupational Safety and Health Administration (OSHA) defines a confined space as a space that is large enough for an employee to enter fully and perform assigned work, is not designed for continuous occupancy by the employee, and as a limited or restricted means of entry or exit (OSHA, 1993). These features may lead to hazardous conditions that are not normally present in an open workplace. The main cause of fatal accidents occurred in confined spaces in Italy is asphyxiation, followed by drowning and engulfment (Botti et al., 2016). Italian data partially confirm the statistics published by the American National Institute for Occupational Safety and Health (NIOSH), which identified the main causes of accidents in confined spaces as asphyxiation, poisoning, and engulfment (NIOSH FACE Reports: Confined Space, 2020). High accident and fatality rates confirm the lack of situation awareness about the risks of work in confined spaces (Botti et al., 2022). A recent study investigated the contributory factors of confined space accidents (Naghavi et al., 2019). The results revealed that 77% of causal factors for accidents in confined spaces are due to inadequate organizational and supervisory levels, with the predominant influence of the organizational process. Hence, organizational and supervisory-level interventions are necessary to control and prevent further accidents due to working in a confined space. Also, it appears that inadequate safety culture, organizational process vulnerability, inadequate supervision, supervisory violations, decision errors, and operational violations are frequent causes of the accidents in confined spaces (Xia et al., 2021). Wine-production plants include confined spaces, e.g. wine tanks, autoclaves and fermenting tanks, in which workers access for ordinary work activities, e.g. cleaning, inspection and maintenance, and non-ordinary interventions, e.g. periodic verifications and internal surfaces restoration activities. Confined space accidents in wine-production plants lead to serious injuries, which frequently turn into fatalities. These accidents are mainly due to work activities, e.g. inspections and cleaning operations, performed in autoclaves, wine tanks, or close to other containers used for grape fermentation (MacCarron, 2006; Stabile et al., 2017; Youakim, 2006). Previous research on confined space fatalities and guidelines to managing risks in the wine industry remarked the need for developing and implementing work procedures for safe entry and execution of works in confined spaces (MacCarron, 2006; Safe Work Australia, 2018; SafeWork NSW, 2016; Stabile et al., 2017) Such procedures should include training requirements and information on the proper equipment for air monitoring and personnel rescue.

This research takes into consideration the result of an investigation on the working methods adopted for work in confined spaces, by the wineries situated in the north-Italian province of Pavia (De Paschale et al., 2015). The aim is to help employers, safety representatives, and winery workers to identify and to apply effective risk control measures, and to prevent unsafe behaviors that may lead to confined space injuries and fatalities. The methodology in this paper supports the design of procedures for work in confined space in the wine industry, addressing the definition of confined space entry and working procedures in wine-production plants. The proposed methodology is the result of an investigation on procedures and instructions for work in confined spaces adopted by the emergency and rescue (ER) teams, the fire brigades, and the wineries situated in the north-Italian city of Pavia. The developed approach does not replace the mandatory risk assessment required by the Italian regulations on occupational health and safety, nor it provides an exhaustive list of replicable operations that applies to any wine-production process.

2. The wine-production process

2.1. Process description

The wine-production process involves several phases, during which the grape arriving at the winery in agricultural trailers becomes bottled wine. The transformation of grape into wine is operated by different types of yeast. *Saccharomyces cerevisiae* is the most important yeast species involved in wine fermentation. The presence of oxygen in the wort allows the yeast aerobic respiration. During this phase, yeast cells use oxygen and sugar, i.e., glucose, to produce the energy required for cell multiplication. Alcoholic fermentation, i.e., the anaerobic respiration, starts as the cell oxygen consumption increases. The result of this phase is the production of energy that cells use for vital functions. Ethanol and carbon dioxide (CO_2) are the refuses of the process.

