New Ways to Fabricate Large High Pressure Vessels

Massive construction is not always the best engineering approach to attaining great strength. New techniques are showing it is possible to choose useful alternatives.

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It has been a continuing feature of the chemical industry that process designers, faced with increasing world appetites, encourage the building of bigger and bigger plants, dangling before management the elusive carrot of the economic advantage of larger units. These incentives are much admired by the higher executive branches of the industry.

Implementation of these paper schemes is not as simple as might be assumed. To a degree, mechanical designers and fabricators can cope by saying "Well, it's only twice as thick as last time," and then uprating their costs on a per-hour basis together with the current inflaction factor.

But the lonely voices of the metallurgist and materials engineer have been saying for a long time that life ain't that simple: Metal twice as thick is *not* twice as strong. It is not twice as hard to weld but many times more difficult. High-strength alloys are great but they are more difficult to form, to weld, and are more susceptible to the nasty environments that the chemical industry expects them to live in. To quench and temper 1-in. steel is believable and acceptable, but how can you quench the center of a 20-in. plate?

Many processes today use equipment which is close to the metallurgical limitations; for example, hydrocrackers in the petroleum industry, large ammonia converters, high-pressure reactors in say the polyethylene process, and nuclear reactors. The embarrassment to the nuclear industry of an incomplete appraisal of the difficulties involved resulted in delays of reactors vessels measured in years. The delivery of any major vessel of present-day sizes is measured in years.

And still the cry arises for bigger, and hopefully better, plants. Processes now being considered in a more massive form than before include methanol and coal gasification; and some of the details make horrifying reading. Can you conceive of one mile of welding in 10-in. plate in one vessel, site-fabricated, which has to undergo post-weld heat treatment, and exhaustive non-destructive testing? What is likely to be the delivery period? Is it a variable proposition? And what will be the cost?

We should be failing in our duty as engineers if we could not conceive of a solution. We must try to think of methods which will allow us to achieve the desired objective, without indulging in the obvious stupidities that over-extrapolation of present-day methods is bound to result in.

What are our requirements? Firstly, very large vessels are not going to be transportable, thus site erection only must be considered. Secondly, it follows from this that heavy forming equipment is not going to be readily available. Thirdly, it would be advantageous to dispense with massive welding equipment, and lack of heavy weldments will improve the predictability of fabrication time. Fourthly, the requirements for post-weld heat treatment should be kept to a minimum. Fifthly, requirements for non-destructive testing should be minimal.

The overall governing requirement is to complete the vessel in a reasonable time—predictably, and believably, because this is the essence of implementation of the process designer's economic incentive.

A start has already been made in dispensing with the conventional in the nuclear industry. Some years ago, French engineers investigated the possibility of prestressed concrete pressure vessels and this is now a reality in France, Britain and the U.S.A. Concrete by itself is a ridiculous material for a pressure vessel, but the loads are borne by steel elements in uniaxial stress.

It has recently been suggested in Germany that the same philosophy can be applied to prestressed cast-iron vessels—and what is wrong with that? By use of uniaxially-stressed steel members and foregoing present ideas of using the same piece of steel to endure both longitudinal and hoop stresses more steel is needed, obviously (at equivalent strength levels) than a conventional welded vessel, and such is the case in the concrete and cast-iron vessels. But why indulge in padding this with a superfluity of masonry or cast-iron, can it not be done without this? The answer is yes, it can and has been done.

During the Second World War, all major pressure vessels in Great Britain were forgings, either one-piece or two-piece mechanically joined. The source of these vessels were two large forges in the city of Sheffield, and an alternative method of construction was urgently sought lest these forges should be destroyed by enemy action.

A method of construction was devised very quickly by two Imperial Chemical Industries Ltd. engineers *(1)*, in which a thin shell was reinforced by a series of forged rings to constrain the hoop loads, and the end covers were held in place by a massive portal frame structure fabricated from steel plates enclosing the whole vessel.

