Safety in Pressure Vessel Design

Too often the designer considers the mechanical details of the pressure vessel sufficient if they "conform to code". However, these codes are not intended as design requirements and should be evaluated in light of specific circumstances.

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THE DEFINITION OF A PRESSURE VESSEL MAY VARY depending upon the code or standard being consulted. For the purposes of our discussion on safety in pressure vessel design, such equipment will be any vessel which contains an inherent hazard, be it pressure, temperature, or an obnoxious fluid.

The engineer who has evolved the basic process may look on a pressure vessel as merely a block on a piece of paper with fluid streams entering and leaving it. Once the need for a pressure vessel has been established and placed in the process scheme, it is reviewed as part of a complete plant by the project engineering section which defines the dimensions, pressures, and temperatures involved more completely than did the process engineer. This group may make a preliminary drawing of the vessel and present recommendations as to the materials of construction to be used etc. At this stage, the vessel is viewed much more thoroughly by the pressure vessel designer whose responsibility it is to see that a safe and economic unit capable of performing its design function is delivered to the plant. He should carefully review what has been passed down from the project section since the materials of construction that are initially chosen are sometimes unsuitable.

As a pressure vessel designer, I am convinced that the designer's best friend is the metallurgist. Codes will give considerable help in stress analysis and design details, and in many cases they may designate the materials which can be used, but the specific material to be used for the purpose one has in mind is nowhere defined by a code. This, along with the tremendous variation in process conditions that can exist, make it mandatory to consult an expert opinion on this aspect. Too often the choice of material is based on similar previous experience, but even small differences in constituents in fluid streams may make considerable difference to the material to be used. Many vessel failures, not all catastrophic of course, are attributable to a bad choice in material, and the metallurgist is called in to try and retrieve the situation, whereas if he had been consulted in the first instance the problem might never have arisen. It is also important to remember that a vessel is designed to fulfill a specific function in a chemical plant, in the most economic fashion, and that it should not be considered as a 300 ton chunk of indestructible steel. It should be obvious that if it has been economically designed then fairly high stresses will be employed in the vessel as it stands.

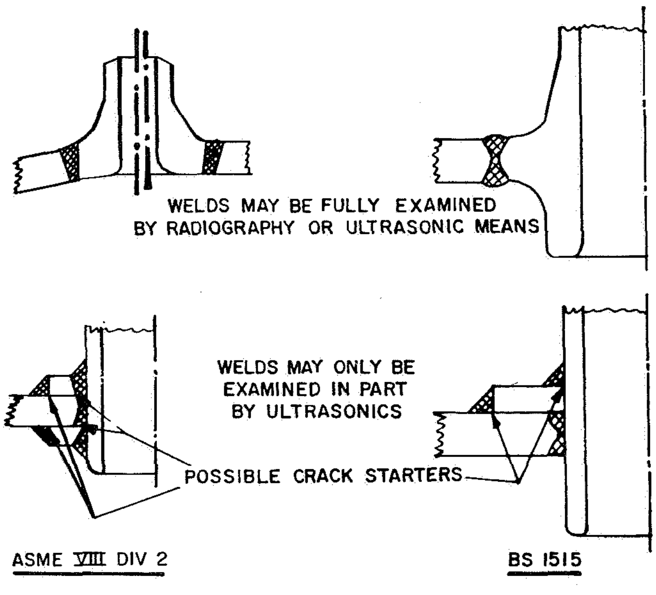


Figure 1. Nozzle details.

