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SAFETY ASSESSMENT FEDERATION

Guidelines

Pressure Systems

The Integrity Management of Process Vessels.
Guidelines for Users and Competent Persons.

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1. Introduction

IMG01 The Mechanical Integrity of Plant Containing Hazardous Substances. A guide to periodic examination and testing was published by SAFed in 2012, and subsequently revised in 2019. This document supplements the guidance in IMG01 for the periodic examination and testing of process vessels.

Many different types and designs of process vessel are used in industry for a wide variety for applications. Any tank or vessel that operates with the objective of completing a sub process as part of an overall process may be considered to be a process vessel.

Process vessels can be designed to accept a wide variety of fluids. The nature of the examination required to ensure their mechanical integrity and suitability for further service will depend on the specifics of the fluids involved, the design of the vessel and its operating conditions.

This guidance refers to the regulatory framework of the UK. However, much of the content of good practice it contains may be relevant in other areas.

2. Scope

This guidance is aimed at Duty Holders and/or Competent Persons creating Written Schemes of Examination (WSE) for process vessels.

There are specific requirements for the creation of a WSE under the Pressure Systems Safety Regulations 2000 (PSSR) which will apply to process vessels if they contain or are likely to contain a relevant fluid. However, even if the PSSR does not apply, the production of a WSE where other regulations and industry guidance applies can still be of value for process vessels handling hazardous substances.

Please see SAFed Guidance IMG01 for specific information on the regulations that pertain to process vessels.

This guidance does not cover the maintenance or operation of process vessels.

3. Types of Process Vessel – Common Design Types

Process vessels are produced in a variety of designs to suit the specific process in which they are intended for use.

When determining the inspection requirements for a process vessel, the construction and use of each vessel must be considered on an individual basis. The characteristics of the fluids that flow through each part of the vessel will have a role in determining what form of examination is required. Some process vessels may have different modes of operation such as when they are carrying out their normal function, and when they are being operated differently such as when sterilisation or cleaning is being carried out. The specifics of all these functions will contribute to the type of examination required.

There are some broad design features that are common to many process vessels which may affect the extent of the examination that is required, as shown below. It is possible that a process vessel will comprise of a number of these design features.

3.1. Open Vented Vessels

Some process vessels are designed such that the vessel is open to atmosphere and therefore do not operate under pressure. However, they may have component parts that do operate under pressure which can affect the nature of the examination required. Such design features are shown in figures 1A to 1D, although various combinations are possible.

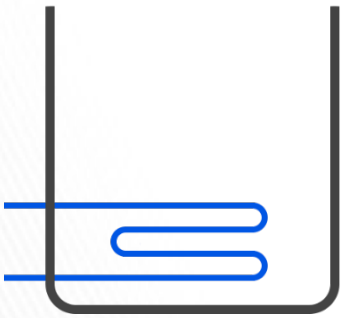

Figure 1A. Open vented vessel with an internal coil.

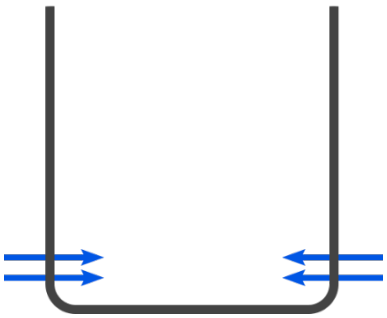

Figure 1B. Open vented vessel with a fluid injected through nozzles.

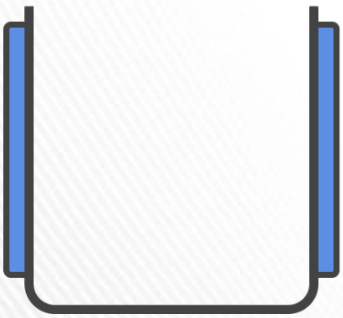

Figure 1C. Open vented vessel with an external jacket.