This method is commonly used today in the U.S. for

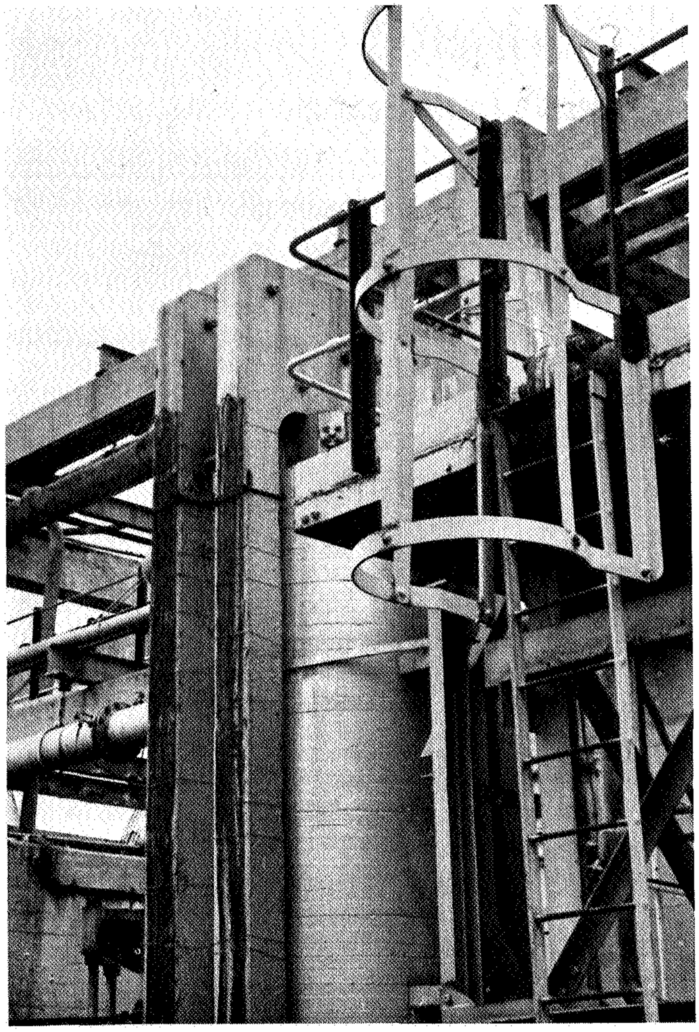

Figure 1. View of a pressure vessel which was built according to the design principle of Birchall and Lake *(1)*.

very high pressure research autoclaves; being designated the double-yoke principle. Two such vessels were made during World War II for ICI, and one of these was still in use in 1973 after some 30 years continuous service. The same basic principle is used in that most venerable of chemical process vessels, the beer barrel, in which the staves constrain the ends, while the hoops take the hoop loads. The photograph in Figure 1 shows one of the early vessels.

The cylindrical shell itself can consist of a ductile and leakproof membrane connecting the two ends of the vessel. Around this would be placed a series of longitudinal members fabricated from plate or bar and attached mechanically to the end members, or heads, of the vessel. Around these members would be a series of rings to take the hoop loads. *(2)* These could be forged rings, rings cut from sheets, rings rolled from sheet, or a multilayer construction. They might be separately fabricated and lightly shrunk onto the vessel; or alternatively they could be wound *in situ*.

In any case there is no heavy welding. Nor after initial qualification of the materials is there much need for nondestructive testing. Heavy section material is not required because material 1/2-in. thick, or even 1/16-in. in the case of hoops, could be employed.

The incentive to go to higher strength steels is removed, because the requirement to weld even heavier plate in a low-strength shell no longer obtains. The inherent qualities of low-strength steel—availability, ductility, weldability, and resistance to many forms of stress-corrosion—are all made available once more. At the same time, expensive and strategically important alloying materials are released for more deserving use.

One major disadvantage does present itself; no piercing of the wall of the cylinder is reasonably possible for branches, manholes, and the like. Provision for entries must be made through the vessel ends.

Vessel ends may be made in conventional fashion, yet here too an area where some new thought might well be applied. In large sizes, flat plate ends are obviously impractical; elliptical or, preferably, hemispherical covers are indicated. Once again, as sizes increase so will the thickness of the metal wall, and once more there will be the requirement of heavy weldwork, forming equipment, etc.

Krupp in Germany, among others, has proposed multilayer heads for vessels, and this may be a promising area. Then again, the re-entrant spherical segmental cover *(3)* in which the material of the cover is subjected to compressive stresses. This opens the field to materials of good compressive characteristics such as cast iron. Furthermore, because the loads involved are compressive, a cover might be made of elements which are *not* connected together at all. After all, arches and vaults have been made by this method for hundreds of years.

