Design of an Ammonia Converter for Large Plants

The opposed flow converter is designed with a full bore closure which allows quick exit in case of an emergency, and facilitates internal inspection.

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The principle of combining hydrogen and nitrogen to form ammonia on an iron catalyst is as simple. as the economic exploitation of this principle is complicated. The development of this particular technology has accelerated rapidly over the past decade. The need for a rapid increase in world cheap food production called for the large scale cheap manufacture of fertilizer. Ammonia and the large single stream ammonia plant met this challenge. As a consequence, the challenge to produce large converters in a single high pressure shell also had to be met. This article presents ICI's solution to the particular problems associated with large plant converters based on our experience of what is economic and safe.

In producing a plant design one has to consider and balance a number of interdependent factors which effect its economy. In particular, two major factors, fabrication and operating costs, have to be balanced to give the cheapest result.

Fabrication and operating costs

A large proportion of the cost is for the high pressure vessel, the converter's dimensions must be the minimum compatible with safety and the production of the required amount of ammonia. Thus, one of the major objectives in the converter design will be to make maximum utilization of the shell internal volume. Also, the simpler the cartridge, the more cheaply it can be made. The skill of the HP vessel fabricators and the material specification will determine the safety and cost of the vessel, and there will be limitations of pressure, temperature, and size which the designer must recognize and take into account.

The operating costs are those associated with compressing and circulating the gas through the converter. In addition to being interrelated, both of these costs are related to other factors which go into designing a synthesis loop. For instance, the degree of cooling the circulating gas will determine the quantity of ammonia returning to the converter and, hence, the amount of ammonia produced per unit of circulation. The amount of money which can be spent on cooling will depend upon the type of cooling available, their relative costs (of materials and power), and relate to the cost of circulating the gas, which is a function of the total loop pressure drop and the quantity of gas circulating through the loop. It can also be appreciated that there are other factors which influence these economics, viz, the condition and temperature at which the product is required, the inerts content in the loop, purge requirements, the loop pressure, and the value of recovered heat. The problem is very complicated and ideally solved on a computer. Thus, most designers have produced programes to assist them in producing a solution which is as close to the optimum in terms of capital and operating costs as practicable.

Having done the complicated mathematics, the answer in terms of plant hardware should be as simple as possible, compatible with safe, reliable operation, and safe and easy maintenance. The converter to be described can be designed into synthesis loops to fulfill, in ICI's opinion, these criteria.

A diagrammatic representation of the converter, shown in Figure 1, is covered by U.S. Patent 3,458,289. It consists of a low pressure cartridge placed in a high pressure shell with an annulus between them. Gas passes into the converter via a nozzle in the shell, flows through the annulus to keep the shell cool, and then passes into the internal heat exchanger where it is heated to strike temperature before passing into the single continuous catalyst bed. At startup, a porportion of gas passes through a startup heater before entering directly into the top of the converter and on to the catalyst bed. At two points within the converter bed, gas is injected into the passing gas stream through specially designed lozenge quench gas distributors which provide maximum mixing efficiency with minimum voidage and pressure drop. The temperature, quantity, and distribution of quench gas in the bed are designed to effect maximum cost saving in terms of capital and operating expenditure.

After leaving the catalyst bed, the gas passes through the other side of the heat exchanger before passing out of the converter. A direct by-pass line permits cold gas to enter

