OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

United Nations Industrial Development Organization

Distribution
LIMITED

ID/WG.[illegible]/3
[illegible] November 19[illegible]

Original: ENGLISH

UNIDO/FAI Interregional Meeting on Safety in
the Design and Operation of Ammonia Plants

New Delhi, India
[illegible] - 24 January 19[illegible]

STEPS TO BE TAKEN DURING FABRICATION OF EQUIPMENT TO ENSURE SAFE OPERATION OF AMMONIA PLANTS 1/

by

[illegible]. Sarma*

---

* Officer on Spl. Duty (Projects), The Fertilizer Corporation of India Ltd. New Delhi - 110049, India, UNIDO Consultant

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

id.75-8700

16810

United Nations Industrial Development Organization

[illegible]

Original: ENGLISH

[illegible]

[illegible], India
[illegible]

[illegible] EQUIPMENT [illegible] AMMONIA PLANTS

[illegible]

[illegible]*

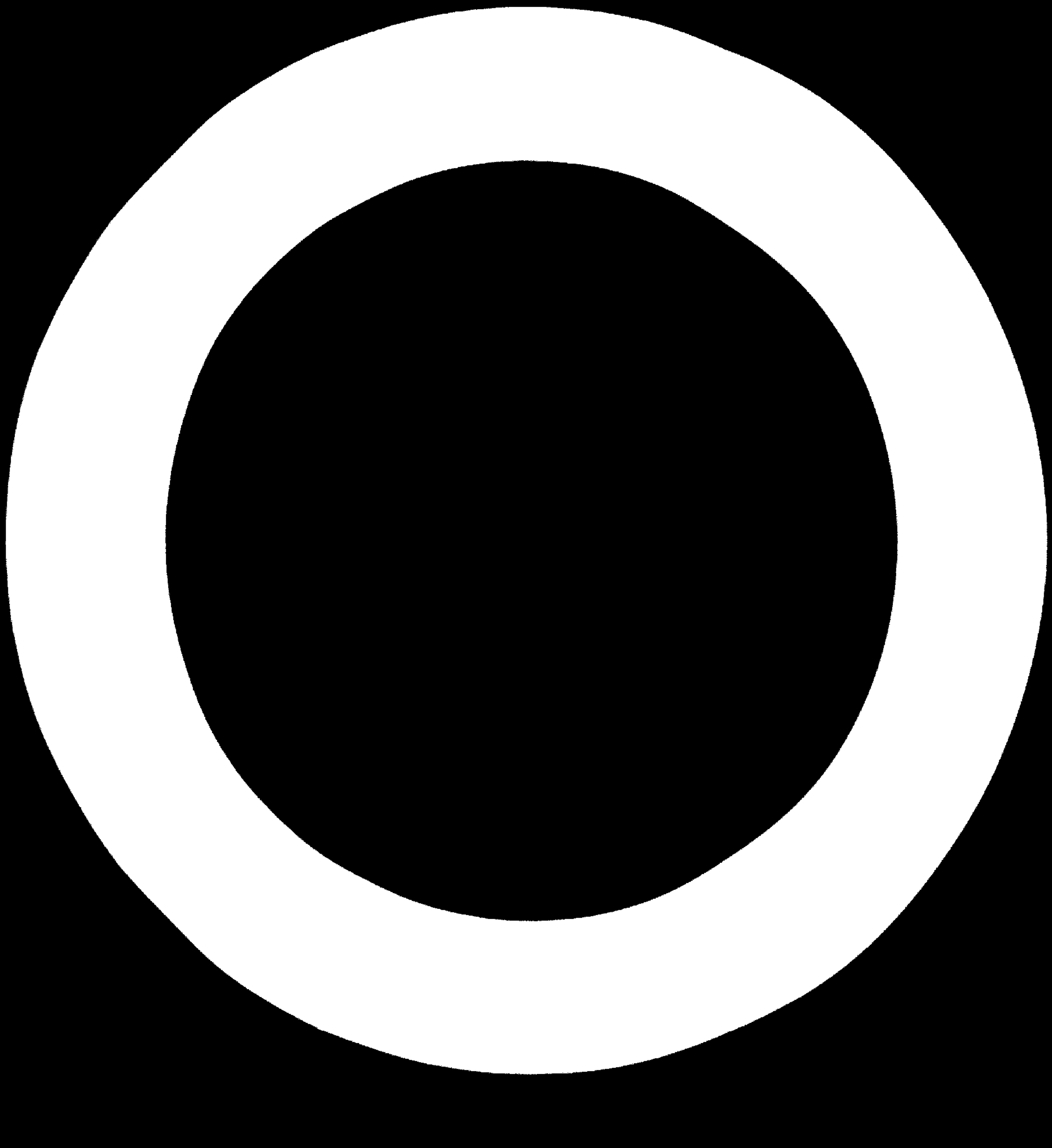
The fabrication of process equipment for ammonia plants is being done by a number of firms in the World. Many of these firms have taken this up as an extension of their earlier production programme, which might have been the fabrication of structures, ship building, manufacture of pressure vessels for steam and power generation units or other similar industries.

