PRESSURE VESSELS

A pressure vessel is a closed vessel of any capacity consisting of one or more independent chambers, any or each of which is or may be subjected to internal pressure greater or less than atmospheric.

Registration

Before any pressure vessel is brought into service, it shall be registered by a unique number and an appropriate file created. It should be inputted into the MERLIN pressure vessel equipment register.

The file shall include its identification number, the order number, drawing reference, specification, materials lists, inspection reports during manufacture, test certificates relating to the material and to tests on the completed equipment. It should also contain a DVC (Design Verification Certification) or equivalent.

The registration documentation shall give the classification and inspection category to which the vessel has been allocated and the intervals between inspections. This information is placed o the MERLIN record of the vessel for periodic activity scheduling (PAS).

All subsequent inspection reports are also to be contained in the file.

Purpose of inspection

The objective of a vessel inspection is to detect any deterioration such as corrosion, cracking or distortion indicating possible weakness that may effect the continued safe operation of the vessel. Primarily, inspection shall be visual but it may be supplemented by other techniques and measurement to determine the extent of any loses of thickness, pitting, cracking etc. From the results of the inspection the vessel is assessed for continued service at its design pressure and the length of time is may remain in service before the next inspection is to be carried out. The inspection interval may be increased or decreased depending upon the condition of the vessel. The inspection is to be fully recorded with details of any unusual or notable features. Thus any change in condition between subsequent inspections can be monitored and assessed.

Preparation for Inspection

Normally the inspection requirements to carry out an internal and external examination as already prescribed on the INS/1 form.

1. MATERIALS

The material for a vessel is chosen to suit the duty, in particular the contents. Apart from the various metals, such as mild steel, stainless steel etc., vessels can be manufactured in non-metallic materials such as thermoplastics (polypropylene etc.) or glass reinforced plastics. Specific requirements for BS 5500 are covered in Section 2 of the code or lined to protect the material from the product.

2. DESIGN CONDITIONS

The design condition, i.e. pressure and temperature are usually decided by a Process Engineer. There must always be a sufficient margin between maximum operating and design **pressures** (very often 10%), so that relief devices are not blowing frequently. Accurate **temperature** assessment is important, especially the possibility of sub-zero temperatures. A corrosion allowance (see later) is also defined at an early stage before any design calculations are started.

3. DESIGN CODES AND SPECIFICATIONS

There are several British Standards covering the design of Pressure Vessels, four of which are:

BS 5500: 1990	-	Pressure Systems
BS 5500: 1982	-	Unfired, Fusion Welded, Pressure Vessels
BS 1113: 1969	-	Water tube, Steam Generating Plant
BS 5169: 1975	-	Fusion Welded Air Receivers
BS 4994: 1973	-	Vessels and Tanks in Reinforced Plastics

We will concern ourselves with BS 5500 only since this is the major British Standard. ICI requirements in addition to those in BS 5500 are covered by Purchase Specification No. E365A which fabricators are asked to comply with.

4. VESSEL CATEGORY (Class of Construction)

The designer has a choice of three categories within **BS 5500.** It is the intention that all three categories will have the same integrity or reliability, no matter what the vessel contents. However, it has always been ICI policy to use the higher classes of construction if the contents are hazardous or toxic. Section 3.4 of the Code should be read. The higher category 1, requires full non-destruction testing (NDT) inspection (e.g. radiography) which is essential for thicker materials or those difficult to weld and thus more likely to have weld defects.

5. ALLOWABLE STRESSES

Once the material and category of construction have been decided, then the allowable stress to be used in calculations can be determined from Table 2.3 of BS 5500 (Categories 1 and 2) or Section 3.4.2 (Category 3). Stresses in the table have been calculated in accordance Appendix; K of the code (which can also be used for materials not covered by the tables). They also vary with plate thickness, since mechanical properties usually reduce for thicker plates.

6. AREAS OF DESIGN

6.1 Internal Pressure

The methods in the code for internal pressure are laid down fairly clearly and are fairly easy to follow.

6.2 External Pressure

Section 3.6 of the code covers the design of vessels under external pressure. It is a complicated procedure, Method A being the simplest. It is worth nothing that VACUUM is treated as an external pressure. Flat ends would be treated as for internal pressure.

6.3 Corrosion Allowance

Most vessels require an allowance for corrosion. The extra thickness to be allowed has to be based on the expected rate of corrosion and the number of years service required from the vessel. In many cases 1.5mm will suffice for mild steel.

6.4 Calculations

BS 5500 caters for the design of cylindrical and spherical shells, domed (or dished) ends, conical shells (or ends), compensation of openings and branches, flat ends, spherically domed ends, vessel supports, flanges and tube sheets (for heat exchangers).

i) Branch Compensation

Whenever an opening is cut in a shell (or end), the shell is weakened and a concentration of stresses is formed around the opening. This has to be compensated for, to reduce the stresses, either by thickening the shell or branch, or by adding a compensating ring local to the branch. Two methods are given. The first in Section 3.5.4 is based on limiting the stress concentration factor at the opening to a certain value, the second in Appendix F is based on area replacement, i.e. putting back the area of metal removed. Appendix F is intended for use only where similar applications have proved satisfactory.

ii) Flanges and Tubesheets

Worksheets are provided in this code. Both methods are much more laborious than the worksheets would suggest and the designer is advised to use a computer program, wherever possible (see under ‘COMPUTER AIDS’).

6.5 Strength of Welds

It is essential that welds attaching branches, flanges, supports and other fittings are adequately sized, to give the full strength required. In the case of weld attaching branches, these are sized accordingly to the thinner of the two parts being joined. Fillet welds are always sized on the ‘throat’ dimension of the weld. The distance between welds attaching two different components should not be too small.

