

# SPECIFICATION OF PROCESS VESSELS AND LIFE CYCLE COSTS

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## Abstract

Advances in materials technology, information and management systems have significant impact on the engineering design, procurement, construction, installation and commissioning of columns and vessels for use in petrochemical applications. The focus on front-end engineering implies rigorous specifications of the end-user requirements with regard to technical integrity and life cycle costs. Initial specification of user requirements for process vessels is always a contentious issue because of the trade-off between the capital costs, operating costs, and disposal costs. This paper examines user requirements for process vessels in a large petrochemical complex so as to identify the impact of specifications on technical integrity and life cycle costs. Respondents were asked to rank the impact of specifications on technical integrity and the results were compared to historical failure modes.

**Keywords:** User Specifications, Pressure Vessels, Technical Integrity, Life Cycle Management.

## 1 Introduction

Advances in materials technology, information and management systems have led to significant improvements in engineering design, procurement, construction, installation and commissioning of columns and vessels for use in petrochemical applications. What is now generally known as front-end engineering design (FEED) is a concerted effort to specify a facility in detail during the design phase of the project so as to engineer out potential problems. The focus has shifted to high quality engineering design upfront so as to mitigate errors or oversights during the construction phase. Design and construction codes listed in standards such as ASME (American Society of Mechanical Engineers), BS (British Standards) or AD Merkblätter (German Code), and country specific Occupational Health and Safety Acts are typically specified towards satisfying technical integrity requirements for process vessels.

Over and above the design code chosen, an owner, a user or an operator may, during acquisition, stipulate specific requirements to be taken into account in the design and manufacture of a vessel. Initial specification of requirements is always a contentious issue particularly on large capital projects, because of the constant trade-off between the capital costs during the project phase against the life cycle operating and disposal costs. Specific user requirements may arise from unique safety and environmental conditions, past experience,

maintainability, project and plant constraints, etc, and thus affect capital, operating and disposal costs over the life cycle of the vessel.

According to Burke (2001), the total life cycle of a vessel may be viewed as consisting of a project phase life cycle and an operating phase life cycle as illustrated in Fig. 1.

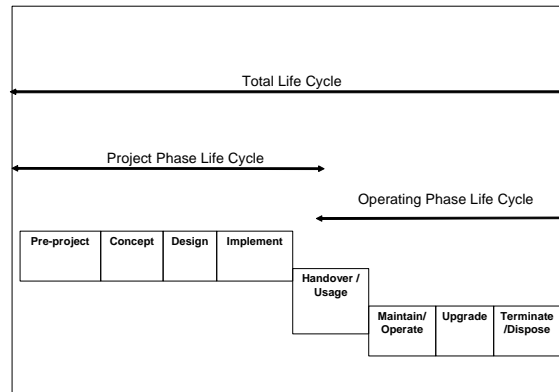


Figure 1. Technical Life Cycle of a Process Vessel

A business view of the total life cycle of a vessel is illustrated in Fig. 2 in terms of costs, risks and returns (Amadi-Echendu (2004)). The emphasis during FEED in the project phase life cycle is to maximize the opportunity cost of capital concurrently with mitigating financial and technology risks; whereas the goals throughout the operating phase life cycle are to maximize returns concurrently with minimizing social responsibility costs arising from deploying the vessel.

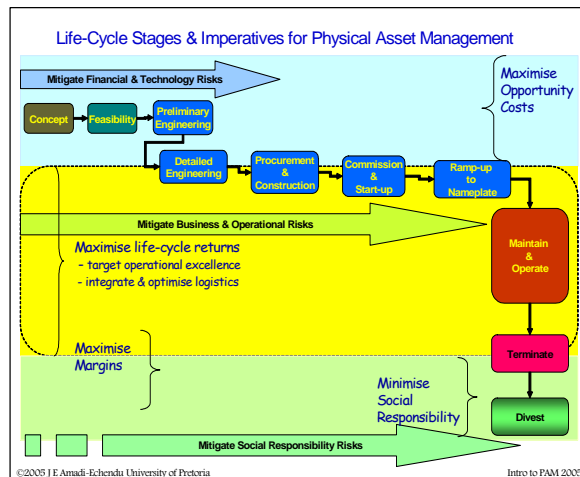


Figure 2. Business Life Cycle of a Process Vessel

This paper presents an examination of the specifications made during the design stage of the project phase life cycle and the corresponding impact on the technical integrity and operating phase life cycle costs. Empirical evidence is obtained through a survey of personnel as well as examination of records available at an established petrochemical complex.