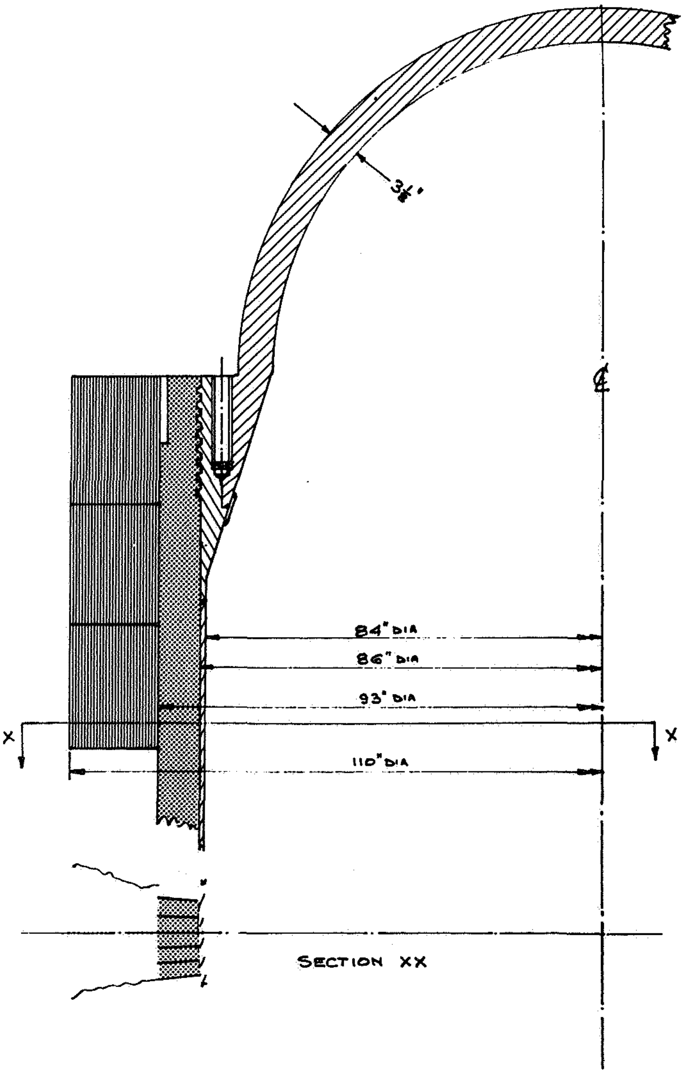

Figure 2. A 7-ft. inside diameter vessel for service at 5,000 lb./sq.in.

Much of this may sound like rank heresy in the "conventional" pressure vessel world, but the day is at hand when the conventional is no longer convenient. Though the methods may seem strange, they are likely to prove more practical and predictable in time, cost, and performance than further extrapolation of present day technology.

A few examples of vessels constructed according to new design principles are shown in the accompanying drawings. Figure 2 shows a 7-ft. I.D. vessel for service at 5,000 lb./sq.in. Longitudinal members are connected to the end members by splines, and the end cover is secured by shear studs. *(4)* The end cover can be made removable or alternatively can be seal-welded in position. Hoop rings are made of spiral-wound construction.

Figure 3 is a 20-ft. I.D. vessel, also for service at 5,000 lb./sq.in. Longitudinal members are connected to the end members by shear studs, as in the removable inverted spherical segmental cover. *(3)* The longitudinal members are extended at the bottom to provide a support for the vessel.

Figure 4 is a 30-in. I.D. vessel for service at 45,000 lb./sq.in. Sheet metal rings are used for hoop members. Sealing details are notional.