The paper attempts to bring out the fact that the requirements to be met by equipment for an ammonia or similar plants include not only the ability to withstand pressures and temperatures from a purely structural point of view but also to ensure that the equipment fabricated can continue to operate efficiently and safely for long

* Officer on Spl. Duty (Projects), The Fertilizer Corporation of India Ltd. New Delhi - 110049, India, UNIDO Consultant

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

id.75-870



periods with [illegible] temperature conditions [illegible] corrosion and other factors.

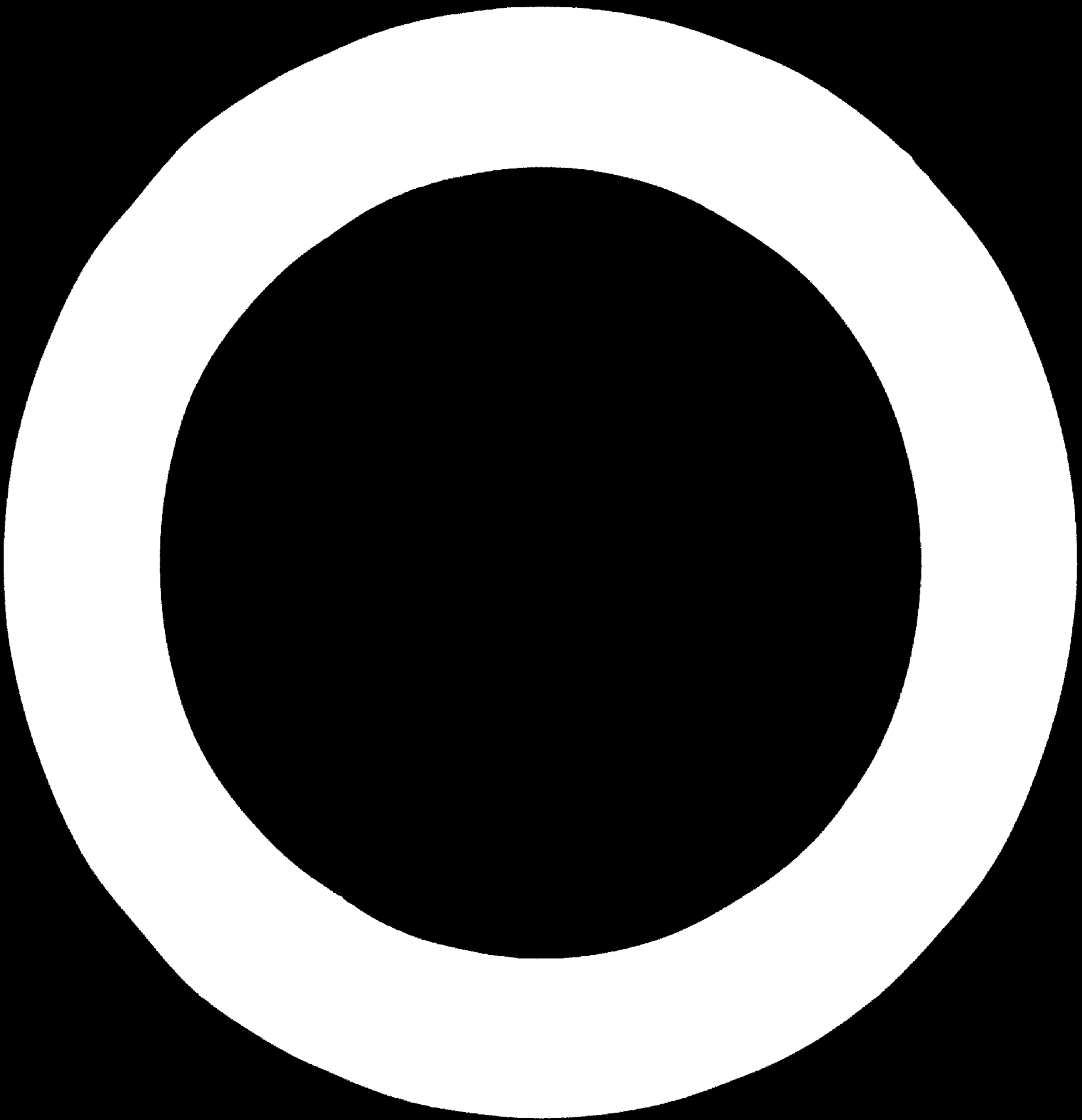
Attention [illegible] drawn [illegible] that the material meant [illegible] equipment for ammonia plants should [illegible] and every care should be taken to [illegible] right material goes on the right job. [illegible] materials during fabrication, [illegible] should be prevented by close fol[illegible] need to check the materials well before fabrication [illegible], in spite of the materials being [illegible] by certificates from the manufacturers or [illegible] has also been stressed.