## 2 Research

It is widely acknowledged (cf. Sullivan, Wicks & Luxhoj (2003)) that about 80% of the total life cycle costs of a process vessel may be committed based on the acquisition decisions or specifications, even though only about 20% of the actual costs are incurred during the project phase life cycle. The result is that 80% of the actual costs are expended during the operating phase life cycle, hence, the potential for total life cycle cost savings is mostly influenced by the FEED process. This implies that the total life cycle costs are highly sensitive to specific requirements made by the owner, user or operator of a process vessel, and the potential for cost savings diminishes over the operating phase life cycle.

Process vessels dictate the energy and mass balances and also tend to constitute the highest capital cost of the process equipment used at petrochemical facilities. Thus the design, construction and operation of a process vessel encompass more than just the vessel itself but have significant impact on the business value and risks, i.e., technical integrity of the associated process plant. To a large extent, user specifications determine the technical integrity of a process vessel. Here, we define technical integrity as *“the assurance that, under specified operating conditions, there is no foreseeable risk of vessel failure that will endanger the safety of personnel, the environment, or adversely affect the business value of the associated process plant.”*

Theoretically, the basic design of a process vessel is governed by the simple relationship between the height and diameter dimensions since the geometry affects the adiabatic and hydraulic efficiency. Typically, where the diameter of the vessel is fixed, then the overall height is determined by stacking vertical sections (see, for example Ulrich (1985)). Technical specifications are incorporated to ensure that the fabrication, installation and operation of pressure vessels meet user requirements dictated by statutory regulations and industry best practices (e.g., Harvey (1978); Dhillon (1989); Peters and Timmerhaus (1991); Chuse (1993); (Dell’Isola (2003)). The addition of operating experience means that the specifications are usually treated as intellectual property of competitive significance for the user, owner or operator and hence are usually not available for general access but in confidence.

Operating experience relates to specific stresses, material characteristics, fabrication methods, failure modes, safety issues and knowledge gained by the user in particular applications. For brevity, the total life cycle cost of a process vessel is determined by its weight (arising from technical specifications) and fatigue induced failures (arising from operating conditions).

In conducting this study, it is assumed that there is a correlation between the technical specifications and failures, and the hypothesis is that this is also directly correlated to total life cycle costs. Based on these assumptions, the research methods included a Dephi survey to validate a set of technical specifications, and the capturing of primary data on failure and cost histories from a petrochemical complex. The respondents to the survey constituted a judgemental, non-probabilistic, convenience sample of mechanical and metallurgical engineers with relevant experience ranging from 2 to 30 years because of the highly technical nature of the subject matter.

The range of applications of process vessels at the case study petrochemical complex is also wide, ranging from gasification to liquefaction. The age range of the vessels span over 40 years, hence, both historical failure and cost information were only limited to columns since 2001 when business information systems were used to structure, record and retrieve such data.

Twenty respondents ranked the specifications that they felt had the most impact on technical integrity and hence failure modes. The specifications were grouped into three categories of requirements viz:

- (i) Design and constructability
- (ii) Materials selection
- (iii) Welding

Failures of pressure vessels may also be broadly categorised according to the survey of Phillips and Warwick cited in Mannan (2005) and summarised in Table 1, showing that in-service related failures occur more frequently than during vessel construction. About 89.3% of pressure vessel failures may be attributed to cracks caused mostly by fatigue as depicted in Table 1.

TABLE 1: Pressure vessel failure categories

	No. of Cases	% of total Cases
Causes of failures:		
<b>Cracks</b>	118	<b>89.3</b>
Maloperation	8	6.1
Pre-existing from manufacture	3	2.3
Corrosion	2	1.5
Creep	1	0.8
	132	100.0
Causes of cracks:		
<b>Fatigue</b>	47	<b>35.6</b>
Corrosion	24	18.2
Pre-existing from manufacture	10	7.6
Miscellaneous	2	1.5
Not ascertained	35	26.5
	118	89.4
Method of detection:		
Visual examination	75	56.9
Leakage	38	28.8
Non-destructive testing	10	7.5
Hydraulic tests	2	1.5
Catastrophic failure	7	5.3
	132	100.0

### 3 Discussion

It can be seen that, with respect to design and constructability requirements, the respondents ranked the design of weldments highest, i.e., the requirement for integral reinforcement as opposed to compensation pad reinforcement for nozzle openings. This reduces the amount of welding on the vessel. The requirement that addresses the weld design of the head to skirt attachment welds for process vessels classified as being slender, i.e. a length over diameter ratio of greater than 10, was ranked second highest. Here, attention to the weld is given to ensure that fatigue cracking does not occur.