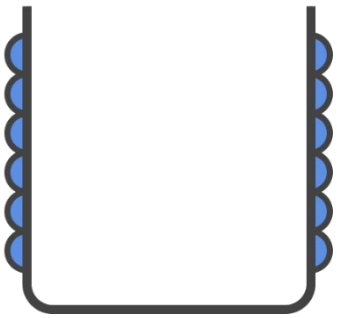

Figure 1D. Open vented vessel with an external limpet coil.

3.2. Enclosed Vessels

Some process vessels are designed such that they are enclosed and operate as a pressure vessel. They may also have additional component parts that contain a fluid under pressure. Such design features are shown in figures 2A to 2F, although various combinations are possible.

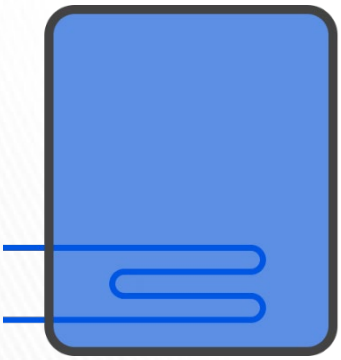

Figure 2A. Enclosed vessel with an internal coil.

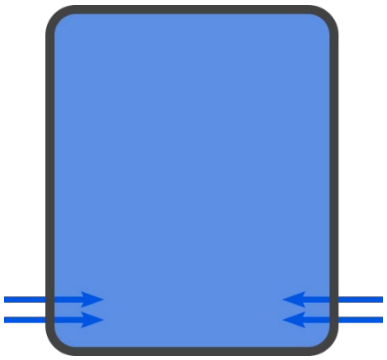

Figure 2B. Enclosed vessel with a fluid injected through nozzles.

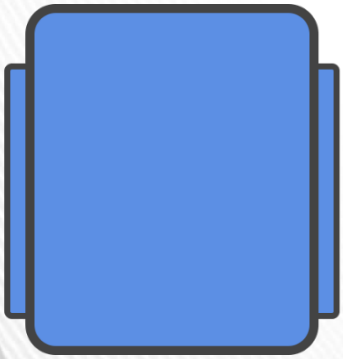

Figure 2C. Enclosed vessel with an external jacket.

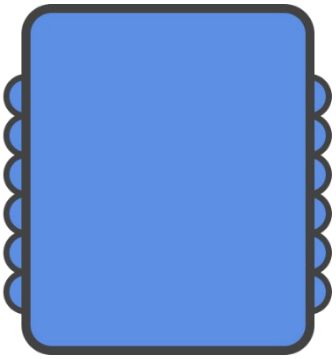

Figure 2D. Enclosed vessel with an external limpet coil.

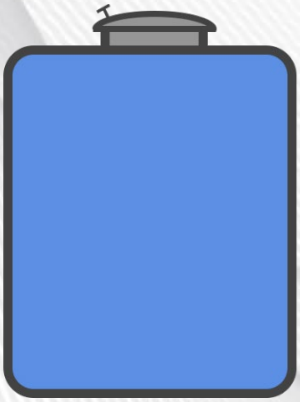

Figure 2E. Enclosed vessel with a quick opening door/lid.

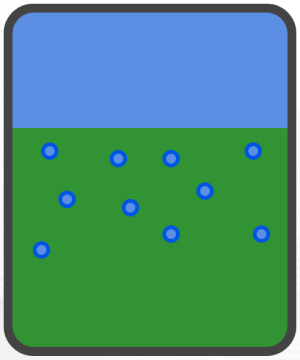

Figure 2F. Enclosed vessel where a reaction between multiple fluids causes an increase in internal pressure.

4. Types of Process Vessels – Common Material Types

The materials used in the construction of process vessels varies depending on the nature of the process.

Many process vessels are constructed of either mild steel or stainless steel, and some will contain internal coatings that have been applied to protect the material from degradation caused by the contents.

Process vessels may also be constructed of other materials such as GRP or thermoplastic.

The nature of the contents must be confirmed as suitable for the material of construction.

5. Specific Operating Characteristics

Process vessels may be operated in specific ways that are not common to other vessels, and which may cause a relatively accelerated rate of degradation.