Attention is drawn to Section 3.10 of BS 5500, which gives some requirements in the design of welds. Appendix E provides some typical weld details and minimum sizes.

6.6 Local Loads

Loads at supports, lifting lugs and sometimes branches, induce stresses in the vessels, local to the point of attachment. Because these stresses die out quickly away from the attachment, much higher values can be allowed than the normal design stress. Appendix A of the code is used to determine the allowable local stress.

6.7 Other Loadings

Wind loading on tall columns can be critical in their design. Appendix B of BS 5500 caters for the design of vessels subject to the combined effects of wind/earthquake and pressure.

Cyclic loading on a vessel, such as repeated fluctuation in pressure or vibrations, can quickly cause failure and must be given careful consideration. Appendix C of the codes gives guidance on the procedure to be adopted.

STRESS RELIEF

There are several reasons why stress relief of a vessel, after manufacture, may be necessary, especially with vessels of mild steel. Tresses will be ‘locked’ into a vessel during manufacture by welding or cold forming of components. In some cases this can be tolerated but in other cases can cause problems when in contact with the vessel contents (e.g. Caustic) or subjected to sub-zero temperatures. In such cases, mild steel vessels may be stress relieved.

9. INSPECTION AND TESTING

Section 5 of the code lays down requirements for the approval of welders, test plates, radiography and inspection during manufacture, depending on the category of vessel. The procedure for pressure tests is also laid down. The pressure test is essential and can be either Pneumatic or Hydraulic. Because of the Hazardous nature of Pneumatic testing (i.e. the high energy stored) this is rarely done and is subject to particularly stringent requirements.

In-service inspection of vessels is important. Registered pressure vessels within ICI are subject to periodic inspection. The period between inspections will depend on the duty of the vessel.

10. MANHOLES AND INSPECTION OPENINGS

Section 3.12 of BS 5500 requires that these comply with BS 470. Larger vessels will require at least one manhole. The minimum outside diameter of a manhole to comply with the Factories Act is 18” (457 mm). However, this is insufficient in most cases, especially where breathing apparatus has to be worn, and the recommended minimum is 575 mm ID (usually 24” OD – 610 mm).

11. PRESSURE RELIEF

Appendix J of BS 5500 gives requirements for pressure. All vessels must be protected against over-pressurisation. This is usually achieved by the provision of a bursting disc or relief valve, or a combination of the two. The setting of any bursting disc or relief valve not be higher than the design pressure of the vessel. It is *not* necessary to increase the design pressure to cater for the accumulation pressure of the relief device. The accumulation pressure is lifted to a maximum of 10% of the design pressure by choice of the size of the relief device.

These requirements inform maintenance of the minimum amount of dismantling necessary to be done in order to inspect the vessel both internally and externally.

Before entry into a vessel it must be isolated by breaking all branch connections into the vessel and blanking off accordingly (closed valves are not acceptable). A regulation No. 7 certificate should be issued by plant Regulation No. 7 certificate issue number. Internally the vessel should be thoroughly clean with no product scale on the shell and ends, well ventilated and illuminated. Externally access to all branches should be afforded in order to examine them internally and externally and also to any other parts of the vessel which the Inspector considers necessary. If the vessel is lagged the Inspector will select areas of lagging for removal.

REPAIRS, MODIFICATIONS AND NEW REPLACEMENT VESSELS

Repairs to registered pressure vessels must be authorized and an INS/5 form completed before the repairs are commenced, this form requires the Inspector’s involvement. The Inspector must approve and witness all repairs carried out and any test thereafter.

Modifications to be registered pressure vessels however trivial must be approved by Engineering Department. Vessel Section who will issue a Design Verification Certificate (DVC) for approval of the modifications. If these modifications are carried out to site or at Division Workshops, Inspection Section should be involved. If they are carried out at a Contractor, IQ or I.S.I Service should be informed.

New and Replacement vessels. All new vessels including replacement vessels must be approved by Engineering Department, vessel Section who will issue a Design Verification Certificate for the vessel. It is important that drawings of replacement vessels are approved before ordering the vessel in order that they may be brought up to present day design standards if applicable.

Appendices:

Form INS/1	*:*	*Details of Inspection Requirements – Pressure Vessels*
Form INS/3	*:*	*Report of Pressure Vessel*
Form INS/5	*:*	*Repair of Registered Equipment*

PRESSURE VESSEL EXAMINATIONS

Procedure

Form INS/1 'Details of inspection Requirements – Pressure Vessel' is completed by the inspector and accepted by the plant engineer. This form mainly asks for:

1. Factors affecting type and period of inspection.
2. Results of any previous examinations and relevant history.
3. Details of inspection requirements.
4. Details of preparation, cleaning and dismantling requirements.

All these requirements are agreed between Inspection Section and the Works. Consideration is taken of products and its effect on the vessel, material and any other effects that may occur, e.g. thermal cracking, stress corrosion, cracking etc.

VISUAL EXAMINATION INTERNAL

1. Access, scaffolding may be required.

2. Know what effect the product can have on the vessel.

3. Vessel should be purged and cleaned for entry. All Works procedures must be adhered to with respect to entry in the vessel, e.g. Regulation No.7 Certificate, Plant Clearance Certificate etc.

4. Look for signs if corrosion/pitting etc., assess depth and size.

5. Look for signs of erosion on shell at run off branches and other branches. Shining a torch along the surfaces will highlight corrosion areas particularly pitting.

