Main Focus

Performance-based innovation for boilers and pressure vessels

by Stuart Cameron, UK expert on ISO/TC 11, Boilers and pressure vessels

Boilers and pressure vessels are used in industrial systems for electric power generation, chemicals, petrochemicals, pharmaceuticals, food processing, paper and other types of manufacturing. They are also essential elements in the systems that heat and cool homes, offices, hospitals, schools, factories and places of worship, to name just a few.

In many countries, boilers and pressure vessels are regulated by government bodies, either through technical statutes or by the application of standards and conformity assessment requirements.

Not surprisingly, the market in pressure equipment is highly internationalized. Companies naturally wish to control costs and optimize equipment designs and sources, and, in an ideal world, there would be a single, comprehensive ISO standard they could follow.

Reality check

However, the development of a single comprehensive boiler and pressure vessel standard would be a very lengthy process, not least because of the difficulty of achieving the necessary level of compromise among the member countries. The main reasons for this are the differing approaches historically taken by regulatory authorities, and differences in the underlying design and construction philosophies in the various national and regional product standards.

Up to now, codes, standards, certification systems and regulations have together formed a set of interlocking requirements to assure that the equipment is safe to operate.

Nonetheless, with the increasing globalization of economies and imple-
Mechanical innovation of trade agreements, customers and regulatory authorities need international standards in order to provide the structure to facilitate free trade while assuring the expected levels of equipment safety.

Standardization in this field must strike a balance between safety, function and technical innovation. It is also important to recognize that developing countries need assurance that the standards of other countries and regions provide the necessary safety requirements for specific failure modes.

An innovative solution

Given these various constraints, the development of a performance-based international standard was seen as the most realistic approach to facilitate world trade and enhance the recognition of national and regional standards with a proven history of supporting public safety and good commercial operating experience. Such an international performance-based standard would enable these standards to coexist, providing an approach that could accommodate technical innovations, existing regulatory frameworks and business needs.

This was an innovative approach for ISO. The main objective was to produce and encourage the use of an international performance-based standard that ISO members could use to accommodate their specific market needs – for both users and regulatory bodies.

One of the priorities was to identify obstacles that in the past have impeded the development of such a standard and to provide recommendations to overcome them. The second priority was to ensure that decision makers, particularly in emerging economies, understood the benefits of this performance-based standard.

It was also important to emphasize that the alternative of a single ISO standard that could replace all others – however preferable that might appear to be in theory – is simply not feasible in the short term, given current market and regulatory impediments. Rather than force a scheme that could not work, ISO decided to take a new, flexible approach to work around existing barriers.

Essential common element

Pressure equipment standards result from the consensus distillation of experience, research and development. They have proven to be a successful way to ensure optimal performance, safety, trade and compliance with regulations.

An element common to all standards is that they must address the various failure modes applicable to boilers and pressure vessels. This evaluation of failure modes can be carried out by different methods and some standards may not cover all the potential failure modes. Therefore, before specifying the use of a particular standard, it is important to first be aware of which failure modes it addresses.

The designer may mitigate against failure modes through a combination of design techniques, material selection, manufacturing features, levels of inspection and operation of the boilers and pressure vessels.

From basic to comprehensive

Conceptually, there are two basic types of standards or system of standards – those which cover basic requirements and those which cover comprehensive requirements. In practice, there are very few...
standards which fit neatly into either of these two categories. In some cases, both types may be combined in one standard. In other cases, a standard may lie somewhere between the two extremes.

A standard addressing basic requirements would be applicable to vessels that are expected to be subject to steady-state operational conditions (i.e. nominal load cycles, no rapid temperature changes, etc.), and where minimum design effort is required (essentially based on mandatory formulae for determining wall thicknesses, etc.). In general, the failure modes are addressed by the use of code limits, which result in relatively low stresses when the loadings are applied. This also accommodates secondary effects, which are not considered in detail.

A comprehensive standard would be applicable to both low-duty and severe-duty vessels. The allowable design stresses are relatively higher than those in a basic design code, and a design assessment to address the applicable failure modes should be carried out by competent engineers. In this type of code, there is usually detailed methodology directly addressing the failure modes that could result in malfunction of the pressure equipment.

Addressing failure modes

In both cases, failure modes can be addressed through more than just design calculations; for instance, by limitations on use of materials, welding techniques or heat treatment requirements. Geometric features may also be specified to minimize the stress concentration factors for cyclic loading or excessive local strains. The acceptable limits for non-destructive examination may also vary, depending on the failure modes being considered.