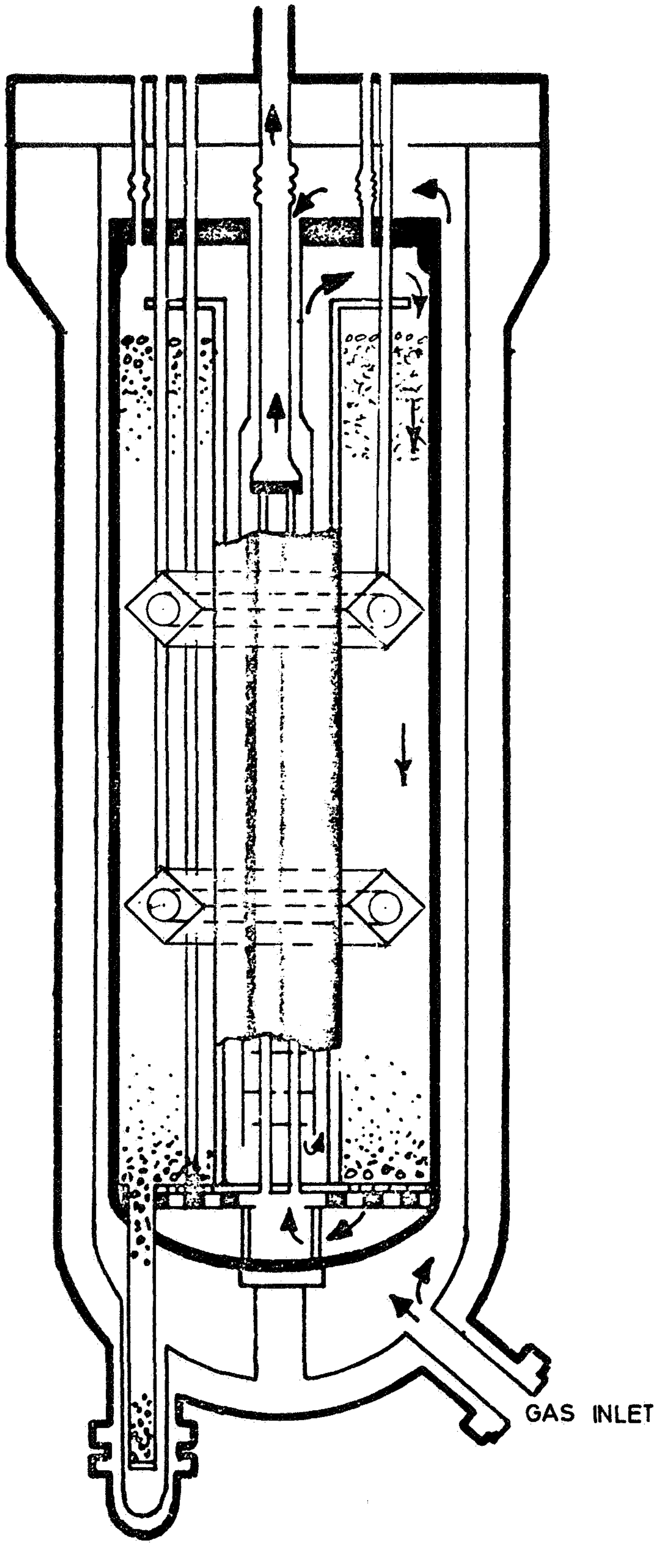


Figure 1. Lozenge quench converter.