These operating characteristics may include but are not limited to:

- Town's water being used in vessel cooling jackets – resulting in the potential for stress corrosion cracking in stainless steel vessels if the chlorine content is not adequately controlled.
- Process fluids that contain chlorine such as hydrochloric acid – if suitable precautions are not taken to control the chlorine concentration or additional processes put in place such as adequate cleaning-in-place (CIP), there is the potential for stress corrosion cracking in stainless steel vessels and corrosion in mild steel vessels.
- Frequent full pressure cycles – as a process is started and completed or a vessel is sterilised, the vessel may be taken through a full cycle.
- Frequent temperature cycles - as a process is started and completed or a vessel is sterilised or cleaned, the vessel may be taken through a full cycle. Depending on the design of the installation this may also be done rapidly sometimes referred to as 'crash cooling', which can put additional stress on the materials.

6. Failure Mechanisms

Process vessels are subject to a number of failure mechanisms including but not limited to:

- Thermal cycling
- Pressure cycling
- Corrosion
- Internal coating breakdown
- Stress corrosion cracking
- Erosion

None of these are specific to process vessels, but the person drawing up the WSE should consider the following relevant points when determining the extent of examination required.

In some processes, vessels will be fitted with agitators to keep the contents in motion whilst they are being processed. If a failure of the agitator blades occurs, or if part becomes detached, the motion of the agitator can cause erosion of the vessel as the damaged part is drawn across its surface. This can ultimately lead to failure of the vessel.

The system supplying fluids to the external jackets or limpet coils may be arranged to circulate different fluids. One example of this may be for cooling water to be circulated during processing, and steam to be circulated post processing, to sterilise the internal chamber. This regular heating and cooling can cause significant stresses from thermal cycling.

Figures 3 and 4 show a leg of a process vessel that had undergone a number of such cycles, resulting in cracking of the leg attachment welds to outer cowling.

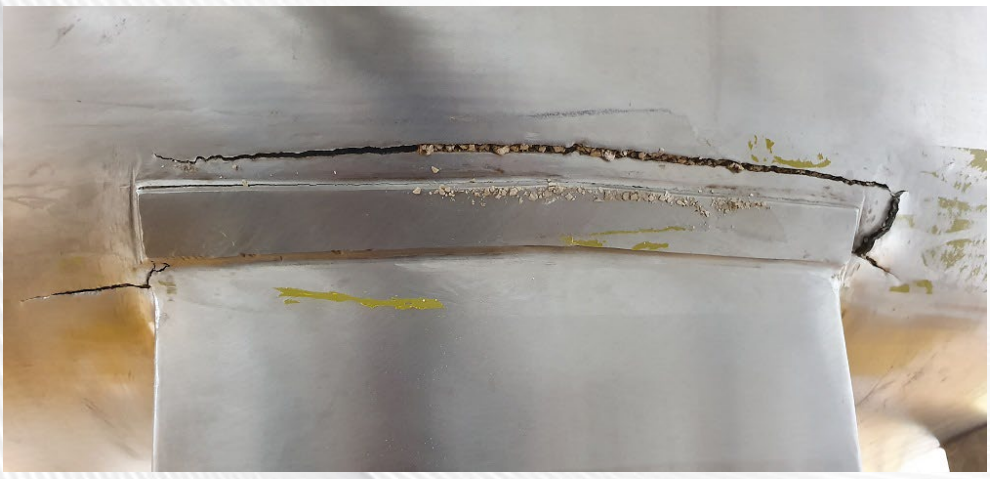

Figure 3. Cracking in leg attachment welds to outer cowling

Figure 4. Cracking in leg attachment welds to outer cowling

These cracks were found in the outer cowling of a process vessel, the purpose of which was to contain the limpet coil and the insulation. It was not a failure of the pressure vessel itself but still had the ability to affect the structural integrity of the vessel. The cracks may have had the potential to extend to a critical size whereby the weight of the vessel and its contents were enough to cause a failure.