6. Thickness test at suspected areas for loss of metal and also random other areas.

7. Look for evidence to show *little* corrosion has taken place, e.g. plate lining up pop marks, other fabrication marks etc.

8. On dished ends the knuckle radius is the most stressed area, always take thickness test readings in this area as well as elsewhere on the dished end.

9. Look for signs of cracking in the welds and heat affected shell areas. If suspect, clean the area off and if necessary grind lightly to have a good surface before crack detecting preferably with an AC Magnet if shell is magnetic, otherwise use dye-penetrant method. To estimate depth of cracks before ultimately grinding out ultrasonics may be used.

10. Inspect inside of all branches, look for erosion on any internal welds particularly on run off branches.

VISUAL EXAMINATION EXTERNAL

Unlagged Vessel

1. Look for corrosion, mainly it will be evident on the shell upper surfaces, assess size and depth of corrosion.

2. Look for trapping areas containing rainwater or product, corrosion could be severe in these areas.

3. Branches can suffer considerable corrosion, check thickness with D.R Caliper, thickness test or hammer testing will give a good indication if thinning is taking place.

4. Look for corrosion on flanges and bolts.

5. If spillage has taken place, the product should be cleaned off to prevent corrosion.

6. Check branch compensating plate tell-tail holes for signs leakage.

7. Inspect around the seating of vessel for corrosion, inspect welds for cracking.

Lagged Vessel

1. Remove selected areas.

2. Look for evidence of bulging of the lagging that may indicate rainwater or product has got under the lagging and lodged in the bulged area.

3. Look for cracks and damage to the lagging.

4. Lagging can cause water trapping areas particularly around branches which can lead to severe corrosion.

5. In all cases where there is evidence to show that the lagging is defective and would allow water or product between the lagging and vessel then it should be removed to examine the shell in the defective areas. All lagging repairs should be made good and water tight and equal to the original lagging specification of the vessel.

From the results of the examination the Inspector will assess the vessel for continued service at its design pressure and the time interval before the next examination taking into consideration all the relevant factors of the examination;. With respect to Class A vessels the inspection frequency is prescribed, however with Class B vessels the Inspector reviews the inspection frequency at each examination. Pressurised System Regulations come into force in July '94 and many more vessels will become statutory, the two new regulations are (AP) for statutory vessels and (BP) for non-statutory vessels.

TABLE 2 ICI REQUIREMENTS: VESSELS AND PIPING SYSTEMS

Description	Initial Examination Intervals	Maximum Examination Intervals		
		Examination Grade Z	Examination Grade Y	Examination Grade X
Process Vessels including reactors, heat exchangers and fired heaters. (see Notes 1, 4 and 6)	26 months	26 months	50 months	12 years
Pressure Storage Vessels (see Notes 1 and 2)	74 months	74 months	74 months	12 years
Atmospheric Pressure Storage Tanks (see Notes 1, 3 and 6)	74 months	74 months	74 months	12 years
Piping Systems (see Note 1)	26 months	26 months	50 months	12 years
Gasholders (water sealed) (see note 5)	2 years ext 20 years int	2 years ext 10 years int After first int	2 years ext 10 years int After first int	2 years ext 10 years int After first int
Process Vessels and piping Systems with declared Code Life	After 80^{o} of Code Life	14 months	26 months	26 months

COMMON CAUSES OF DETERIORATION

A number of modes of deterioration are common to substantial numbers of items of pressure equipment.

a) Corrosion Under Insulation

The occurrence of corrosion of carbon steel Vessels and piping beneath insulation is a common problem. It occurs under cold insulation if subject to repeated freeze-thaw cycles, but more significantly beneath warm insulation. The corrosion arises as a result of water entering and remaining within the insulation system, producing a warm, wet, aerated environment at the steel surface. It is not always easy to detect that insulation has inadequate sealing against water ingress, but if this is suspected, selected areas of insulation should be removed to permit examination of the steel. Alternative methods of detecting corrosion under insulation on piping are available. These are based on radiographic techniques and do not require removal of insulation.

Wet insulation can damage stainless steel equipment because of stress corrosion cracking by chlorides in the insulation itself or in the water.

b) General Corrosion

General corrosion is an overall loss of thickness due to attack on surfaces exposed to a corrosive environment.

c) Pitting Corrosion

Pitting corrosion produces localized attack which can be deep and lead to local perforation. It occurs at many sites and can arise from oxidation on carbon steels, e.g. from aeration in water, and from chloride in contact with some stainless steels.

d) Crevice Corrosion

Crevice corrosion occurs when two surfaces come into close contact, e.g. flanged joints, welded joints with insufficient penetration and gaps between tube/tube plate attachments. It is usually self-accelerating.

e) Mechanical Damage

This is most often found inside lined Vessels, particularly those with glass or enamel linings. Some types of plastic and rubber linings also suffer from this problem. Craze cracking of glass or enamel linings also results from thermal stressing or thermal shock.

f) Attack of Linings and Bondings

A common mode of deterioration of Vessel linings is debonding of the lining from the parent material. This can occur from absorption of chemicals into the lining, air entrapment or thermal degradation of the bonding medium. Discolouration or softening of the linking is often an early sign of chemical attack. Hard linings can suffer from abrasion and thermal shock. Separation at the edges of joints is a common problem arising from a variety of causes.

g) Erosion

Erosion of metal surfaces can result from turbulence created by fast flowing abrasive or corrosive fluids. It is commonly encountered at changes of fluid flow direction, e.g. at bends, inlets and outlets and at liquor levels in agitated vessels.

h) Stress Corrosion Cracking

Stress corrosion, broadly, is a form of localized failure which is more severe under the combined action of stress and corrosion then would be expected from the individual effects acting alone. Little or not general attack may be associated with the failure. Some cracks may be visible to the naked eye, but others may require low-power magnification or common flaw detection techniques to reveal their presence.

i) Fatigue Cracking

Fatigue cracking can occur where Vessel branches are attached to a pulsating or vibrating pump supply. It can be observed visually, but ht application of flaw detection techniques may be necessary to reveal early signs of the advent of the cracking to confirm its presence.

j) Creep Mechanism

Creep is the slow plastic deformation of materials under a constant stress. Creep can take place and lead to fracture at stresses much lower than when loaded quickly. Failure by creep does not become a practical problem until the temperature exceeds $450^{o}C$ for plain carbon steels.