There is usually a level of involvement by an independent inspection authority – either inherent within the standard or specified by regulation – which may vary, depending on the type and service of the pressure equipment.

Most standards do not fit directly into either one of these two types, but the concept generally applies.

The majority of standards cover failure modes through what is generally known as “design-by-rule” or “design-by-formulae”, where prescriptive formulae are applied to determine the shell thickness, compensation for nozzle openings and other specifications. These normally provide satisfactory designs for pressure loading of a typically non-cyclic nature. However, according to the criteria used when basic failure modes are assessed, a margin may exist to permit a certain number of operational fatigue cycles (e.g. 500 cycles based on experience) rather than have the standard directly address loads such as thermal cycling, rapid start-up and shutdown.

Design-by-analysis may be used as an alternative or to supplement design-by-rule applications. Or it may have to be used for cases not covered by the design-by-rule criteria, which can include significant fatigue, thermal transients and environmental loadings. It may also be used in cases where the specified manufacturing tolerances are exceeded and require a more accurate evaluation of the stresses in a component.

Generally, a basic standard uses a design-by-rule methodology, while a comprehensive standard may include this methodology as well as one or both of the design-by-analysis approaches.
The performance-based standard developed by ISO/TC 11 was published in August 2007. It comprises two parts. ISO 16528-1:2007, Boilers and pressure vessels – Part 1: Performance requirements, defines the requirements for national and regional standards to coexist by providing an approach that can accommodate existing regulatory requirements and market needs. Specifically, it defines:

- the duties and responsibilities of the main parties;
- the failure modes which should be addressed;
- the technical requirements covering materials, design, manufacture, etc.; and
- the methods by which conformity assessment may be accomplished.

Particular emphasis is placed on failure modes, and these are categorized as:

- short-term failures, due to the application of non-cyclic loads which lead to immediate failure, e.g. brittle fracture, ductile failures, instability, etc.;
- long-term failures, due to application of non-cyclic loads which lead to delayed failure, e.g. creep rupture, erosion, corrosion, environmentally assisted cracking, etc.; and
- cyclic failures, e.g. progressive plastic deformation, fatigue, etc.

According to ISO 16528, as a minimum, the following failure modes must be addressed:

- brittle fracture;
- ductile failures;
- excessive deformation;
- elastic or plastic instability.

The standard does not need to address all failure modes, but an explanation must be provided defining limitations in its scope or application relative to the failure modes not addressed.

For each failure mode, a detailed checklist must be prepared, identifying which aspects are covered by:

- explicit design (e.g. formulas for sizing wall thickness for resisting ductile burst);
- implicit design (e.g. design margins on material properties);
- fabrication details (e.g. weld profiles to reduce failure due to fatigue);
- material requirements (e.g. provisions for addressing strain hardening);
- examination requirements (e.g. inspection techniques relevant to the failure mode);
- testing requirements (e.g. hydrostatic test pressure);
- use/application limits (e.g. any limitations on scope).

ISO 16528-2:2007, Boilers and pressure vessels – Part 2: Procedures for fulfilling the requirements of ISO 16528-1, provides a procedure and forms for standards-issuing bodies to demonstrate that their standards fulfill the performance requirements of Part 1. A task force of experts from ISO/TC 11, led by the author, is available to assist in completion of the conformance tables. When available, the completed tables will be published on the ISO Web site. Standards-issuing bodies may also incorporate the forms within their standards.

### Market-based developments

ISO/TC 11 will continue to provide a forum for international cooperation and collaboration in developing common rules and approaches for national and regional standards.

Standards-issuing bodies are currently submitting ISO 16528 assessment forms for review. ISO/TC 11 intends to build on the information gathered during the development of the performance-based ISO 16528 to begin development of a common market-based international standard.

### About the author

Stuart Cameron is Chief Engineer at Doosan Babcock, a large engineering company with offices in the UK, USA, Korea, India and China. He has specific responsibility for technical risk management and investigations throughout all parts of the company including compliance with existing and new legislation regarding pressure equipment. He has been involved in boiler and pressure vessels standards for 25 years and is the UK expert on ISO/TC 11, Boilers and pressure vessels, and its two working groups. He is also Chairman of the BSI Boiler Code committee and a member of ASME subcommittees on Power boilers and Boiler & pressure vessel accreditation.

### Special acknowledgement

Sadly, three major contributors to the development of ISO 16528 passed away just as ISO/TC 11 concluded this work, and the author would like to dedicate this article to them. They are Dr. Yasuhide Asada from Japan, Convenor of ISO/TC 11/WG 10, and two experts from the US, Ernie Steen and John Fishburn.