The paper [illegible] proper procedures in the [illegible] the properties of the [illegible]. In this connection, special attention [illegible] post welding heat treatment.

Throughout the paper [illegible] the importance of a high degree of quality control as the prime requirement while [illegible] equipment for the ammonia industry due to the [illegible] conditions under which the equipment operate [illegible] has been indicated that the quality control [illegible] should have an independent status in the organisation and they should be able to exercise their judgement and their authority to make sure that the quality of the products leaving the shop is first class. It is pointed out that to achieve this, it is essential that stage-by-stage inspection starting from the time the raw material is received at the shops to the time of final despatch of the fabricated equipment should be arranged for and such inspection executed scrupulously.

Attention has been drawn to the fact that careful training of supervisors and workmen to the need for strictly following the procedures and to understand the implications of deviations is necessary to modify their approach to fabrication of equipment.

In brief the burden of this paper is that the maintenance of a high standard of quality in the equipment being manufactured for ammonia production and similar industries is not just part of one's work but the basic philosophy which governs all actions in the shop.



1. [illegible]

1.01 With [illegible] development of the heavy chemical industry [illegible] and [illegible] of synthetic fertilizer, [illegible] and many other industrial and consumer [illegible], the fabrication industry has recorded a significant expansion in many countries. A number of engineering [illegible] in developing countries [illegible] equipment to the process industry.

1.02 Many of these firms started as structural fabrication shops engaged in the fabrication and erection of factory buildings, bridges and other similar installations. Some firms engaged in the ship building industry have diversified into the process equipment manufacturing field. Similarly firms engaged in the manufacture of boilers for steam and power generation have also taken up the manufacture of process equipment. In addition to these, a few firms have been established primarily for the fabrication of [illegible] equipment as their main product.

1.03 The [illegible] gained in the fabrication of structures, [illegible] of ships or manufacture of steam generation equipment has certainly been valuable and has assisted these shops in diversifying into the process equipment field. Their contribution to this comparatively new field of [illegible] has been substantial.

1.04 However, the [illegible] or the approach required to be adopted for the manufacture of process equipment, particularly [illegible] processes like the synthesis of ammonia requiring the use of high pressures and including plants based on complex processes for the production and purification of the synthesis gas, is, in certain ways, different from what is required for the production of engineering goods - whether they be heavy bridges or ships or even steam generation units and auxiliaries. This is not to say that these industries do not require the use of modern technologies or competent supervisors and workmen. The equipment required in the shops also is, in many cases, similar to what is required for the manufacture of equipment for an ammonia plant. In fact, it is this similarity that has made it possible for factories engaged in structural or boiler work, to diversify into chemical plant equipment fabrication.

1.05 The engineers in the design offices and the shops in an engineering works would, to a great extent, understand the effects of any deviations from the specifications on the final stability of the structures as basically they are, by education and training, familiar with the structural and mechanical aspects of the structures or vessels that they fabricate. To this extent, the structures or machinery that are fabricated get the necessary informed attention and significant deviations from what is specified are avoided in the normal course.

1.06 In the case of building chemical plants, however, any deviation in the process of manufacture or errors in the treatment of the materials under fabrication may contribute to failures on account of factors, such as, accelerated corrosion, even though from the point of view mechanical strength the equipment may be satisfactory. These factors, therefore, have to be specifically and effectively brought to the attention of persons responsible for the production of these equipment.

1.07 Again in the case of the engineering industry producing a certain type of structures or equipment, the range of quality of raw materials required is fewer in number compared to the range of materials used in the manufacture of equipment for the process industry. Starting from ordinary low strength structural quality steel through various qualities of pressure vessel or boiler quality steels and a variety of low alloy steels, stainless steel, aluminium and, some times, exotic materials like titanium and zirconium, a large number of qualities of materials are used in the manufacture of equipment for the process industry. These materials have their desirable strong points and, some times, peculiar weak points. Any mix up that may inadvertently occur during storage or fabrication can have profound affects on the finished product. Sometime, even the use of a superior quality material in place of another, which is comparatively inferior, can result in damage under certain corrosive conditions leading to rapid damage to the components made of the comparatively inferior, though normally suitable, material.