REQUIREMENTS FOR THE EXAMINATION OF SPECIAL CATEGORIES OF EQUIPMENT

LIMITED LIFE CATEGORISATION

Vessels and Piping Systems may have limited life because either:

a) they operate at high temperature, and design stresses are based on creep data;

or

b) they are subjected to pressure cycling by process conditions or frequent start-up and shut down, which may cause fatigue cracking if the cycle life of the equipment is exceeded.

Equipment subjected to such conditions is required to be categorised as either:

1) having a life limited due to temperature (LLT);

or

2) a life limited due to pressure cycling (LLC).

In addition to being classified A or B and graded X, Y or Z, and are to be allocated a "Code Life" which is to be entered on the registration documentation.

The "Code Life" is determined by the Design Authority during design and is the life for which the equipment is known to be safe in terms of the criteria used in design.

For equipment already in service which may be subject to these conditions, reference to the Design Authority and Materials Authority should be made for guidance.

Equipment Categorised LLT – Limited Life due to Temperature

Where equipment has a limited life due to temperature, the following applies:

a) Prior to the equipment entering service, baseline measurements are to be recorded in order that they may be compared with subsequent in-service measurements to detect creep strain.

b) Operating temperature and pressure are to be recorded and stored in the Registered Equipment File.

c) When 80% of the "Code Life" has expired, a detailed review of the Examination reports and process history of the equipment is required in order to determine its future life and to make any changes in the Examination frequency which may be considered necessary.

d) High stress areas such as nozzle to shell welds etc. are required to be examined for cracking since experience has shown that such areas can suffer creep damage before expiry of "Code Life". Guidance on such areas should be obtained from the Design Authority.

As a guide, equipment should be considered for classification LLT if the operating temperature is above those shown in Table 3.

EQUIPMENT TO BE CONSIDERED FOR CATEGORY LLT

Material of Construction	**Operating Temperature (^{o}C)**
Carbon steels	400
½ % Molybdenum Steel	430
Chromium – Molybdenum Steels	470
Austenitic Steels	570
Incoloy, Inconel	600
Aluminium Alloys	100
Copper Alloys	200
Titanium	150

Equipment Categorised LLC – Limited Life due to Pressure Cycling

Where equipment has limited life due to pressure cycling, the following applies:

a) Records should be kept of the number and magnitude of pressure cycles to which the equipment is subjected in service and entered on the Registered Equipment File.

b) During Examination, special attention should be given to highly stressed areas where cracking is likely to initiate. Guidance on such areas should be obtained from the Design Authority.

c) A formal review of the equipments' history should be made at appropriate intervals, including a review when 80% of the "Code Life" has expired, and an assessment made of its remaining life.

ATMOSPHERIC PRESSURE STORAGE TANKS

Registered tanks which are deemed to be subject to external corrosion only, may be exempt from internal Examination by the agreement in writing of the Works Engineer and the Senior Inspection Engineer. This should be recorded on the Scheme of Examination.
The maximum interval between these external Examinations should not exceed those specified in Table 2.

Consideration should be given to the risk of the contents becoming contaminated with corrosives. In these circumstances, appropriate monitoring should be specified.

REFRIGERATION SYSTEMS

Registered tanks which are deemed to be subject to external corrosion only, may be exempt from internal Examination by the agreement in writing of the Works Engineer and the Senior Inspection Engineer. This should be recorded on the Scheme of Examination.

The maximum interval between these external Examinations should not exceed those specified in Table 2.

Consideration should be given to the risk of the contents becoming contaminated with corrosives. In these circumstances, appropriate monitoring should be specified.

REFRIGERATION SYSTEMS

Experience has shown that refrigeration systems using ‘Action’ and Ammonia do not deteriorate on the refrigerant side: the refrigerants are non-corrosive and there is little risk of contamination as they are contained in a closed system.

It is therefore, considered that internal examination and pressure testing of the refrigerant side of evaporators, condensers and receivers, where access is normally very limited, may be waived, provided the following examinations prove satisfactory.

EQUIPMENT EXEMPT FROM REGISTRATION

Providing legislation permits, and providing that the equipment is suitable for the working conditions, the following equipment may be exempt from Registration.

(a) Vessels containing gas or liquid at a temperature above its atmospheric pressure boiling point where:

(1) the product of the maximum applied pressure (bar g) and gross volume (m^3) is less than 0.25 and the max applied pressure is les than 15 bar g (the maximum applied pressure is the setting of the Protective Device);

or

(2) the product of the maximum applied pressure (bar g) and gross volume (m^3) is less than 1 and the max applied pressure is less than 0.5 bar g;
or

(3) the max applied pressure is less than 0.1 bar g.

Note: Vessels excluded by this clause and which are directly connected to a Registered Piping System should be included on the Scheme of Examination of the Piping System.

(b) Vessels subject only to a pressure between 0 and minus 1 bar g where failure could not create an Unacceptable Situation.