The wine-production process varies depending on the wine typology (Freire et al., 2020). No grape marcs are present during the fermentation of the white wine wort. The fermentation of dry white wines continues until sugars are finished. After this phase, the decantation ensures the elimination of potential marc residuals. In the case of sweet white wines, the formation is interrupted before the sugars are finished. The fermentation of red wine is characterized by the maceration of the marcs. The dissolving action of alcohol and temperature allows the transfer of the colored pigments and the tannic substances contained in the grape skin to the wort. The final product will contain such substances after the separation of the solid part from the liquid part (racking). The contact with the marcs is limited to a short time to produce rose wine. Then, the clarification ensures the elimination of the marcs residuals. The young wine is produced from carbonic maceration or aromatic fermentation. In this case, the fermentation of the grape, in the form of berries or whole grapes, starts inside the vat. Specifically, the atmosphere inside the vat is saturated with carbon dioxide, which is the product of juice fermentation. Destemming is not present in the production process of muscat wine. Figure 2 describes the phases for the production processes of red wine and white wine. Both the processes start with the grape harvest. After the harvest, the grape is transferred to the winery for weighing and sampling. The sugar content of the grape is responsible for the alcoholic content of future wine. The grape is then transferred inside a hopper. The screw on the bottom of the hopper pushes the grape to the next step of the process. First pressing and destemming phases are operated with different modalities, depending on the desired wine. These two phases are performed simultaneously in the production process of red wine, using centrifugal helicoidal de-stemmer and crusher machine. The heavy red-wine wort descends to the bottom, while the marcs on the surface are expelled through a lateral hole. Soft pressing characterizes the production process of white wine. First-pressing is operated using pneumatic presses. Next, marcs are separated and transferred to the distillation process. The product remaining after marcs separation of the free-run wort, which is approximately 70% of the grape initial weight. White wine is then stored until the suspended impurities settle on the bottom and the wine becomes clearer. This phase, which can be either natural or forced by additional substances, is known as clarification/decantation. Wine must be transferred through pumps in special reservoirs for fermentation, i.e. the fermentation tanks. In this phase, yeasts transform the sugars (fructose and glucose) into alcohol.

Additional yeasts may be added in the case of sparkling wine, aiming to enhance the fermentation process. The carbon dioxide gas released by yeast metabolism pushes the grape marcs upward. Such solid substances are resubmerged and mixed, aiming to optimize the fermentation. This operation is performed either manually or using a mechanical mixer. The addition of sulfur dioxide (SO_2) or potassium metabisulphite characterizes the sulphation phase. Wineries use various means to achieve a purging, flushing, or blanketing operation. Typically, Nitrogen or Argon gases are used to form a layer or blanket on the top of the wine surface. Nitrogen gas is also flushed into those tanks from which the air must be removed to became inert volumes (no oxygen). Other common procedures require to displace the wine from one tank to another. The wort liquid component is transferred through a pump to further fermentation tanks. The solid component, i.e., the marcs, remains on the bottom of the vat. Marcs are transferred to a hopper with a screw, where a pump conveys the solid substances to a pressing machine for the extraction of the residual liquid component (about 10% of the grape initial weight). The residual substances are transferred to the distillery. Wooden barrels are preferred for second fermentation, refinement, and aging. Steel vats, concrete tanks, and fiberglass containers are adopted for tumultuous fermentation, i.e. such containers prevent the slow oxidation and the esterification process. After refinement and aging, the wine is bottled in the bottling line and packed for shipping. Equipment, machinery, and production areas are periodically cleaned and sanitized with chemicals and cleaning agents (Englezos et al., 2019; García-Alcaraz et al., 2020). A caustic soda solution is used for vat cleaning. Specifically, the solution is introduced inside the vat through the bottom manhole and rinsed from the top. The residuals of cleaning operations are collected using pumps and flexible pipes. Manual operations inside the vat may be necessary for removing the remaining residuals.