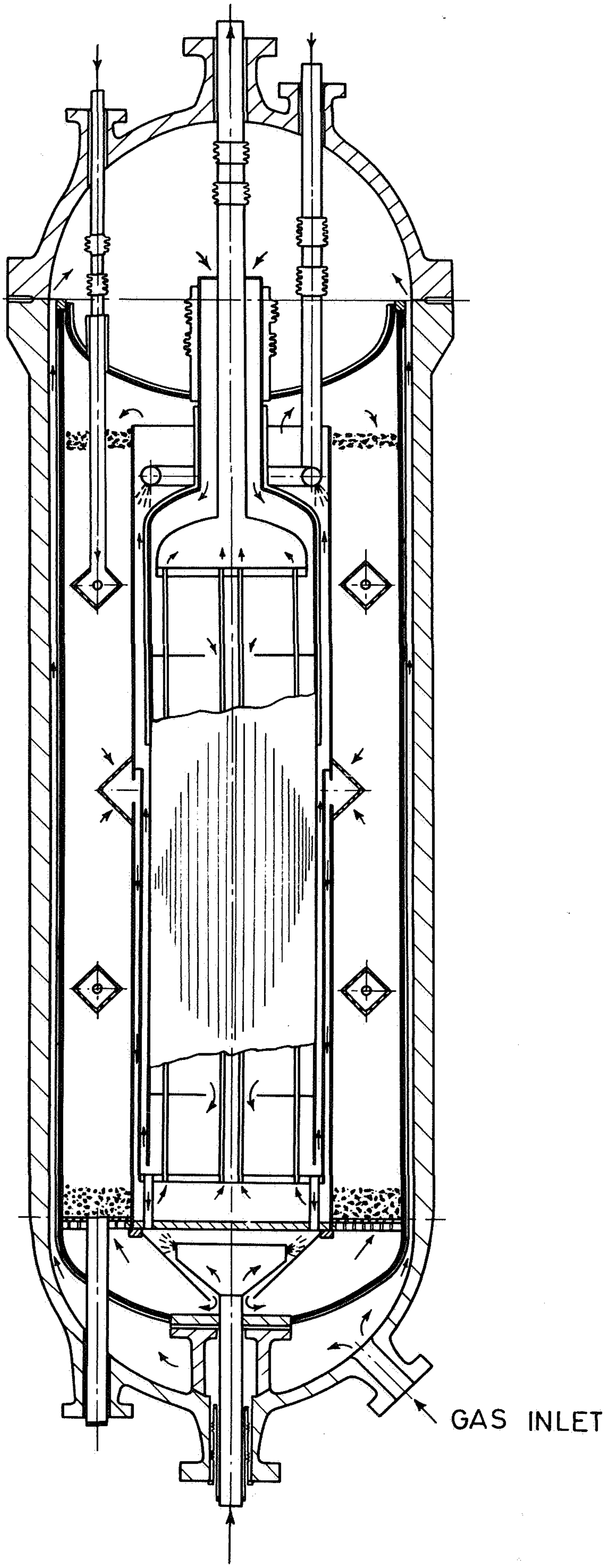


Figure 2. Opposed flow lozenge quench converter.

above the top of the bed to control the inlet temperature. Hot gas can be taken out of the converter from a point just below the bed, before entering the heat exchanger, if recovery of high grade heat is required.

Opposed flow converter

This design is suitable for plants ranging in size from 500- to 1,500 metric ton/day. However, for plant sizes in the range of 1,500- to 3,000 metric ton/day. ICI has designed a converter, known as the opposed flow converter, which utilizes the principle already described, but employs a different flow pattern, as illustrated in Figure 2.

In this case,the gas flows from opposite ends of the single catalyst bed within the converter, passing inwards through the respective halves to meet a gas exit grid (similar to the quench lozenge grid) in the center of the bed where the gas enters the inlet/exit gas heat exchanger. Each half of the catalyst bed contains a lozenge quench distributor to control the temperature at this point in the bed. The economic breakpoint for using one converter or the other would depend, again, upon local circumstances, e.g. the cooling media available, energy costs, equipment costs, product required, etc.

Simplicity of design and operation were major objectives in the development of the converter. Converter assembly, catalyst charging, and discharge have been made as simple as possible.

Each of these converters is fabricated as a number of separate items which are easily assembled. The LP cartridge rests on a cupped support in the base of the HP shell. The heat exchanger which sits in the center of the catalyst bed drops onto a seat in the base of the LP shell. No attachment or gasket is necessary as any leakage does not affect the operation of the converter. The lozenges are supported from the LP shell and the heat exchanger.

The design of the lozenge quench distributor is illustrated in Figure 3. Gas passing down the bed enters the distributor through the top grid which prevents catalyst from entering the lozenge. This gas mixes with the quench gas which is injected into this void, and the mixed gases then pass out through the lower grids into the next section of the bed. The spaces between the distributor and the heat exchanger and cartridge walls, which permit the easy discharge of catalyst, do not allow more than 5% of the gas to by-pass the lozenge. This has a negligible effect on the size of the converter and no effect on its operation. Very effective distribution of shot gas has been achieved with this device on running units.