(c) Pressure Vessels containing liquids which cannot be pressurised by a gas or vapour, are at a temperature that would not cause the liquid to flash on release to atmosphere, and where failure could not give rise to an Unacceptable Situation.

(d) Protective Devices where failure to operate could not result on an unacceptable Situation.

(e) Pipe coils of conventional design other than those forming part of fired heaters or steam raisers.

(f) Equipment made from standard piping components where the gross volume is less than 0.5 m3 and which are designed to an appropriate piping specification. These items may require registration, however, as part of their associated piping systems.

(g) Vessels of small volume which are connected to, or are an integral part of instruments, e.g. positive displacement meters, DP cells, condensation chambers.

(h) Radiators invented heating systems for warming buildings.

(i) Hydraulic operating cylinders other than any communicating with a gas loaded accumulator.

(j) Pneumatic operating cylinders.

(k) Equipment containing highly viscous polymers or pastes (e.g. extruders, dies, melt filters) which are not Pressurised by gas or vapour.

The guidelines are:

a) Do not use salt or contaminated water for testing (e.g. bore hole, river, canal. lake or sea water).

b) When the process operating temperature is less than 70^oC then test water containing up to 30ppm chloride is permitted.

c) When the operating temperature is above 70^oC but the metal is flushed by process fluids or condensing steam at start-up, then the use of up to 30ppm chloride test water is permitted.

d) When the operating conditions are above 70^{o}C and the metal is not flushed by process fluids or condensing steam on start-up, then, providing the equipment is completely self-draining, test water with up to 30ppm chloride can be used, flushing with water containing less than 1ppm chloride.

e) When the operating temperature is above 70^{o}C and the Vessel is not flushed by process fluids or condensing steam and is not completely self-draining, only use test water less than 1ppm chloride. Dry out carefully by swabbing, and/or blowing with warm air (less than 70^{o}C).

Note:	Less than 1ppm chloride	=	demineralised water, or pure Condensate
	Up to 30ppm chloride	=	most portable or town supply waters

TEMPERATURE OF TEST FLUID

In-service Testing

When Vessels are made of carbon, carbon manganese or low alloy steels which have not been impact tested for use at sub-zero temperatures, there may be a risk of a brittle fracture during in-service testing. The liability of a brittle fracture in a ferritic steel increases as the metal thickness increases or the temperature decreases and is reduced by thermal stress relief.

To minimise the risk of failure, the minimum hydraulic test temperature for carbon and carbon manganese steel Vessels should be selected by reference to BS 5500 Appendix D. In view of the consequences of a possible failure, somewhat higher minimum temperatures should be selected if the hydrostatic head is substantial.

Tests should not deliberately be done at temperatures above those at which the item will be pressurised in service.

When Vessels are made from alloys steel, the Regional Materials Authority should be consulted when fixing the minimum test temperature.

If the test medium is water, as is usual, consideration should be given to the danger of water freezing.

Other service conditions may make certain steels prone to fracture if subject to an in-service pressure test at ambient temperature.
Where the Vessel operates:

a) above 200^{o}C in contact with hydrogen at more than 100 bar g partial pressure;

or

b) above 300oC, and is of low alloy steel;

then the in-service test temperature should be that agreed with the Regional Design and Material Authorities.

Acceptance Test after Modification or Repair

The acceptance test, after modification or repair, should be done above the minimum temperature specified for the original acceptance test. If this is not known, the Regional Materials Authority should be consulted. If the factors detailed in 4.1 (a) or (b) apply, a higher minimum temperature may be required and again, the REGIONAL Materials and Design Authorities should be consulted.

PROCEDURE FOR HYDROSTATIC TESTING

The works Engineer Nominee is responsible for ensuring that the following points are observed.

Supporting Structure

Before implementing hydrostatic testing, it is essential to confirm that the structure supporting the Vessel, and its foundations, are capable of withstanding the total weight of the vessel when full of water.

Joints

Joint ring and/or gaskets used for the test should be of the same material and dimensions as used for the operating duty, unless specified otherwise. Joint surfaces should be clean and bolting evenly torqued where a value is specified.

Removal of Air

Trapped air during hydraulic testing is a source of danger, due to it high energy content as compared with water and could cause an explosive failure should any part fail under test. For this reason, adequate steps should be taken to ensure the removal of air from the Vessel before applying the hydraulic test pressure.

Pressure Gauges

Calibrated gauges are required for the pressure test. The inspector should ensure that the positioning of the gauge and the effects of static head are considered when checking the applied pressure.

There have been several incidents in the Company where Vessels have been over pressured during a pressure test due to the inlet of the pressure gauge becoming blocked during he test and giving a false reading. It is recommended that dual pressure gauges are used to reduce the risk of this occurring.

Application for Test Pressure

The test pressure should be applied gradually to avoid shock and to avoid any danger of exceeding the specified pressure.

For repairs and modifications it is required that the test pressure be maintained for a minimum of 30 minutes, and then decreased by 5% to permit close observation of all parts of the vessel and its joints by the Inspector. The Inspector should record on the test report the time for which the pressure is held.

Hammering while Under Test

Vessels are not to be hammered under test.

Multiple Chamber Vessels

Each chamber of multiple chamber Vessels should be tested to the pressure detailed on the registration form, with no pressure in the other chambers (unless the registration form specifies that certain chambers shall be coupled together for testing)

Precautions during Filling and Emptying

Care should be taken during filling to prevent over-pressurising by mains pressure, thermal expansion or freezing. Particular care should be taken to avoid over-pressurisation when using high capacity air operated pumps due to the rapidity with which conditions can change. Use of a relief valve to prevent over-pressurisation is strongly recommended. Similarly, during emptying, steps should be taken to ensure adequate venting of the Vessel. This is to avoid subjecting the Vessel to vacuum as Vessels are not necessarily designed to cope with vacuum conditions. In all cases the test pressure and minimum liquid temperatures agreed with the Design and Materials Authority should be observed.