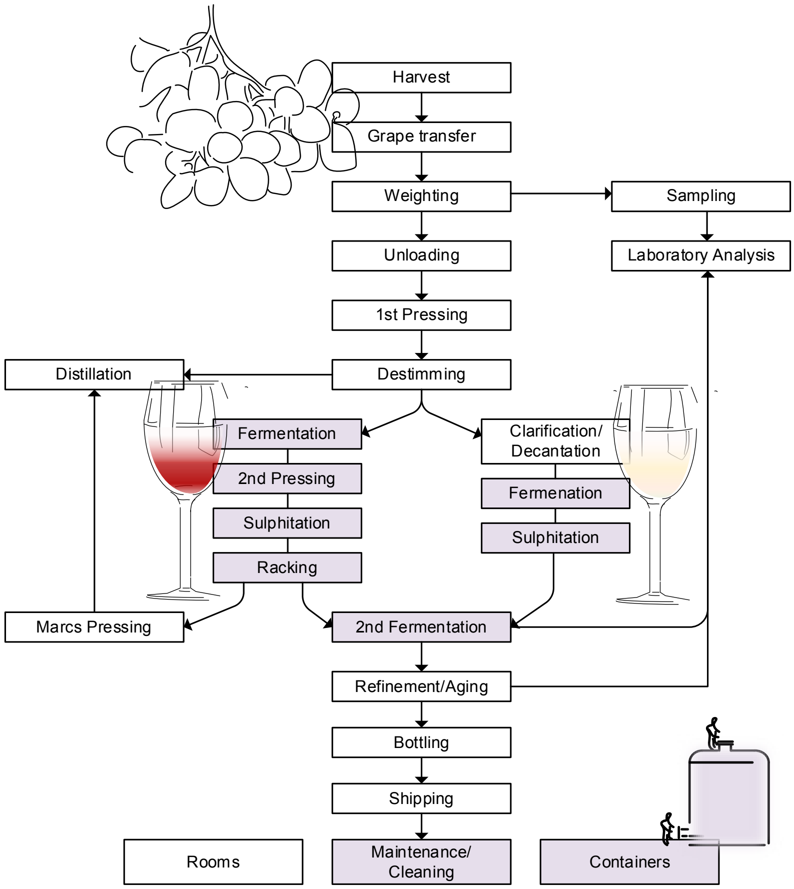

Fig. 1. The wine-production process. Phases that require the access of workers in confined spaces are in light blue.

2.2. Confined spaces in the wine production process

Confined spaces are present in multiple phases of the wine production process. Blue cells in Figure 1 identify phases in which workers access to confined spaces. Typical interventions are cleaning and inspection operations in fermentation tanks, vats, autoclaves, tanks, or machinery, as de-stemmer and crusher machines. These operations require the workers to access inside confined spaces, in which the stored substances or the residuals of cleaning agents may have generated a hazardous atmosphere. Table 1 shows the risks that characterize each phase of the wine production process. Many wine production phases may require interventions in confined spaces.

Fermentation, second pressing, sulphation, racking, second fermentation, and maintenance of wine containers may require interventions in confined spaces. The risks factors due to confined space work in such phases are asphyxiation, exposition to CO_2, exposition to SO_2, and exposition to alcohol. Professional equipment is required to identify the presence of gases that are typically adopted in the wine-production process, like CO_2, nitrogen, and argon (De Paschale et al., 2015).

Table 1. Risks in the phases of the wine production process. Phases involving work in confined spaces and the related risks are in bold.

		Investment	Manual material handling	Cutting	Slipping	Falling from height	Falling of objects from height	Contact with moving parts	Burns	Tripping	Dust	**Asphyxiation**	**Exposition to CO_2**	**Exposition to SO_2**	**Exposition to alcohol**	Noise
Harvest		X	X	X	X	X	X									
Grape Transfer		X	X		X	X										X
Weighing							X	X								
Sampling and analysis								X								
Unloading		X	X					X		X						X
First pressing								X		X						X
Destemming				X		X	X	X		X						X
Clarification/decantation						X										
Fermentation					X	X	X		X				**X**		**X**	
Second pressing						X				X			**X**		**X**	
Sulphation						X						**X**	**X**	**X**	**X**	
Racking				X		X		X				**X**	**X**	**X**	**X**	
Marcs pressing				X		X		X				X				
Second fermentation						X	X	X					**X**		**X**	
Refinement/Ageing			X	X		X		X			X					
Bottling		X						X								
Shipping		X	X	X			X	X								
Maintenance	Rooms		X	X	X					X	X					
	Containers		X	X						X		**X**	**X**	**X**	**X**	

2.3. Gas measurements

The Province of Pavia, in Northern Italy, is well-known for its wine industry, which is one of the main pillars of the local economy. The exposition to asphyxiating gases in the wineries has been registered as the cause of multiple serious injuries in this area. This phenomenon lead the local authority, in collaboration with the wineries from the territory of Pavia, to investigate technical and procedural solutions for the prevention of such events. A set of gas measurements was performed between September and November 2014. The aim was to identify the concentration of gaseous chemical agents in the winery areas. Measurements were performed inside and in proximity to confined spaces, e.g. in proximity to vats and concrete tanks during racking, indoor storage tanks and fermentation vats during tumultuous fermentation. A telescopic probe, an external pump, and a multi-gas analyzer were adopted for gas measurements.