A small test vessel was constructed to test the validity of construction (see Figure 5). The vessel had an inside diameter of 6-in. and an internal length of 1-ft., 9-in. The end covers were made from 1-1/2-in. Type 304 plate, and were welded directly to the internal diaphragm which was made from 1/16-in., Type 304 sheet. The longitudinal members consisted of 3/8-in. square, mild steel bars and were at-

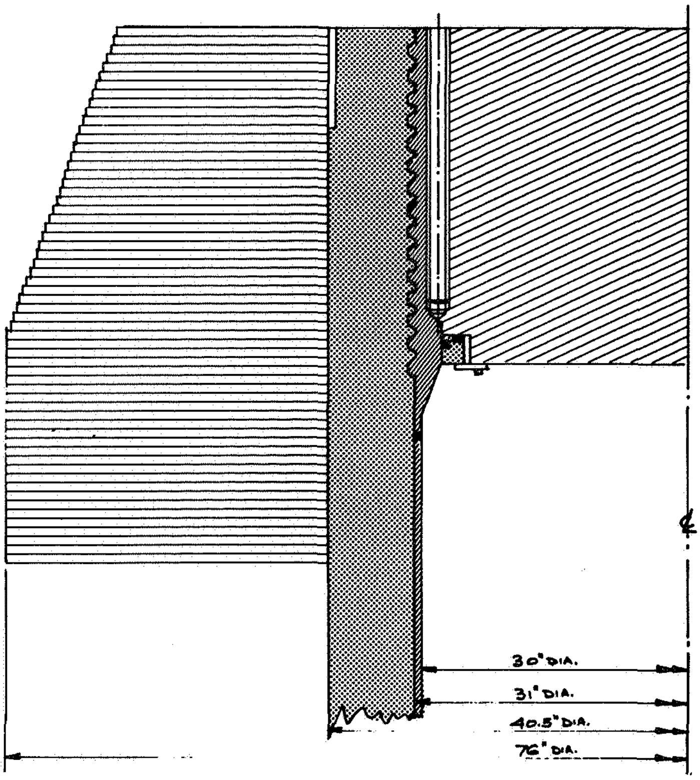

Figure 4. A 30-in. inside diameter vessel for service at 45,000 lb./sq.in.

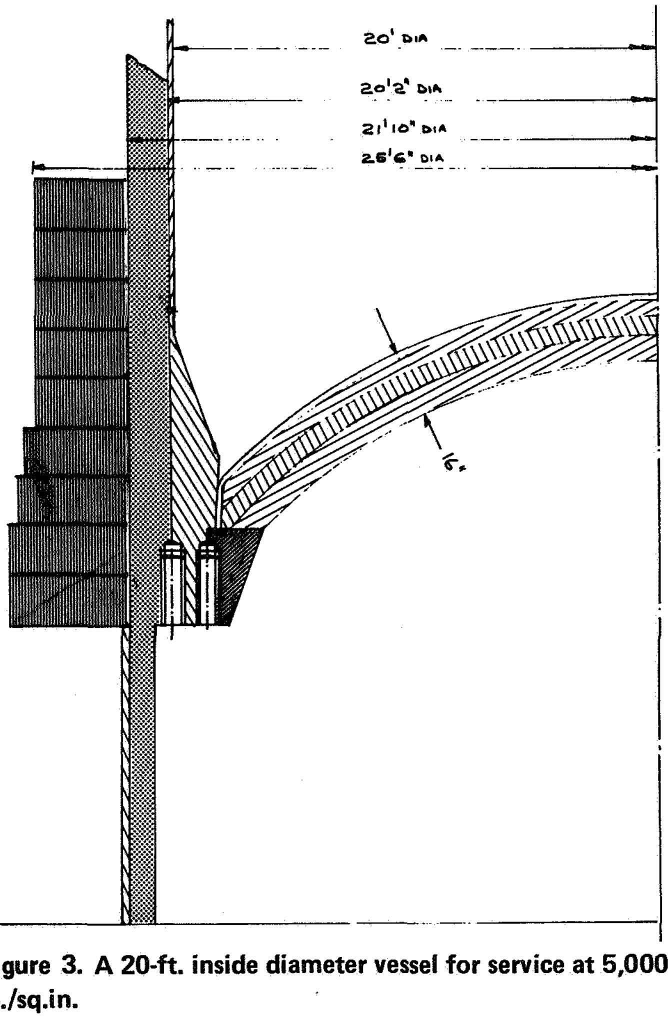

Figure 3. A 20-ft. inside diameter vessel for service at 5,000 lb./sq.in.