Catalyst is loaded through the top. Control of packed density is easy and straightforward. Each lozenge is lowered in when the bed below is nearly full. Only one levelling operation is required, after charging is complete. Discharge of the catalyst is achieved simply by opening two ports in the converter base, and this discharge can be safely done without oxidizing the catalyst, provided certain precautions are taken. The time for discharge depends upon the rate at which trucks can remove it from the converter base,

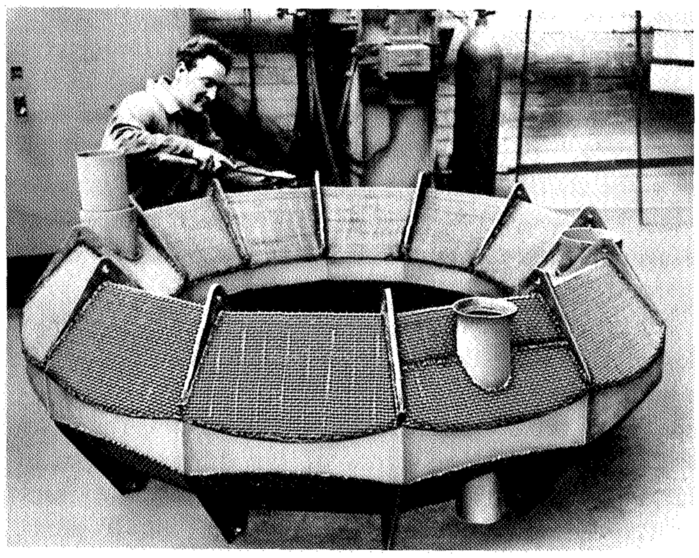


Figure 3. Lozenge quench distributor.

approximately 2- to 4 hr. for a 1,000 ton/day converter.

Safety and reliability factors

All converters of this type built so far, or being built, have a full bore closure to allow free access. Besides allowing full visibility of anyone inside the converter, the closure provides a quick exit from the converter in case of an emergency, and facilitates internal inspection of the HP shell.

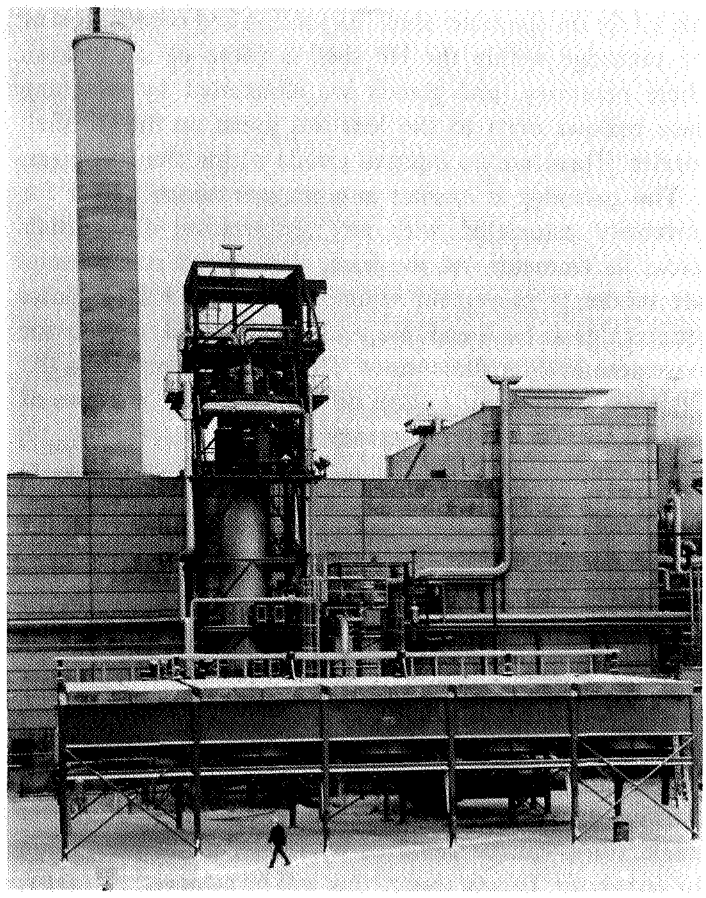
The LP shell is externally insulated with chloride free material to avoid stress corrosion cracking. This insulation is further sheathed completely in stainless steel to retain this safely on the inner shell. Expansion and contraction of the cartridge within the HP shell is taken up on bellows where necessary, and glands are eliminated by attaching these bellows units to the lens ring joints on the HP shell nozzles. There are no internal glands within the converter.

