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# Safe Management of Pressure Equipment/Assemblies in Biorefineries: Case Study of a Reactor

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In Europe some companies have started to modify part of their processes to allow the production of biofuels from oily biomass (green setup). Considering both the new production processes and the new type of loaded fluid (oily biomass), the user will have to manage the residual risk of the pressure equipment/assemblies (vessels, exchangers, reactors, pipes, etc.). In order to manage such risks, some steps are required:

- Step 1: Nowadays, in EU, all pressure equipment/assemblies must be both designed and built according to PED Directive. PED Directive shall apply to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure, which is greater than 0,5 barg. In particular, it concerns the certification of products and components, the qualification of materials, personnel, and processes.
- Step 2: In addition to design and manufacture, attention must be also paid to aspects related to installation, use and any reasonably foreseeable improper use, identified by the manufacturer in the use and maintenance manuals, considering the complexity and danger in all operating conditions of the plant. Each EU Member State, which is subject to minimum safety and health requirements, regulates commissioning and operation with its own legislation. In Italy commissioning and operation are regulated by Ministerial Decree 329/04, Legislative Decree 81/08 and Ministerial Decree 11/04/2011.
- Step 3: In the event that these establishments are regulated by the Seveso Directive, the operator should have a general obligation to take all necessary measures to prevent major accidents, to mitigate their consequences and to take recovery measures. The operator must identify also the critical elements for safety and environment in order to prevent major accident hazards. In Italy, the Seveso Directive was implemented with Legislative Decree 105/15.

Furthermore, in case of flammable gases/vapours or combustible dusts presence, in accordance with ATEX Directive, the employer is obliged to classify the areas, where potentially explosive atmospheres could occur.
Considering the three steps described above, the authors propose, through a case study, appropriate measures to ensure a put into service of a reactor in an establishment for the production of biofuels from oily biomass.

## 1. Introduction

In order to reduce both the dependence on oil and, at the same time, the levels of greenhouse gas emissions in the transport sector, the European Union, as well as other states including USA, has decided to produce biofuels. In Europe, several companies have begun modifying part of their processes to enable the production of biofuels from oilseed biomass (green setup). Such modifications almost always involve the introduction of new equipment and pressure assemblies (vessels, heat exchangers, reactors, piping, etc.). The regulatory framework in Europe consists of Product Directives (aimed at manufacturers) and Social Directives (aimed at employers, workers, and also citizens, such as the Seveso Directive). With reference to the product directives,

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they govern a wide range of products and associated risks, which can overlap and integrate, resulting in multiple directives potentially being applicable to the same product (e.g., PED, "Pressure Equipment Directive," and ATEX, "Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres"). It is the manufacturer's responsibility to determine whether their product falls within the scope of one or more directives. It is the responsibility of the Employer/Manager to identify which social directives to apply (one or more directives). Only through an organized management of the application of the various directives, it is possible to avoid accidental events involving pressure equipment/assemblies, the impact of which can cause plant and production shutdowns for extended periods, as well as fires, explosions, and releases of hazardous substances into the environment, generating damage to: 1) the safety and health of workers and citizens living near industrial sites; 2) the environment; 3) the production (economic damage).
The objective of this work is to provide a concise but comprehensive overview of the evaluations to be carried out to manage the risks arising from the use of pressure equipment/assemblies, both during the design and construction phases and during the operational phase of such equipment. It will also present how to integrate the potential application of different directives to avoid conflicts and/or confusion among them, referencing the case study of a deoxygenation reactor to be installed “ex novo” in a biorefinery.

## 2. State of the art of the relevant legislation

### 2.1 Design, manufacture and certification of pressure equipment and assemblies: European Product Directive PED (Directive 2014/68/EU)