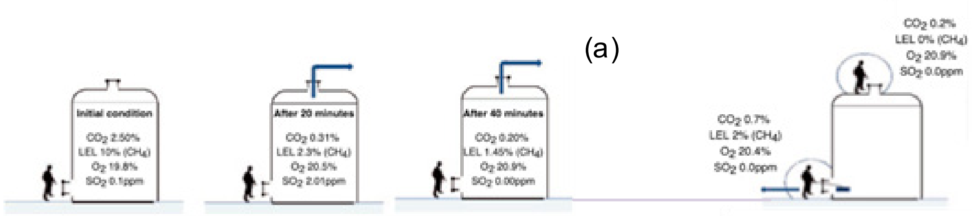

Fig. 2. (a): Gas measurements inside the fiberglass tank; (b): Gas measurements in proximity to the fiberglass tank before cleaning operations.

Figure 2a and Figure 2b show the gas measurements performed inside and in proximity to a fiberglass tank used for fermentation. The tank was emptied eight days before the measurements. Two manholes of 500 mm in diameter are present at the top and the bottom of the vat. A suction hose was positioned inside the tank. Forced ventilation was performed by connecting the suction hose to a ventilator. Three measurements were registered at the beginning of the experiment, after 20 minutes of forced ventilation and after 40 minutes. Results show a reduction of CO_2, SO_2, e CH4 contents inside the tank and an increment in the O_2 content. Ventilation was interrupted allowing cleaning operations with water from outside the tank. Gas measurements were performed before and after cleaning operations. Results reveal a reduction of CO_2, SO_2, e CH_4 contents inside the tank and an increment in the O_2 content (Figure 3a).

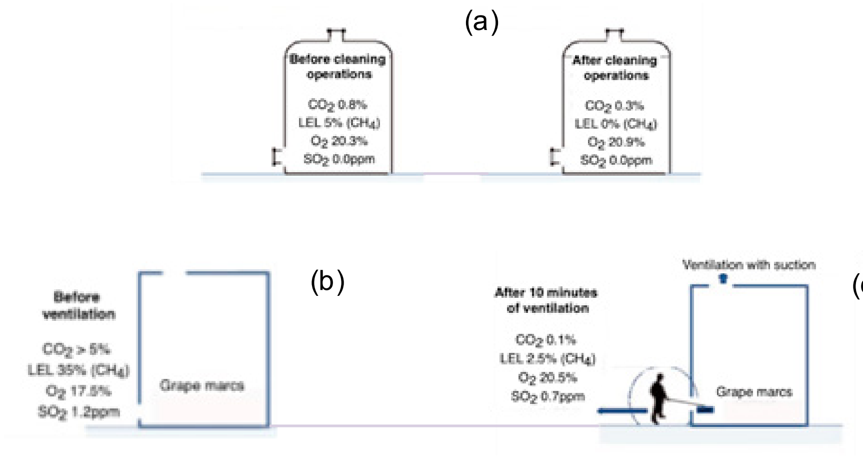

Fig. 3. (a): Gas measurements before and after cleaning operations; (b): Gas measurements inside the fermentation vat before ventilation; (c): Gas measurements in proximity to the bottom manhole after ten minutes of forced ventilation.

Figure 3b and Figure 3c show the gas measurements performed inside an empty fermentation vat before manual cleaning. Two manholes of 500 mm in diameter are present at the top and the bottom of the vat. Measurements in Figure 3b refer to the gas content before ventilation. Then, natural ventilation was followed by forced ventilation, with an axial fan positioned in proximity to the top manhole. Figure 3c shows the results of the gas measurements in proximity to the bottom manhole after ten minutes of forced ventilation.