1.08 It is with this background that this paper has been prepared, the purpose being to draw attention to the imperative need to maintain a close watch at every stage of fabrication of equipment for the ammonia and other similar industries and ensure that every step is taken to achieve the most effective means of quality control.

2. Increasing complexity of equipment.

2.01 The synthesis of ammonia, on an industrial scale, has always called for equipment of a high quality in view of the severe conditions under which the different plants have to operate. High pressures, required for the synthesis reaction, necessitate the use of vessels, heat and cold exchangers and other associated equipment to be designed and fabricated using techniques not ordinarily required for many other processes. In certain sections high pressures combine with fairly high temperatures of operation.

2.02 In the early days of the ammonia producing industry, plant capacities used to be comparatively small. With the large scale use of ammonia - particularly in the production of synthetic nitrogenous fertilizers - the trend towards larger capacity plants offering economies of scale was inevitable. Development of very large capacity plants, however, had to await development in the technology for manufacture of larger equipment - both static and moving.

2.03 In the earlier plants for the production of ammonia, high pressures were more or less limited to the final purification and ammonia synthesis sections. The largest or the heaviest equipment was the ammonia converter with other vessels and heat exchangers in the synthesis loop forming most of the remaining high pressure equipment. These could conveniently be manufactured using forgings for vessels. These forged high pressure vessels held the field for a comparatively long time, but this type of construction imposes certain limitations in regard to size.

2.04 With the realisation of the need to go in for larger capacity plants, alternative methods for the manufacture of large vessels for high pressure operation were investigated. Solutions in the form of strip wound vessels, multilayer vessels and other methods of manufacture on similar lines were developed. Today a good percentage of these vessels are made up of a number of layers, there being a few variations in the design of the equipment used and the manufacturing technology adopted. Layers varying in thickness from about 4 mm to about 50 mm are adopted depending on the particular technology selected.

2.05 While these developments would have enabled larger sized synthesis units to be manufactured, limitations on the capacities of mechanical equipment like compressors, circulators, etc. delayed the emergence of really large capacity single stream ammonia plants as a practical and a more economical alternative. The development of centrifugal compressors for the compression of synthesis gas made the construction of plants with single stream capacities of the order of 600 to 1500 te/day possible.

2.06 These developments and the consequent increase in the capacities of process equipment for ammonia synthesis by themselves call for much more sophisticated equipment than required earlier. New processes perfected on the gas generation, shift conversion and the purification sections progressively raised the possible capacities of the front end of the ammonia plants also. Conditions of operation, such as pressures and temperatures, conditions conducive to rapid corrosion and other factors also had to be contended with while adopting these new processes.

2.07 Thus, while a stage has been reached now when large capacity single stream plants can be constructed and consequent benefits reaped, these features have brought in the need for a much higher amount of specialised techniques and care in the fabrication of equipment required to ensure safe operation of these plants over long periods. While down-time in plants was, in the earlier days, primarily due to unsatisfactory operation of the mechanical equipment, problems that arise now more frequently can be on account of static equipment unless extreme care is taken in the design and fabrication of such equipment. This stresses the importance that has to be attached to the fabrication of equipment required for an ammonia plant.

2.08 Design of equipment for containing and transmitting process fluids at high pressures and temperatures often combined with corrosive conditions, assumes great importance. These equipment should be strong enough to be capable of safe operation under these conditions but, at the same time, flexible enough to accommodate thermal expansion and contraction during operation and under standby conditions. Careful analysis of stresses on various points in the equipment under different conditions and making provisions for these to be taken up without possible damage to any of the parts of the equipment is a challenge to be faced by designers. Such designs, as are evolved to meet these requirements can be quite complex from the point of view of fabrication and maintenance and, therefore, the real success in terms of reliable operation of the various units would be impossible unless the fabrication of the equipment also is done with great care.