It is emphasized that almost always, accidental events involving pressure equipment or assemblies begin with a loss of containment of substances (i.e., a release). Depending on how the release occurs, the equipment involved, and the surrounding circumstances, the event may evolve through three main phenomena: fire, explosion, and dispersion of hazardous substances. Therefore, the first prevention measure is to avoid leaks from pressure equipment/assemblies. It is crucial to ensure their integrity, as well as the presence of efficient safety and control devices correctly installed. Furthermore, if hazardous substances escape through openings (e.g., safety valves, rupture discs, etc.) despite all precautions, the exiting flowrate must be properly channeled into designated containment vessels to prevent damage to people, structures, and environment.
In Europe, the pressure equipment/assemblies manufacturers must follow the Product Directive 2014/68/EU (PED), which replaced the old PED Directive 97/23/EC in 2016. These regulations specify the characteristics that pressure equipment or assemblies operating at a pressure above 0.5 barg must possess to be both marked "CE" and introduced into the European market. The manufacturer is the main interlocutor of this directive, responsible for producing safe pressure equipment/assemblies. Additionally, he/she is responsible for both the CE marking and the manufactured products (at the design, construction, and marketing levels). In other words, he/she must comply with all the Essential Safety Requirements (ESR) imposed by the PED Directive. This directive outlines the manufacturer guidelines, starting from the design phase of a pressure equipment/assemblies construction. First, it is necessary to distinguish between Pressure Equipment and Assemblies:

- ‘Pressure equipment’ means vessels, piping, safety accessories and pressure accessories, including, where applicable, elements attached to pressurized parts, such as flanges, nozzles, couplings, supports, lifting lugs;
- ‘Assemblies’ means several pieces of pressure equipment assembled by a manufacturer to constitute an integrated and functional whole.

Generally, the PED applies to piping, safety accessories, pressure containers, and, in general, all vessels subjected to a maximum allowable relative pressure (PS) greater than 0.5 barg. Equipment with a pressure equal to or less than 0.5 barg is excluded from the application of the regulation.
After determining whether the equipment falls within the scope of Directive 2014/68/EU, the next step is to define the PED risk category according to Annex II of PED directive.
The Risk Analysis is carried out considering the relevant PED risk category. It is able to verify and trace compliance with the Essential Safety Requirements (ESR) listed in Annex I of the PED, ensuring fidelity to the Technical File and the preparation of the Operating and Maintenance Manual.
The final step, before entering the community market, concerns the CE marking of the equipment and the possibility of involving a Notified Body (for PED risk Classes from II to IV). The notification number issued by the Notified Body must be displayed on the certificate and the license plate.
In conclusion, a manufacturer can introduce a pressure equipment/assemblies into the European market only after he/she complies with: 1) CE marking by means of a specific license plate on the pressure equipment/assembly; 2) the EU declaration under Directive 2014/68/EU (PED); 3) the preparation of the Operating and Maintenance Instructions. It should be noted that the Technical File underlying these three elements must be retained by the manufacturer. Finally, the three highlighted elements that form the basis for

the market entry of PED equipment/assemblies must be provided or verified (license plate) to the Employer/User.

### 2.2 ATEX certified pressure equipment and assemblies (Directive 2014/34/EU, and Directive 1999/92/EC)

A potentially explosive atmosphere consists of a mixture of air, gas, vapours, mists, or dusts that can ignite under certain operating conditions. Devices and protection systems intended for use in potentially explosive atmospheres find application in multiple sectors such as oil, mining, chemical, and food industries, etc. The ATEX Directive 2014/34/EU (ATmospheres and EXplosives) applies to devices and protection systems intended for use in potentially explosive atmospheres. According to Annex II point 1.3, the following points are relevant: i) potential ignition sources must be avoided; ii) appropriate measures must be taken to prevent electrostatic charges that could cause dangerous discharges; iii) it must be ensured that parasitic or electric currents do not form in the conductive parts of the devices; iv) during the design phase, overheating of devices caused by friction or impacts should be avoided as much as possible; v) pressure compensation processes must be regulated, from the design stage, with integrated measurement, control, or regulation devices to avoid shock or compression waves that may lead to ignitions. Directive 2014/34/EU establishes the technical requirements to be applied and the related conformity assessment procedures before placing equipment on the European market. The procedures for obtaining the CE marking of conformity depend on the device and the level of safety ensured. The Directive highlights the procedures to be followed for the various categories of devices and protection systems intended for use in potentially explosive atmospheres. In this regard, in accordance with Article 7 of the Atex Directive 1999/92/EC, the plant employer/manager is obliged to classify the workplace areas (Atex zones) in which potentially explosive mixtures could be generated. It follows that it must be assessed whether the identified potential sources (flanges, valves, pumps, etc.) of release of gas, flammable vapours or combustible dust are capable of generating a dangerous or non-dangerous area for the purposes of forming a potentially explosive atmosphere. This classification can be carried out by applying the international Technical Standard CEI EN 60079-10-1, which, in case of identification of the Atex zone, also allows its geometric extension (hazardous distance) to be estimated (Lauri, 2018).
In the construction of pressure devices and installations, it is often necessary to consider containers intended to operate in potentially explosive atmospheres, which in turn contain and/or interface with process atmospheres that may transform into potentially explosive atmospheres (even if only for short periods). The ATEX analysis, which the manufacturer is required to perform, must consider the aforementioned aspects for both the external and internal sides of the equipment. In summary, a pressure equipment certified under the PED Directive must also be certified under the ATEX Directive if used in explosive atmospheres and if it presents its own potential ignition sources.
It is the responsibility of the employer/user of the pressure equipment under the ATEX Social Directive 1999/92/EC to inform the manufacturer of the pressure equipment in advance, indicating the type of zone (see Table 1), in order to match the appropriate ATEX category (1, 2 or 3) of the device.
The Manager/Employer must choose the categories of equipment (in the case of pressure equipment) with reference to potentially explosive areas. Table 1, reported in the following, relates the zoning (Directive 1999/92/EC) made by the Manager/Employer with the categories of equipment (Directive 2014/34/EU) made by the manufacturer.