A further experiment was conducted aiming to investigate the carbon dioxide capacity to saturate a space with no ventilation. The doors of a room containing eight fermentation vats were locked for 20 consecutive hours during tumultuous fermentation. An axial fan was present in the upper part of the room. Gas measurements revealed CO_2 stratifications in the room. Specifically, CO_2 saturated the lower air layer, despite the presence of the fan, i.e. the position of the fan did not allow proper ventilation in the lower part of the room. Then, doors were opened and natural ventilation was restored. Carbon dioxide content reduced from 5% (50,000 ppm) to 1% (10,000 ppm).

3. Procedure for the execution of interventions in confined spaces

A work procedure is a tool defining the proper behavior that workers should adopt during work, aiming to avoid errors and omissions. The procedure tackles some of the safety issues addressed in the risk assessment performed by the company, providing an accurate description of each work phase, the aim of the intervention, the necessary equipment, and the preventive and protective measures defined in the risk assessment. Each worker receives proper information and training about the company work procedures, which include: the author, the person responsible for the adoption of the procedure in the organization, the target workers, the description of the operating modes for the target work phases, proper and improper actions, and the date on which the procedure enters into force. The following Table 2 shows the sequence of operations that should be included in the procedure for confined space work. The procedure in Table 2 applies to generic interventions in confined spaces. However, safety managers and safety professionals should fit the proposed procedure to the specific characteristics of their confined spaces.

Typical interventions in confined spaces in the wine industry are maintenance and cleaning of vats, tanks, autoclaves, or inspections after during the second pressing and the sulphitation. Workers are required to operate in an atmosphere that could be saturated with multiple gases, e.g., CO_2, SO_2, N_2. Such gases may be the natural products of wine fermentation or additional substances adopted for improving the wine properties and to facilitate the wine transfer. Fermentation vats are situated in fermentation rooms. Proper natural or mechanical ventilation are required before accessing to these rooms, ensuring continuous O_2 measurement. Vats manholes should be opened before to access and, in case of insufficient natural ventilation, a fan with adequate air flow could be adopted to ensure complete replacement of internal atmosphere. Cleaning operations with nebulized water may enhance this operation. During the intervention, O_2 content inside the confined space should be close to the levels in the atmosphere (about 21%). A portable gas detector with acoustical and optical signaling must be worn by workers and placed in proximity to worker's airway. The Attendant (the employee who remains outside the confined space in proximity to the manhole) must maintain the communication with the worker inside the confined space, guards the space against unauthorized entry, warns the entrants of any unusual conditions and call ER Team if needed.

3.1. Non-ordinary interventions in confined spaces in the wine industry

Non-ordinary interventions in confined spaces are periodic verifications and inspections operated by qualified personnel or institutions, e.g., the local health authority. Wine production equipment and plants that require periodic verifications and testing include fermentation autoclaves, water storage autoclave, bottling machinery, cooling and heating systems, vapor generators. The Italian legislation on occupational health and safety (Italian Ministry of Labor and Social Policies, 2008) specifies the reference standards for pressurized equipment and periodic verifications (Parliament of the Italian Republic, 2000). The Italian legislation on safety and health at work (Italian Ministry of Labor and Social Policies, 2008) and the Decree 329/2004 of the Italian Ministry of Production Activities (Italian Ministry of Production Activities, 2004) define the scheduling for each type of verification. Specifically, verifications of pressurized equipment for wine production should be performed every three years, and the frequency of internal inspections of vapor generators should be once per two years. Integrity verifications of pressurized equipment are performed every ten years. Other periodic verifications should be scheduled according to the manufacturer's manual. Some periodic verifications require the access of the worker inside the confined space, e.g., for the inspection of the internal surfaces of fermentation autoclaves, pneumatic presses and vessels with compressed. Two main factors increase the complexity of the intervention: the limited dimensions of manholes (ellipse of 300 x 450 mm for autoclaves and rounded rectangle of 600 x 800 mm for pneumatic presses) and the container main axis (horizontal or vertical). These factors may make it more difficult to perform internal operations and rescue interventions. Hence, training and information are fundamental for both workers and ER teams.

Table 2. Procedure for interventions in confined spaces.