Improper welding a danger

Too often it is considered a simple matter to attach half a dozen lugs on the outside of the vessel to support a ladder so people can climb to the top of the unit. In most cases, the vessel itself may have large welds made by full penetration techniques which have been thoroughly examined by radiographic and ultrasonic methods. These additional lugs are attached by fillet welds which, even when done under the best of conditions, can rarely be thoroughly examined to make sure that there is no incipient failure beneath them. Cases are on record where cracks propagating from such seemingly unimportant appendages have threatened the integrity of the complete vessel. Similarly lagging support rings are frequently attached by fillet welds around the vessel, whereas, in many cases, this could be done by means of a bolted ring which can at least be removed at maintenance intervals to see if deterioration is taking place underneath. Too often ladders, walkways, davits for the removal of manway covers etc. are treated as trivia which cannot affect the vessel. The larger, thicker, and more expensive a vessel is, the more it is necesary to give careful attention to any weld made upon it, no matter how small.

Some attempt should be made to keep the vessel as simple as possible consistent with fulfilling its function. It should not be overburdened with manways and inspection openings for which there is only a remote chance of usage.

Too often the pressure vessel designer is inclined to consider the mechanical details of his vessel suffi-

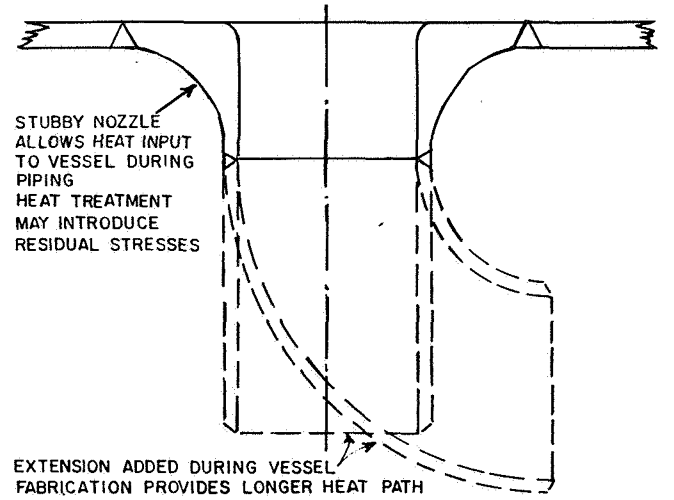


Figure 2. A soundly-designed nozzle for attaching piping to a pressure vessel on site.

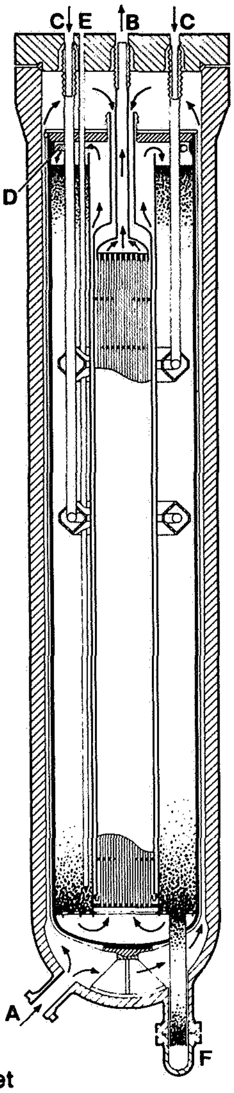
cient if they "conform to code". The authorities who formulate codes, specifications and regulations for the design of pressure vessels have a tremendous job on their hands to try and encompass the many variations which are inherent. For example, as already mentioned, they do not specify the material which should be used in any given case. In other instances, what the codes may suggest should be taken in the spirit in which it is offered i.e., as a minimum safe standard. It is not necessarily politic or economic to adhere to these minimum standards since, if they are insufficient in the light of specialized experience, the failure of a vessel may require a greater financial outlay than if it had been properly designed in the first place. In this context two examples are shown, the first from ASME Boiler and Pressure Vessel Code Section VIII, Division 2, and the second from British Standard (BS) 1515 of acceptable nozzle attachments, Figure 1.