*Table 1. Zoning according to the Directive 1999/92/EC and categories of equipment according to Directive 2014/34/EU.*

| Zones (Gas, vapours), (Dir. 1999/92/CE) | Zones (dusts), (Dir. 1999/92/CE) | Device/Equipment categories (Dir. 2014/34/UE) |
|---|---|---|
| 0 (explosive atmosphere is continuously present or its persistence time is extremely long) | 20 (explosive atmosphere is continuously present or its persistence time is extremely long) | Category 1 (very high safety level) |
| 1(explosive atmosphere presence is probable during the operation) | 21 (explosive atmosphere presence is probable during the operation) | Category 1 or 2 (high safety level) |
| 2 (explosive atmosphere presence is unlikely and, in case of formation, its duration would be extremely short) | 22 (explosive atmosphere presence is unlikely and, in case of formation, its duration would be extremely short) | Category 1 or 2 or 3 (normal safety level) |

### 2.3 Installation and Use of Pressure Equipment/Assemblies (Directive 2009/104/EC)

In the previous paragraph, it was highlighted what the manufacturer of a pressure equipment/assembly must do to correctly place it on the European market. Once the equipment/assembly is brought to the full plant, it begins to become equipment used for a specific process and, therefore, it becomes “work equipment”. According to this, the employer must follow the European Social Directive 2009/104/EC related to the minimum safety and health requirements for the use of work equipment by workers.
In this regard, the employer must fulfil certain obligations:

1. The employer shall take the necessary measures to ensure that the work equipment, made available to workers in the establishment, is suitable for the work to be carried out or appropriately adapted for that purpose, thus ensuring the safety and health of workers when using such work equipment.
2. When choosing the work equipment that he/she plans to use, the employer shall take into account both the specific working conditions (and characteristics) and the risks to the safety and health of workers existing in the establishment, in particular in the workplace, or the risks that could be added due to the use of that work equipment.
3. If it is not possible to ensure fully the safety and health of workers during the use of a work equipment, the employer shall take appropriate measures to reduce the risks to a minimum level.

As highlighted above, pressure equipment/assemblies are work equipment.
Each EU Member State regulates the commissioning and operation of work equipment with its own legislation. In Italy, with regard to pressure equipment/assemblies, the main reference standards are Ministerial Decree 329/04, Legislative Decree 81/08 and Ministerial Decree 11/04/2011.