7. Inspection Methodologies

The WSE may include some or all of the requirements below.

7.1. Visual Examination

The primary technique for examination of process vessels is a thorough visual examination, checking for the damage mechanisms specific to the construction and operation of the vessel being inspected.

7.2. Non-Destructive Testing (NDT)

In addition to the visual examination, the WSE may require specific NDT in certain areas of a process vessel in order to identify a specific damage mechanism, this may include:

- Comprehensive thickness survey of shell/base/head. (corrosion)
- Crack detection of seams/shell to base weld. (fatigue/stress corrosion cracking (SCC))
- Nozzle welds. (fatigue/SCC)

Non-destructive testing is continually developing, suitable techniques should be used for the damage mechanism concerned and this would need consideration at the time of assessment/deployment. For new techniques, it is essential that the system has been validated as fit for purpose.

The use of Non-Invasive Inspection techniques should be validated as suitable for purpose. Further guidance on these techniques is available from HOIS, HOIS Recommended Practice for Non-Intrusive Inspection of Pressure Vessels – HOIS-RP-103.

7.3. Pressure testing

As process vessels may contain component parts that cannot be inspected visually, such as coils or jackets that are beneath lagging and cannot be seen internally, a pressure test may be considered a suitable alternative method of inspection. On occasion and in order to locate and identify specific suspected failure mechanisms, this may be coupled with additional testing such as NDT.

In instances where it is deemed necessary to carry out a pressure test of the vessel, the maximum load bearing capacity of the structure must be taken in consideration. For example, if a hydraulic test is proposed but the vessel has only been designed to withstand the weight of a gas inside, it may fail structurally when filled with water. In these cases, alternative testing methodologies should be sought.

Further information for Competent Persons on witnessing pressure tests can be found in SAFed Guidance PSG21.

7.4. Lined vessels

Lined vessels require additional consideration to ensure the integrity of the lining. A breach in the lining may cause rapid deterioration of the vessel. Typical testing techniques include:

- Holiday (Spark) testing.
- Conductivity testing.

If a pressure test of a lined vessel is deemed necessary, the appropriate test pressure should be applied so that it does not cause damage to the lining. This would typically be less than that applied to a non-lined vessel.

8. Repairs and modifications

Repairs and modifications have the potential to significantly affect the integrity of the vessel and therefore should be assessed for suitability.

If the WSE has been produced to meet the requirements of a particular set of regulations, there may be specific requirements for the way in which it is repaired. When drafting the WSE, consideration should be given to any specific regulatory requirements and in any event, it should outline where and to what extent the Competent Person needs to be involved in such work.

8.1. Structural parts

Any work carried out on the primary containment envelope of the vessel and any supporting structure should be documented to the extent that its suitability can be evaluated. Where the work involves welding then the quality of the welding should be evaluated through welding qualification records and/or non-destructive testing where appropriate. New openings in the shell should be considered for the adequacy of any associated opening reinforcement. New pipework connecting to the vessel should be adequately supported so as to minimise the load on the vessel. Vessels that have changed use should be considered for suitability for the new fluid contained. It should be noted that it is rarely feasible or practicable to carry out repairs on non-metallic vessels.

Where repairs or modifications are carried out on a pressure vessel containing a relevant fluid under the PSSR, the Duty Holder must ensure they are carried out in accordance with the regulations.

8.2. Fixtures and fittings

Any repairs or modifications to items attaching to the vessel which are critical to the safe operation, should be assessed to ensure their function/operation isn't adversely affected. This includes, but is not limited to, access ladders and walkways; vents; pressure/vacuum relief devices; fluid level alarms and indicators. Ideally, valves and instruments should be replaced on a like for like basis but in some cases, it may be appropriate to replace with more state-of-the-art equipment. In either case, the new equipment needs to be confirmed as suitable for the application.

9. Relevant Publications

- SAFed IMG01 – The Mechanical Integrity of Plant Containing Hazardous Substances.
- SAFed PSG21 – Guidelines for Competent Persons Involved in Witnessing of Pressure Tests.