TABLE 2: Delphi survey results

<i>Respondent Ranking of Grouped Specifications</i>	<i>Weighted Average as a % of total</i>
<b>Design and Constructability:</b>	
- Integral reinforcement on high pressure and high temperature pressure vessels	7.67
- Skirt to shell weld on tall vessels to be fatigue resistant	7.32
- Cyclic loaded vessels to have lip type forgings	7.27
- Full penetration welding of nozzles 3" and larger for nozzle to shell weld	7.21
<b>Material Selection and Quality:</b>	
-Stress relieving of formed heads	7.75
-0.25% max carbon content for carbon steels	7.57
-No dissimilar metals welds in process service	7.50
-Re-certification of hot formed parts	7.49
<b>Welding:</b>	
-Fatigue finish of welds in cyclic service	14.89
-PWHT for welds in amine service	14.12
-Corrosive service austenitic stainless steel to be of low carbon or stabilized grade	13.14
- Load bearing attachment weld to be full penetration welded to vessel	12.93

The third ranking requirement addresses the connection detail of nozzles where cyclic loading occurs. In this case the nozzle to shell attachment weld is changed from a corner weld to a full penetration butt weld, where the root can be inspected, and takes the weld away from the area that would see the highest stresses during nozzle loading and so reduces the risk of crack generation in the weldment of the corner weld.

The fourth ranking requirement addresses the nozzle to shell attachment weld for all services. The requirement states that all nozzles 3-inch and larger should be attached to the vessel using a full penetration butt weld. The change from a fillet weld to a butt weld is to remove the uncertainty of the stress raiser that might occur at the root of the fillet weld that could cause a crack to propagate.

In the section on material selection and quality, the requirement ranked the highest addresses the stress relieving of formed heads. Residual stresses induced during the forming process need to be relieved, and stress relieving the head ensures that residual stresses do not result in crack formation in the heads. The second

requirement in this section addresses the maximum carbon content for carbon steels. The carbon content of steels affects the weldability of the steel, making the weldment harder and more brittle. The maximum limit on carbon content is therefore used to ensure that brittle zones, prone to cracking, do not form. The requirement ranked third addresses the welding of dissimilar metals. This is prohibited for welds in contact with the process since a galvanic corrosion could result. The re-certification of hot formed parts was the fourth ranked requirement and addresses the issue of ensuring that hot formed parts are restored to original material properties using certification to record the process.

In the section on welding, the highest ranked requirement addresses the finish of welds in cyclic service. The welds are to be fatigue dressed, i.e. the weld is ground to a smooth even transition and no stress raisers are allowed. This requirement ensures that no area of the weld is prone to cracking. The second ranked requirement addresses the Post Weld Heat Treatment (PWHT) of welds in amine service. Here, again the weld is relieved of residual stresses to ensure that the weld is not prone to cracking. The third requirement addresses the use of stainless steels in corrosive services. The requirement ensures that low carbon content or stabilized stainless steels are used for these applications. The focus is on reducing the possibility of carbon rich zones forming at welding sites, and therefore reduces the susceptibility to preferential corrosion at these areas. The fourth ranked requirement ensures that load bearing attachment welds to the shell in full penetration. This ensures that fillet welds are not used as they can crack into the shell material if a load is applied.

The failure history data obtained is as shown in Table 3.

TABLE 3: Failure history data

	<i>No. of Cases</i>	<i>% of total Cases</i>
Total Number of Cases	<b>83</b>	
<b>Causes of failures:</b>		
<b>Corrosion</b>	<b>71</b>	<b>85.5</b>
Fatigue	8	9.6
De-lamination of Thermal Coating	4	4.8
<b>Causes of Corrosion:</b>		
<b>Incorrect material selection</b>	<b>70</b>	<b>98.6</b>
Galvanic Corrosion	1	18.2

The results presented in Table 3 reveal that 85.5% of process column failures were due to corrosion and this compares reasonably to the Phillips and Warwick data where cracking due to fatigue and corrosion is the dominant failure mode. The respondent feedback suggests that the root cause of corrosion may be attributable to welding specifications since the overall ranking was weighted highest. This somewhat contrasts with the failure history data which indicates that the main cause of corrosion is incorrect material selection; although it can be argued that this may be related to the selection of inappropriate welding materials.

## 4 Summary

It is perplexing that the assumed correlation between technical specifications and failure modes did not manifest from comparing the Delphi survey results to the history of failures. Perhaps, this may be as a result of the inspection, failure detection and recording method. Unfortunately, the history data did not indicate the position of failures even though it may be subsumed that the dominant failure mode of cracking is most likely to occur at the welds separating the vertical sections of the columns. The suggestion here is that inspection reports should include explicitly the method and the location of failure so that the links with technical specifications become readily apparent.

Information regarding life cycle cost was not available as it was very difficult to collate the haphazard and unstructured recording of such data over time. Also in this regard, it was not possible to substantiate the assumed relationship between technical specifications, failure modes and life cycle costs. It thus begs to question how management decisions regarding life cycle costs are arrived at with such unavailable and unreliable data on failure and cost history.

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