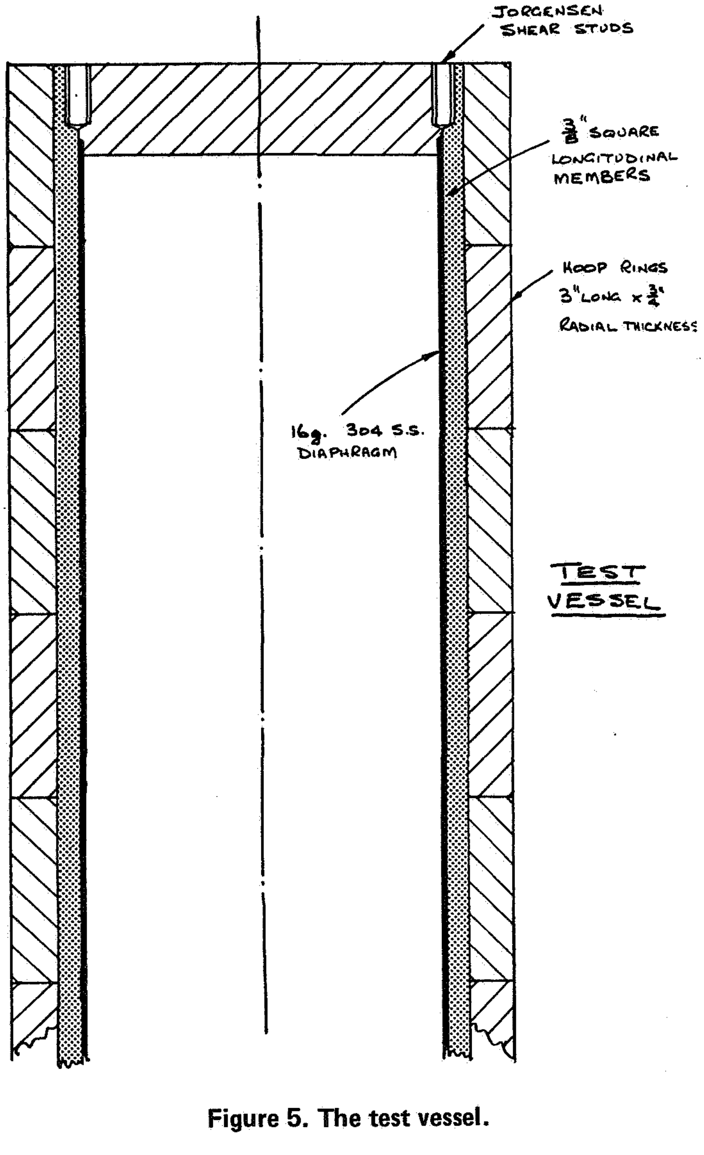

Figure 5. The test vessel.

tached to the end covers by 1/4-in. shear studs. Rings, 3/4-in. thick and 3-in. long, were made of mild steel and lightly shrunk onto the assembly. The design pressure of the vessel, if designed to ASME VIII Division I, would be 3,750 lb./sq.in.

The vessel was tested to determine the ultimate mode of failure. In this we were disappointed, because at a pressure of some 7,800 lb./sq.in. a leak developed in the internal diaphragm. Investigation showed that the failure occurred at a weld junction in the diaphragm. Difficulty is obviously present in producing a smooth weld in such thin material, and subsequent grinding to prepare a smooth surface to allow fabrication to proceed had resulted in a localized thin spot which failed.

The structural components of the vessel, however, showed no signs of distress whatsoever. The hoop rings separated one from the other by about 0.001-in. when under a pressure of some 7,000 lb./sq.in., and this gap reclosed when pressure was removed.

The original object of finding the ultimate failure mode was unachieved, but the tests did indicate that the proposed method of fabrication was completely viable.

Acknowledgement

I should like to acknowledge my indebtedness to Mr. S.M. Jorgensen and the Foster Wheeler Corp. for permission to use their shear stud method in the fabrication of the vessel, and to Mr. S. Fromson of Fromson Heat Transfer, Toronto, for his aid in building and testing the vessel. I should also like to acknowledge the encouragement and support afforded me by Mr. F.W.S. Jones of Chemetics International, Ltd., and my old colleagues in the engineering department of ICI, Agricultural Division, Billingham, England. #

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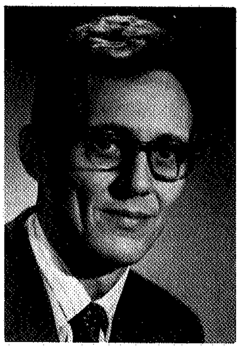

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