The cartridge is located in a manner which allows for movement associated with any temperature differentials across its diameter. At the base, the cupped seat permits safe moderate movement around a point, and the bellows connections at both ends are similarly designed to allow for movement in three dimensions. This prevents damage to the cartridge if any temperature differentials arise at times of start up, shutdown, or emergency.

The annulus and lagging around the LP cartridge, in addition to maintaining an even temperature distribution across the catalyst bed, should be designed to prevent over-stressing of the shell should a situation arise where there is no flow through the annulus when the converter is up to its normal operating temperature. Nevertheless, when the flow through a converter stops, there is a slow transfer of heat from the hot catalyst bed through the annulus to the HP vessel wall and there is, therefore, a slow rise in the wall temperature. A significant reduction in the rate of transfer of heat, and hence in the rate of fall of converter temperature, can be achieved by reducing the pressure in the converter. In any event, this will be achieved naturally, without any effort on the part of the operator, by reaction of gases already in the converter, and possibly through the loop purge line if purge is allowed to continue. In this manner it is possible to extend considerably, the time during which the converter can be commissioned without using the startup heater. A marginal reduction of pressure over a long period of time is all that is generally necessary to avoid over stressing the shell due to a possible rise in temperature.

All converters of this type designed by ICI have full bore closures, although this is by no means demanded by our particular design; it is simply our preference. It carries a capital cost penalty and purchasers must make up their own minds on the relative merits of the different types of closures. The full bore closure demands the same meticulous attention to detail required for all HP joints. However, there are many suitable types of closure and it is understood that double cone, O-ring, delta-ring and Bredtschneider joints have all been used successfully. The joint on the 131 in. closure on the ICI's Billingham ammonia plant has a double metal O-ring joint similar to those used on atomic power station reactors. This joint has given no trouble in 2½ yr. of operation.

Two lozenge quench converters are in operation. An 860 ton/day unit has operated at Billingham for 2½ yr., and another 750 metric ton/day unit has operated at Typpi Oy for about 1½ yr. We have been very pleased with the performance and operability of the design. Two other units, one of 630 metric ton/day capacity, and another 1,000 metric ton/day, are fabricated and due to be commissioned.



Pipework

It is good practice to have as few pipe joints as possible around converters compatible with leaving the facilities necessary for construction and for maintaining the plant. The joints should be placed, if possible, to avoid any leak/fire from impinging on HP vessels, important supports, or walkways. If this is unavoidable, a stiff plate can be clamped over the flange and slots cut in the plate to direct any possible leak in a safe direction. Care must be taken that such a clamp does not increase the flange/bolt temperature sufficiently to cause relaxation of the joint. If flanges cannot be modified in this manner, deflector shields and insulation can be used to minimize the effects of a possible leak.

Corrosion of nuts and bolts and flange faces can present a problem in some areas, and on large important joints it is good practiced to minimize this. In one case, we packed the gap between the two faces (after making the joint) with glass rope and silicone rubber. The nuts have likewise been capped with individual cans also packed with silicone rubber. In this way, no moisture can enter between the faces or corrode the nuts and bolt threads. This material can easily be removed for maintenance if necessary.

Looking into the future it is apparent that single shell converter designs are available to cope with any foreseeable increase in single stream plant capacities. Other factors will probably limit plant size before the converter becomes the controlling feature. How large plants will grow is a matter for conjecture. Although at present the 1,000 ton/day plant seems to be the most popular size, presumably the idea of a 3,000 ton/day plant is no more remote today than the idea of a 1,5000 ton/day plant was 10 yrs. ago. #

RIDLER, D. E.

DISCUSSION

LOU CASERTA, American Oil. It's interesting to me that the three last papers by the engineering companies have shown reactor designs with full bore closures on the top. It appears to be a change from previous practice on the 1,000 T/D designs and our 1,500 T/D design and may represent some new flange technology. These joints can be troublesome. The heads are massive slabs of metal, slight warpage is significant. Correct torquing of the bolts can be especially critical for no leakage. We have a joint somewhat smaller than those described in the recent papers which we have had to enclose and vent because of inability to stop leakage. These new designs appear interesting, but I think they may pose some challenges for the operators, that ought to be clarified because I think it very important.