It is noteworthy that both of these codes allow the use of higher design stresses than are permitted under ASME Section VIII, Division 1, and BS 1500 respectively and, in addition, require greater attention to details, fabrication, and inspection However, both of these codes show nozzle attachments which can be completely examined by non-destructive testing methods and others which cannot. In many cases, questions of economics and delivery are the overriding considerations which decide that the less satisfactory compensation methods using fillet welds shall be used. Perhaps if the codes were not to leave this option open to us we would find that the question of economics and delivery might be improved. Under these circumstances, we might be able to construct most of our vessels, with all details available for full inspection, and with a greater assurance of trouble-free service.

Brittle fracture

Defects which are not detected can propogate by corrosion or fatigue resulting in a catastrophic brittle fracture. Although a good deal of work has been done in the field of brittle fracture, and considerable information is available in the literature on this subject, it is still misunderstood by many engineers and in some circles is considered something of a black art. In this context it is interesting that ASME Section VIII, Division 1, which is considered a very safe and conservative code, does not recognize any mandatory requirements for low temperature operation in carbon steel vessels above a temperature of –20°F. The code committee, and any engineer worth his salt, are well aware that this arbitrary limit may be much too low in many circumstances depending on the material and its thickness. It is possible that low temperature effects can be discovered even as high as +100°F in certain instances. It is hoped that this loophole will be plugged before long since there are vessels in operation that have been fabricated of insufficiently tested materials which have a high statistical risk of failure.

A fairly recent innovation has been the introduction of testing by acoustic emission which has the great advantage of allowing us to detect the propagation of flaws and determining their location during, for example, hydrostatic testing. These techniques should help us to avoid the costly failures which have occurred in the past on hydrostatic tests.



A	**Gas Inlet**
B	**Gas Outlet**
C	**Quench Gas Inlet**
D	**Direct by-pass gas distributor and/or start up heater gas inlet**
E	**Pyrometer**
F	**Catalyst discharge nozzle**

Figure 3.
An ammonia converter with a full-bore closure.