Drying

Where specified the Vessel should be dried out in the designated manner.

Leak Testing

1) Visual Inspection

2) **Radiography:-**

This is used to produce a full scale profile image of the internal and external profile of a pipe. The radiograph can also show the presence of corrosion products and/or weld defects. This technique is useful for indicating corrosion under insulation and thinning of pipework or vessel walls.

3) **Ultrasonics:-**

Ultrasonics are principally used for thickness measurement and flaw detection. Digital instruments are generally adequate for detecting trends within material thickness but detailed surveys will require oscilloscope equipment and a qualified operator.

4) **Magnetic Particle Flaw Detection:-**

This is where a background spray (usually white) is sprayed onto the metal surface to be tested. A spray is then applied to the white metal surface which is being magntised by the application of a powerful magnet, this in turn (because the send spray has metallic particles in it) shows any defects. However, the detection is limited to surface cracks only.

PRESSURE VESSEL DESIGN

1 WHAT A IS PRESSURE VESSEL

A pressure vessel can be defines as "Any closed vessel, of any capacity, which consists of one or more separate chambers, any or each of which is, or may be subjected to internal pressure greater or less than atmospheric".

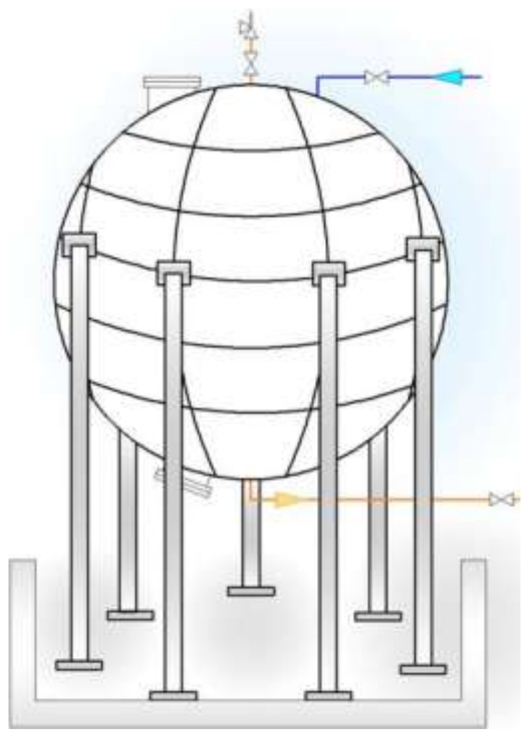
However, if this definition were taken too literally, it would mean that practically every container on the Works would have to be registered as a pressure vessel. ICI Engineering Codes and Regulations, Group B, Vol. 1.4 gives some guidance as to what needs to be registered.

2) VESSEL SHAPES AND TYPES

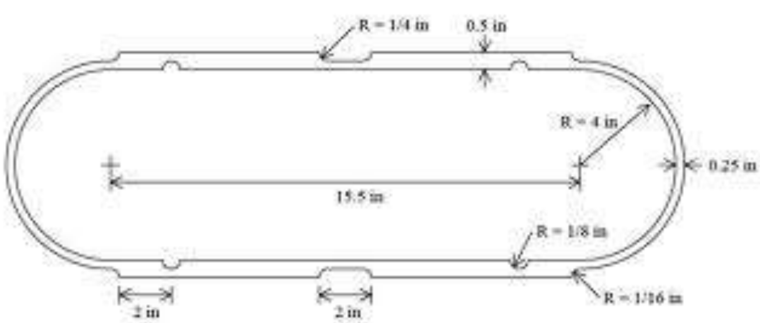
There are various shapes of vessel that can be used – cylindrical (with closed ends), spherical conical (usually as the ends of cylindrical shells), elliptical, rectangular etc. The most sensible (and the most economical) is either spherical or cylindrical. The most common shape is the cylinder, with ends dished to partial spherical form and this is the shape we will mainly concern ourselves with. However, the following notes and diagrams identify the various shapes of ends that can be used to close a cylinder. Vessel types are numerous, but included are:-

Reactors
Storage Tanks
Hoppers
Heat exchangers
Distillation Columns
Absorbers
Scrubbers
Drums
Road and Rail Tanker Barrels

SPHERICAL



CYLINDRICAL WITH DISHED ENDS



2a) PRESSURE VESSEL ENDS

General

The choice of pressure vessel end is affected by a large number of factors, any of which could be of prime importance in a particular case. The choice between Domed, Conical and Flat ends is usually governed by the duty the vessel has to perform.

A conical end would be a logical choice for the lower end of a vessel which is required to discharge its contents by gravity. Vessels which are intended, primarily, to contain pressure, should have ends which use material in the most efficient manner. Ideally, this would be a hemispherical end.

Flat ends are chosen for functional reasons; a typical case being a pressure filter base. Other uses for flat ends could be as ends of low pressure vessels, but as size increases then extra stiffness,, in the form of ribs, would be required.

Other factors affecting the final choice of end include the number of branches in the end, access to chargeholes, any special process requirements and economics of manufacture.

In order to compare the various ends, thickness should be taken as a criterion and the assumption made that each end is subjected to the same conditions of pressure, temperature, diameter and design stress.