### 2.4 Pressure Equipment and Assemblies Installed in Plants with Major Accident Hazards (Directive 2012/18/EU)

With regard to pressure equipment/assemblies, in several cases they are installed and used in industrial plants (including biorefineries) with a risk of major accidents. In this case, in addition to what is reported above, the employer/manager of the plant must follow the provisions of European Directive 2012/18/EU (Seveso Directive). A major accident is an event such as an emission, a fire or a large-scale explosion, due to uncontrolled phenomena that occur during the activity of a plant and in which one or more dangerous substances are involved. In this regard, the Employer/Manager must identify, describe, analyze and quantitatively characterize the accident sequences which can generate a major accident and the reasonably foreseeable scenarios that can evolve from it. Each of the scenarios identified must be correlated with either internal or external causes to the plant: operational causes, external causes (e.g. domino effects, etc.), natural causes (e.g. earthquakes, floods, lightning, etc.). In particular, this analysis is preceded by the identification of the critical units of the plant, involved in the accident sequences mentioned above. For example, some critical issues arise from the biofuel production process, and in particular from the transformation of vegetable oil into biodiesel or green diesel (most commonly HVO). The two products appear to be the same, but they have different qualities so that they can be used in specific areas. The difference between the two products is due to the different transformation reactions: methanol is used on a caustic soda catalyst for biodiesel otherwise hydrogen is used on a metal catalyst (e.g. platinum) for HVO. The original composition of vegetable oil allows in both cases the transformation of triglycerides which, when combined with methanol, produce biodiesel and glycerin through a transesterification reaction at moderate pressures and temperatures, while, when combined with hydrogen (hydrodeoxygenation reaction to eliminate oxygen), they produce biopropane, water and carbon dioxide. Biopropane is a straight-chain hydrocarbon (n-paraffins) which solidify at low storage temperatures; therefore, another reaction with hydrogen will be necessary to transform it into a branched hydrocarbon (isoparaffins) as well as diesel fuel. From the authors' operational experience in the field, almost all pressure equipment/assemblies fall within these critical units. In Italy, the Seveso Directive 2012/18/EU was implemented with Legislative Decree 105/15.

## 3. Case study of a reactor in a plant for the production of biofuels from oily biomass

Pressure equipment or assemblies are often present in the biorefineries. In particular, the examined case study has been focused on a deoxygenation reactor aimed at producing biofuels from oily biomass.

### 3.1 Phase 1: under the responsibility of the Manufacturer who must liaise with the User for the operating parameters (PED scope) and the reactor installation area (ATEX scope)

The reactor operating parameters are:

- maximum operating pressure (Ps): 55 bara;
- minimum and maximum operating temperatures Ts equal to, respectively, 0 and 300°C;
- volume (170,000 L), containing an oily biomass fluid (Group 1, dangerous fluid) with liquid/gaseous physical state.

From these data, it results that the pressure equipment is in PED risk category IV. The Employer/Manager identifies as the appropriate manufacturer the person who designs and builds the reactor according to the PED Directive, 2014/68/EU. It should be noted that the conformity assessment procedures to be applied to pressure equipment are determined on the basis of the category established in Article 13 of the PED Directive, in which the equipment is classified. Since it is in PED risk category IV, the manufacturer has to use the conformity assessment procedure based on the verification of the individual equipment: Module G; involving a specific Notified Body in the construction phase. Following this, the reactor is ready to be placed on the European market. For this purpose, the Manufacturer issues the EU declaration of conformity and the use and maintenance manual to the Employer (Muratore et al., 2021). Furthermore, it applies the data plate with the appropriate CE marking to the reactor. Finally, it keeps the Technical File of the reactor.
Another aspect to take into consideration is the ATEX certification of the reactor. In fact, the Employer/Manager during the order phase indicates to the Manufacturer that the reactor must be installed in an area classified as ZONE 2 (Dir. 1999/92/EC). In this hazardous area, the potentially explosive atmosphere presence is unlikely during the normal operation and in case of formation, its duration would be extremely short. Furthermore, with reference to the reactor, the Employer/Manager indicates to the Manufacturer, that the ATEX analysis must be carried out for both the external and internal sides.
Therefore, the reactor must be manufactured in compliance with Category 1 or 2 or 3 of the ATEX Product Directive 2014/34/EU.
In reference to the case study of the reactor (pressure equipment), the manufacturer, after suitable testing, proceeds with the CE ATEX marking (for the internal and external side) in an environment classified as ATEX Zone 2 as follows:

CE Ⓔx II 2G IIC T2 / 3G IIA T3

*Figure 1: Identifying label for a given pressure equipment.*

From Figure 1 it is clear that:

- "II" stands for devices intended and used in environments where explosive atmospheres may occur;
- "2G" or "3G" stands for the category of the device (see Table 1);
- "IIC" and "IIA" stands for the gas group;
- -"T2" and "T3" stands for the temperature class (T2 = 300°C maximum surface temperature, T3 = 200°C).