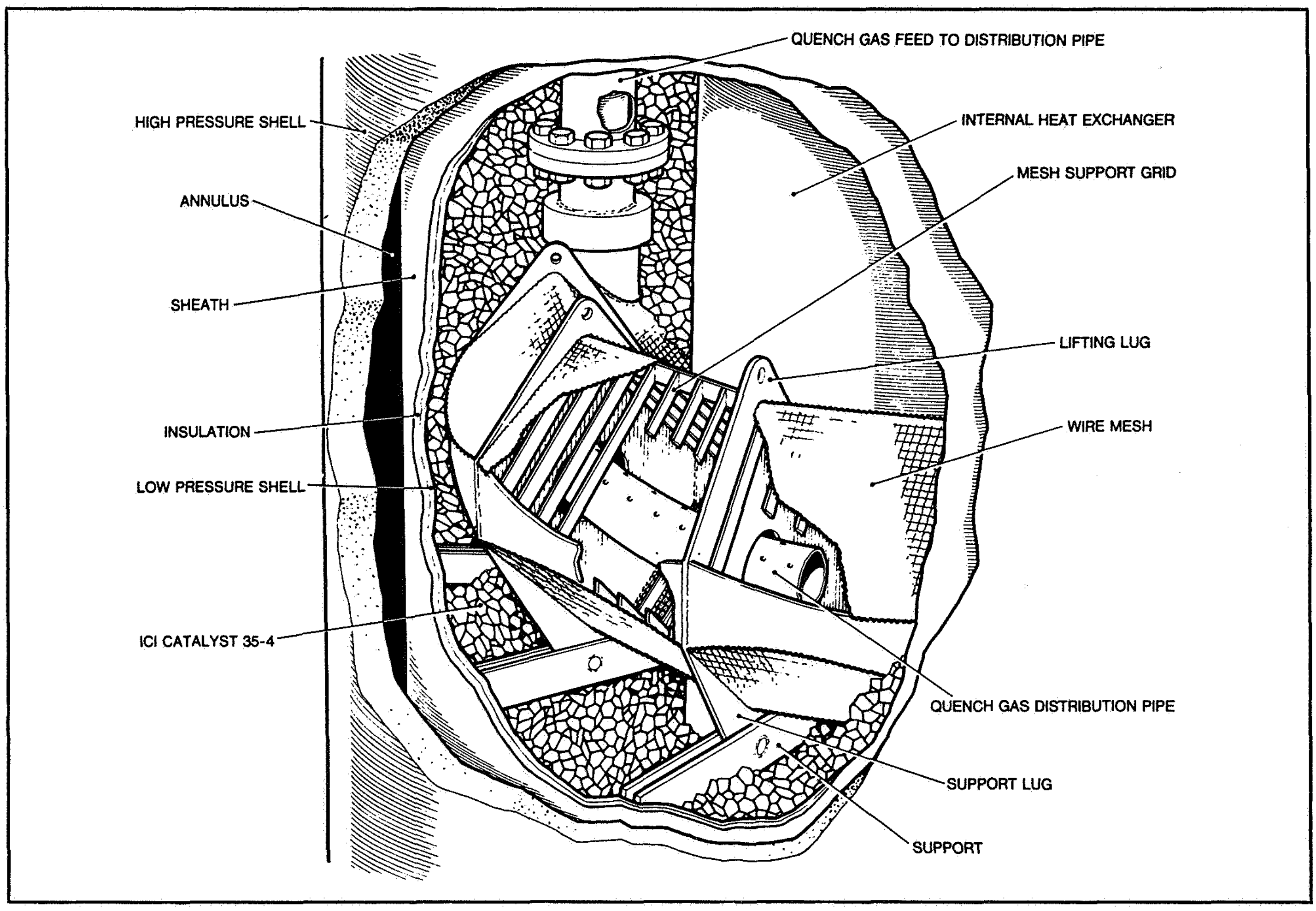


Figure 4. A lozenge distributor for an ammonia converter.

Figure 2, which illustrates a soundly-designed nozzle for the attachment of piping to the vessel on site, is an example of a detail not completely covered by code requirements. For the purposes of hydrostatic testing it has been sealed by a weld cap, or other means. But, when the piping is attached on site it is not economically feasible to heat-treat the piping weld without introducing stresses in the vessel itself. This can easily be accomplished by lengthening the nozzle as shown, or, if an elbow is to be attached, by doing so during vessel fabrication.

Once a pressure vessel is put into service it generally requires periodic inspection to ensure its continued integrity. Many vessels are soundly constructed and tested at the outset but, unfortunately, are difficult to inspect at a later time. An example of this is shown in the schematic drawing, Figure 3, of an ammonia converter which is essentially similar to the one placed on line in our Billingham, England plant. Note that this vessel has a full-bore closure, a fairly rare occurrence in these days of 1,000 and 1,500 ton/day ammonia plants. Full-bore closures are frequently discounted because of the difficulty in making them and the increased capital costs they require.

In this particular instance, the closure covers a bore of 131 in. dia. and has given no trouble whatsoever. However, the provision of such a cover allows free access to the inside. The central interchanger in the converter can be removed with a minimum of work if it is necessary to inspect or to clean it, and the complete cartridge can be removed to allow complete inspection of the high pressure shell from both sides. Perhaps the most noticeable feature of this design, the quench arrangement, is made possible by the lozenge distributors, Figure 4, which are covered by an ICI patent. The principle involved is that the low impedance within the distributor encourages most of the gas to flow through it where it is thoroughly mixed before passing out again in the catalyst bed. This design was developed for the ICI low pressure methanol system where the requirements for rapid and complete mixing are very much more strigent than those normally obtained in ammonia synthesis. Both the methanol system and the ammonia system had proved exemplary in operation and have the added advantage that the catalyst bed is in one piece and can be emptied almost entirely by simple discharge nozzles at the bottom of the bed. In the ammonia converter, thermocouples placed within have shown that the horizontal variation in temperature in the catalyst bed is within 2 to 4°C. #

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