Hemispherical End

This type of end has a true hemispherical form (see Fig. 2). As shown previously, the thickness of a hemispherical end will be half the thickness of a shell of the same diameter. In the region of the ‘shell to end’ junction there will be an increase in stress due to discontinuity effects.

Semi-ellipsoidal End

An end this shape has a central spherically dished area blending into a knuckle which provides the attachment to the cylinder. The contour of the end is very close to an ellipsoid (see Fig. 3).

This end is suitable for highly stressed vessels, because this shape gives the smallest discontinuity stress for a given thickness and height of end, where this is less than the radius of the vessel. Its thickness will be approximately equal to that of the shell which it is attached.

Torispherical End

This type of end consists of a spherical crown with a part toroid forming the transition from sphere to cylinder (see Fig. 4). Ends of this design have a flow profile which allows charge holes, etc., to be positioned close to the periphery of the vessel head, thus providing reasonable access for operators. This is the one reason for the torispherical head being used so frequently.

A second, severe, discontinuity stress occurring at the junction of the crown and the toroidal knuckle produces stresses which are likely to exceed those in the shell. For this reason, the torispherical end is thicker than a semi-ellipsoidal or hemispherical end made for the same duty.

Conical End

This design of end is shown in Fig. 5. The truncated cone may be used as a transition between cylinders of differing diameter. Conical ends may be attached to cylindrical shells without local thickening, but the design criterion will be the thickness local to the intersection. Stiffening rings may be used in other cases, and where local stiffening is inadequate totoidal knuckles may be used, as these are inherently stronger than plain cone/shell junctions. (See Fig. 6).

Flat End

A flat end is simple and compact, it is uneconomic in material and gives rise to very high discontinuity stresses at the shell/end junction. A typical flat end is shown in Fig. 7.