It should be noted that for the examined reactor, there are no parts that operate in the viscous flow field.

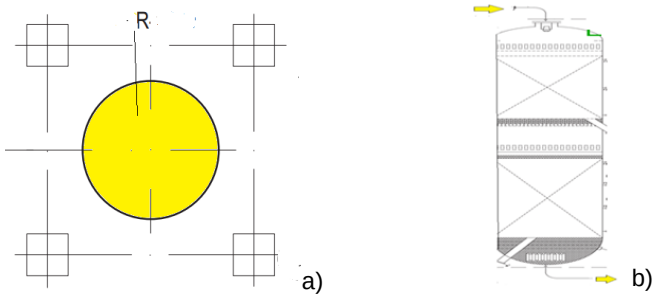


*Figure 2. Reactor view from the: a) top and b) side section.*

### 3.2 Phase 2: under responsibility of the User to manage the residual risks due to the installation, use and reasonably foreseeable improper use, identified by the Manufacturer

Inside the reactor, which consists of two reaction beds, the deoxygenation and decarboxylation of the oil begins through moderately exothermic reactions. The reactor is expected to be used at a Ps = 45 bara and a Ts = 220°C. At this point, the employer/manager has to manage the residual risks due to the installation, use and/or reasonably foreseeable improper use, identified by the Manufacturer in the use and maintenance manual extracted from the Technical File of the equipment and/or in the risk analysis, taking into account the complexity and danger in all operating conditions of the plant. The main residual risks that the Employer/Manager must manage are reported as an example: 1) Provide an adequate fire prevention system to avoid the reduction of mechanical resistance due to fire; 2) Operation must ensure that the Design pressure (Ps) and the maximum Design temperature (Ts) are not exceeded. The user must keep all temperature and pressure control instruments and/or systems in perfect operating conditions; 3) Check the correct installation of the supports

using the reference drawings; 4) The user must guarantee the integrity of the equipment over time by periodically checking the thickness and corrosion in accordance with the provisions of the Use and Maintenance Manual; 5) In the event of modifications to be made to each individual part, the User must make a specific request to the Manufacturer before starting any activity to obtain authorization for the procedures; 6) Thermally insulate the high temperature walls. Report the area with the presence of high temperature parts; 7) Place insulation for personal protection on all surfaces with an operating temperature, which is greater than 65 °C; 8) Classification of the plant areas in relation to the fire risk and equipping them with fixed and mobile fire-fighting equipment that can be used by trained personnel.

### 3.3 Phase 3: under responsibility of the User, concerns the analysis and periodic non-destructive checks to be carried out on the reactor in compliance with the checks required by law

The Manager, as the plant (biorefinery) falls within the field of establishment with risk of major accident (Seveso Directive 2012/18/EU), must identify the critical elements with a specific study. From the operational authors' experience in the field, the examined reactor is a critical equipment for safety and the environment. Its criticality is related to the temperature and aging parameter. Indeed, any reduction in thickness and/or changes in the metallurgical structure and/or growth of defects may affect the pressure members of the critical equipment regardless of the actual response of the material in contact with the processed fluid. In this regard, with reference to the reactor, it is envisaged that the plating, bottoms and nozzles are made of low alloy (1.25 Cr) with welding deposit in AISI 347 stainless steel to have adequate corrosion resistance in relation to the fluid used.
Furthermore, the reactor should be subjected to RBI (Risk Based Inspection) analysis. The results of this analysis and of the periodic non-destructive tests must guide future inspection/maintenance plans of the equipment within the frequencies of the periodic checks required by Italian law (Ministerial Decree 329/2004 and Ministerial Decree 11/04/2011).

## 4. Conclusions

The paper goal was to provide employers/managers of biorefineries with an example of safe management of pressure equipment/assemblies during operation.
The authors, based on their operational experience, provided essential instructions for correct installation starting from the construction of pressure equipment/assemblies in compliance with European Union Directives (PED Directive, ATEX Directive, Work Equipment Directive). Since biorefineries often fall within the scope of the Seveso Directive, the authors provided additional elements that the employer/manager must take into consideration. Finally, the described case study has been examined, also using the relevant Italian legislation.

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