Operations	Description	Examples
1. Initial assessment	Check the equipment that will be adopted during the intervention and of the workplace.	Check the presence of proper personal protective equipment and gas detectors for the workers involved in the cleaning of fermentation vats.
2. Demarcation of the workspace	Identification of the working area in which the intervention will take place. Elimination of any removable obstacle inside or in proximity to the confined space.	Ensure proper allocation and anchorage of flexible pipes. Adoption of signs and pictograms in proximity to the vat, describing the hazards. Installation of barriers preventing the access of unauthorized personnel.
3. Preparation of the work permit	The work permit specifies the details of the intervention, including the personnel involved, the characteristics of the confined space, the necessary equipment, and the measures for ER.	Check the presence of available technologies for avoiding worker access inside the fermentation vat.
4. First meeting	Meeting with the company's safety representative and with the personnel involved in the intervention.	Define the operational procedure for the cleaning operations inside the fermentation vat. Check the suitability of the workers to the work, as instructed by

			the Occupational Physician.
5.	Safety check before entry	Air monitoring, visual inspection, and other checks before the workers access the confined space.	Perform gas measurements at different levels inside the emptied fermentation vat.
6.	Lock-out/tag-out	Isolation of every energy source using locks and danger tags for every worker on every isolation point.	Close the valves that may introduce hazardous substances inside the confined space.
7.	Analysis of the internal atmosphere	Gas measurements inside the confined space with proper equipment and sensors.	Use portable devices for gas measurements, e.g., O_2 and CO_2.
8.	Ventilation	Natural or forced ventilation is operated aiming to ensure a good atmosphere inside the confined space.	Ensure the ventilation of internal rooms containing fermentation vats using floor and wall openings, or through forced ventilation systems.
9.	Access to the confined space	Access of the worker, supervision from the outside, execution of the intervention, continue monitoring of the atmosphere and communication systems.	Continue O_2 measurement with a portable device.
10.	End of the intervention	Conclusion of the work activities inside the confined space and exit.	Exit from the fermentation vat.
11.	Closing meeting	Meeting after the conclusion of the intervention.	Production of the intervention report.
12.	Final check	Check the results of the interventions and restore the plant.	Restore vents and manholes functions.

4. Conclusions

The problem of accidents in confined spaces is a recognized safety issue in many industries, in all the industrialized countries. The study and the analysis of accidents dynamics shows that the lack of awareness about current and potential risks is a leading cause of high fatality rates for work in confined spaces. Multiple confined spaces are present in the wine production process, e.g., fermentation vats, autoclaves and fiberglass containers. The procedure introduced in this paper defines the operations required to employers and employees for the planning and the execution of interventions in confined spaces. The procedure includes twelve steps for ordinary interventions in the confined spaces of the wine industry, e.g., cleaning and inspections of fermentation vats. Employers and safety professionals are invited to adapt the proposed procedure to the characteristics of the confined spaces in their wine production plants and to plan interventions according to it. Non-ordinary interventions, e.g., rescue operations, require specific practices and steps that are not included in the proposed procedure. The Italian legislation on occupational health and safety requires employers to include emergency and rescue (ER) plans in the risk assessment report. ER plans should address each possible scenario and the required ER operations. Hence, specific procedures should be developed, including effective techniques and proper equipment that ensure no additional risks for rescuers and the ventilation of the confined space during the rescue intervention. Intervention time is a critical factor.

Finally, in the main phases of wine production plants are present confined spaces with characteristics that are close the same (inox wine vessels, concrete tanks, big anphora winemaking, ecc.). However, there is not normally specific guideline to design safer confined space in wine production. Also, winemaking production processes are not completely overlapping as they are characteristic according to the wine produced: white, red, rosé, still, sparkling, etc. To obtain fresh and juicy wines, in some Italian areas is applied the carbonic maceration technique. In other areas, is done the sulphitation with SO_2 gas or its salts, refers to its dual properties of anti-oxidation and preservations. Wine is a food and the regulation to which the places of production are subjected are usually oriented towards specific hygienic/sanitary aspects. Occupational safety, on the other hand, is characterized by the general rules on the protection of health and safety of workers in workplaces, based on UE Directive 89/391/CEE (European Agency for Safety and Health at Work, 1989) and often there are safety campaign assessment only after a fatality.

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