Fig 2 Hemispherical End

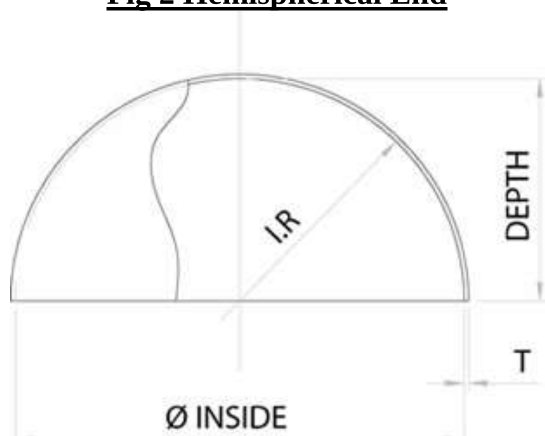


Fig 3 Semi-ellipsoidal End

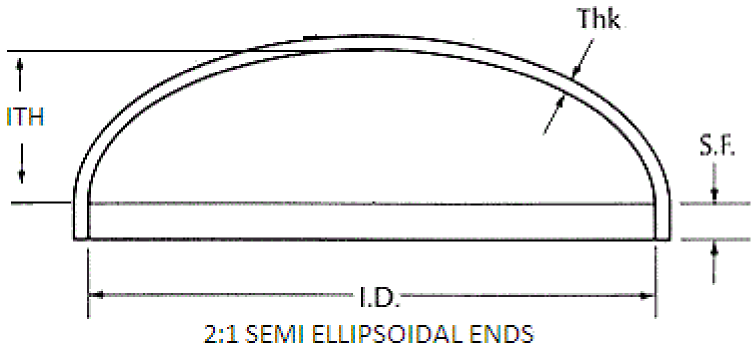


Fig 4 Torispherical End

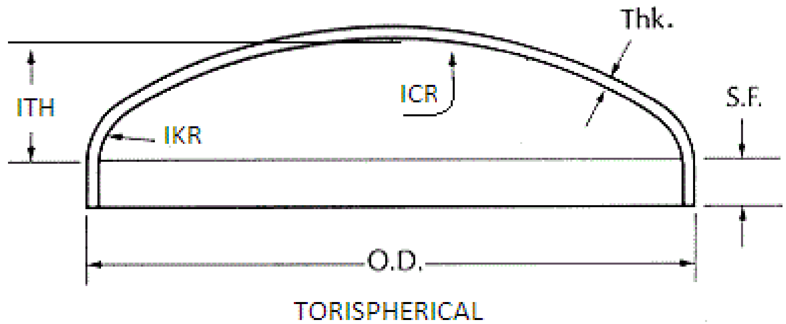


Fig 5 Conical End

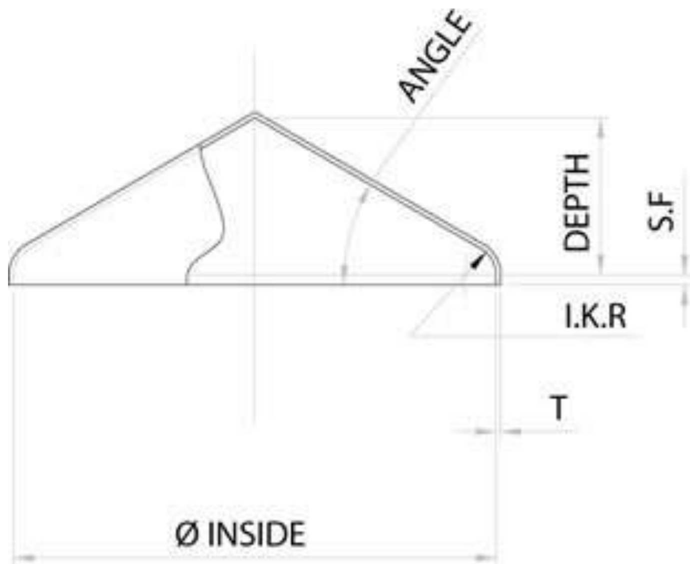


Fig 6 Cone with Knuckle Radius

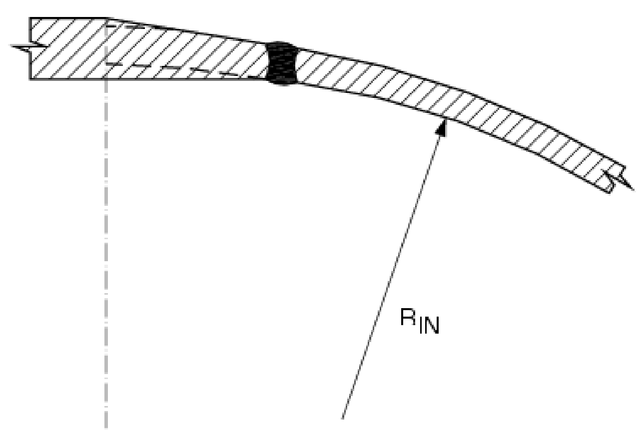
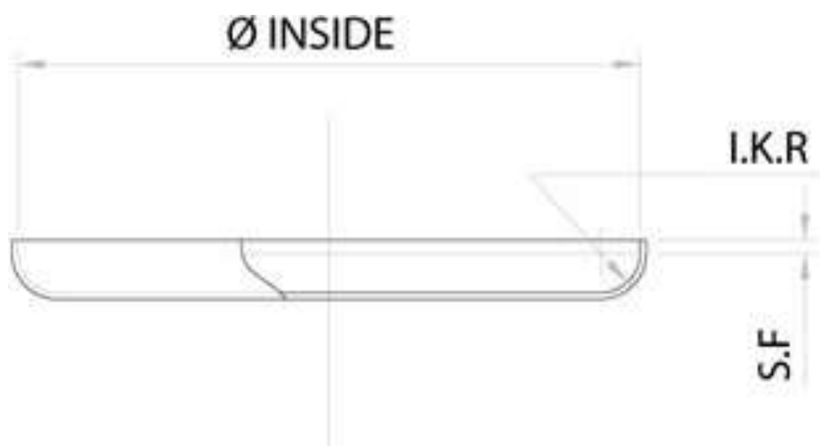


Fig 7 Flat Plate End



3 BASIC THEORY

3a THIN CYLINDRICAL SHELLS UNDER INTERNAL PRESSURE

By symmetry, the three principal stresses in the shell will be circumferential (or hoop) stress, longitudinal stress and radial stress.

If the ratio of thickness to internal diameter is less than 1/20, it may be assumed with reasonable accuracy that the hoop and longitudinal stresses are constant over the thickness and that the radial stress is small and can be neglected (in fact it must have a value equal to the internal pressure at the inside surface and zero at the outside surface).

FIG 1 (a)

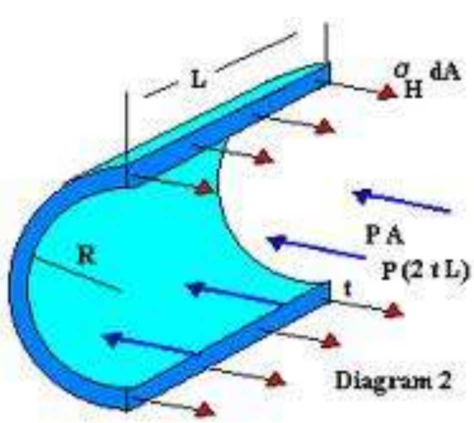
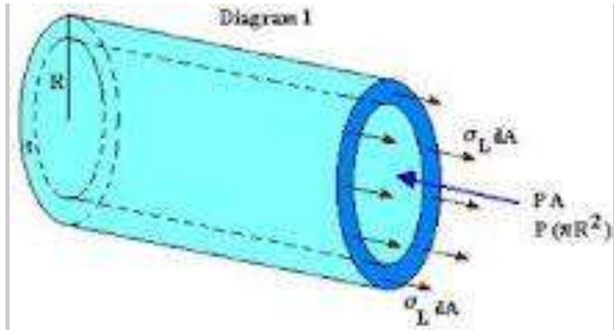


FIG 1 (b)



Let the internal diameter bed and the thickness t; p is the applied internal pressure, f_1 the hoop stress and f_2 the longitudinal stress.

Consider the equilibrium of a half cylinder of length 1, sectioned through a diametral plane. Fig. 1(a) f_1 acts on an area 2 t 1 and the resultant vertical pressure force is found from the projected horizontal area d 1.

Equating forces $f^1 \times 2tl = pdl$

$$f1 = {}^{pd}/_{2t} \quad \text{or} \quad \frac{pr}{t}$$

Consider the equilibrium of a section cut by a transverse plane, Fig. 1(b). f_2 acts on an area approximately = π dt (this should be the mean diameter) and p acts on a projected area of $\pi d^2/_4$, whatever the actual shape of the end.

Equating forces $f_2 \ \pi dt = p \ \pi d^2/_4$

$$F_2 = {}^{pd}/_{4t}$$

3(b) THIN SPHERICAL SHELLS UNDER INTERNAL PRESSURE

Again the radial stress will be neglected and the circumferential or hoop stress will be assumed constant. By symmetry the two principle stresses are equal; in fact the stress in any tangential direction is equal to f.

From Fig. 1(c) it is seen that:- $f.\ \pi\, dt = p\ \pi\, d^2/_4$

$f = {}^{pd}/_{4t}$

(where d = internal diameter)