IAN McFARLAND, Imperial Chemical Industries. I'd like to comment on that. The last speaker just mentioned that full bore closures are an innovation. We have three Kellogg plants in Billingham, and these are the only ones that we have had in our history that are not full bore closure, including some rather archaic ones which I believe are now out of action but worked at 5000 pounds and had a 53 inch joint. These occasionally leaked slightly but after some 40 or 50 years they were still running. You talk about "torqueing up" bolts. If you don't want to pull a joint up, there is the Bridgeman type of closure which gets around this and (it's terrible to say this in the United States of America) there's a variation of this which has developed in Germany called the Bredtschneider joint which uses a hard steel joint ring instead of a soft material. This gives an absolutely beautiful joint which you don't have to torque up. It uses the internal pressure to seal itself.

RIDLER: I think the secret with high pressure jointing, and particularly with large joints lies in the care with which they are made, the preparation of the faces and the care with which the people handle these. The skill of the people who put the joint together very often determines whether a joint is successful or not and, not only the design of the joint.

FRED JONES, Chemetics International, Ltd.: Do we now return to the large masses of structural steel which used to be characteristic in the era of ammonia converters or do these large closures imply a proposal that they are lifted by a crane? I'm wondering what sort of weight we're talking of with the large diameter closures, and at what sort of height in the air one would be involved in handling them and so on.

RIDLER: Well, with the very large bore closure, one might be talking in terms of something like 30 or 40 tons on the very large units. And it is possible to lift this by means of a crane. But on the otherhand, it is very easy to install on the converter structure itself, a small gantry, which is sufficient to allow the lifting of the cover, to move it to one side and expose the bore of the high pressure shell.

Therefore, the only time you would now need to bring a large crane in would be if you wanted to raise the heat exchanger out of the LP shell or if you actually wanted to raise the LP shell itself out of the HP shell. But if it was a simple matter of a catalyst change, and I would assume this is possibly the most frequent thing that is likely to occur, say, every five years, you simply use this gantry to move the lid to one side. You have then exposed the bed and you can charge your catalyst again. Thus, with centrifugal compressors and oil free gas circulating systems, there's no need to use a crane at all over long periods.

ESCHENBRENNER, G.P., M.W. Kellogg Co.: I didn't specifically mention this in my presentation, but it is obvious that with our horizontal converter none of the above problems will occur. Actually, the largest financial savings in favor of the horizontal converter are in the field installation since no heavy high lifts are required. The converter is generally moved to its foundation on heavy rollers and the insertion of the basket requires only a five ton pulley. This advantage also applies to any future maintenance and catalyst withdrawal.

McFARLAND: Basically this is, I believe, the first one of this type we have used, and this design leans very heavily, I think, on the technology of boiling water reactors in the USA, which have given extremely good service. It was on the basis of this that we selected this closure. You're perfectly correct. They do have to be held to very close tolerances, and as far as I know these have been held. I had my doubts about the situation, not so much about holding the tolerances but the possiblity of process men scraping their great big boots on the faces!

Up till the time when we used this we basically had been using double cone joints ourselves in Billingham, and these have given us not too much trouble. Your problem there is designing the thing in the first place, which must be done properly, and tightening it down, which again must be done properly. On those where we did we put these in, we didn't bother about torqueing them. We put strain gauges on the studs initially to get some idea of where we had to go and worked out the tightening technique from that.

Basically - I can say why we have always felt we should use full bore closures because if something does go wrong sometime in your cartridge, and you haven't got a full bore closure you're in trouble. We did in fact have an instance of this in about 1965. We had a converter which lost part of its insulating sheathing on the cartridge. This fell down to the bottom, blocked up the interchanger, created a glorious pressure drop across the system and the cartridge collapsed.

If we hadn't had a full bore closure, we wouldn't have been able to repair this. As it was, we were able to take the top off and although the cartridge was dented in on the top, we eventually got it out, and the job, including the repair of the cartridge, was something like a one month's job. I would have hated to cut the top off a five inch thick steel vessel to get into it.