3. Materials

3.01 The starting point, from the point of view of the fabrication of equipment, is the selection and use of proper materials of construction. Developments in metallurgy and manufacturing processes have made available different qualities, forms and sizes of raw materials like plates, tubes and forgings for equipment fabrication. This has made it possible for the designers to chose materials with the required properties to meet specific requirements of equipment. Unlike industries where the mechanical properties of the material, under certain operating conditions, are almost the only requirement to be met, the materials for an ammonia producing plant have to be capable of withstanding stresses under a wide range of temperatures often combined with the action of process fluids under conditions conducive to steady damage to the structure of the material. While the effect of corrosive chemicals on the various materials of construction may be appreciated by the staff in an engineering shop, they may not realise that action of such apparently harmless gases, like hydrogen, on the materials of pressure vessels can be a direct cause of premature failure of the equipment. It may also not be obvious that materials can fail due to stress corrosion cracking as a result of improper fabrication. This lack of appreciation may sometimes lead to overlooking certain important guidelines in the manufacture of equipment with disastrous consequences.

3.02 Although the different qualities of materials might have been obtained from any of a number of reputed firms and these might have been obtained after inspection by reputed surveyors, it would be better to check the materials at the place of the fabricator well before fabrication is started. It would normally be felt that it should be safe to assume that materials supplied would be in accordance with the specifications. This is particularly so if the quality is confirmed by the certificates issued by well known firms of surveyors. However, cases are not unknown where the actual supplies have not stood up satisfactorily to one or more critical tests at the fabrication shops. Accepting such materials entirely on the strength of manufacturers' or the surveyors' certificates and proceeding with the fabrication of equipment could occasionally result in avoidable rework or - in extreme cases - rejection of fabricated components or equipment. This is not to suggest that any of the concerned agencies are supplying substandard material in general, but only to point out that it pays to take necessary precautions to prevent the fabricator and the customer suffering loss of time and money due to occasional mistakes that may have occurred at the raw materials manufacturing stage.

3.03 As an example, it may be mentioned that in one or two cases it has been found that the actual mechanical properties of the materials, at specified temperatures, have been found to be considerably inferior to the specifications issued as also as indicated in the certificates received from an association of surveyors. As the raw materials, as received, were not tested well before fabrication was to be started and defects were noticed only at the time of testing welded specimens, a certain amount of avoidable loss of time occurred. In one of the cases it has been reported that, as a result of the material supply having been found to be not conforming to specifications after receipt at the shops, the entire lot of material had to be replaced. Although, in this particular case, the supplier, apparently, agreed to replace the material, the time lost, the delay in fabrication and construction of the plant and the loss of effort put in before the faults were discovered could not, obviously, be compensated.

3.04 These become particularly relevant in special cases as when handling special materials for operation at very low temperatures where a specified minimum impact strength is required in the finished products while operating at such temperatures or for duties involving highly corrosive conditions. The conditions of operation and the consequences of failures do not permit of any risk being taken.

3.05 Another defect that could lead to a waste of considerable amount of work done, is the presence of laminations in thick plates. Such laminations may lead to rejection of the plates - particularly if these are noticed at the edges to be welded together. If this defect is noticed only after the edges are prepared, a considerable amount of work done would be wasted. Ultrasonic tests of the plates at a number of points-with special attention to the edges where welding will have to be done - should be considered essential. The time and money spent on this test will be more than compensated by the avoidance of losses on account of rework and rejections that may result even if only a small percentage of the plates happen to have serious defects.

3.06 Equally important is the care to be taken in the receipt and handling of materials in storage and through different stages of fabrication. Without a proper system of identification of the material from the time it is received in the stores and methods for ensuring that each piece from the original material is clearly identifiable at any stage during fabrication, mixing up of materials could occur with forseeable results. Even in the best of shops such a mixing up of materials could happen if extreme care is not taken to ensure that the material being used is exactly the one that is required. A reliable system is essential for the transfer of identification marks from the original material to cut-pieces. The procedures have to be followed strictly through all stages to avoid the entry of the wrong materials into the fabricated equipment. These operations are to be done with the close association of well qualified inspectors employed by the fabrication shop as well as the inspectors of the customers or inspectors belonging to the surveyors who may be appointed to ensure proper quality in the products.

3.07 To stress the importance of the high care required to ensure that wrong materials do not get included in an equipment by mistakes in the handling of materials, a case of the failure of a major equipment in a large waste heat recovery system could be cited. As a result of a detailed study, the failure that occurred, was attributed to the presence of one or two short lengths of carbon steel tubes among thousand of metres of the specified alloy steel tubes used. The severe conditions of operation naturally led to premature failure of the inferior tubes. This, in turn, caused considerable damage to the remaining parts of the equipment as the equipment was handling steam at a high pressure and high temperatures.

The location of the damaged carbon steel tubes and replacement of these as well as the damaged alloy steel tubes took much considerable time and caused loss of production for the corresponding period. This is a case of the oft-quoted story of the King losing a Kingdom for want of a nail.

4. Background

4.01 While each of the variety of materials used have their strong points, many of these can suffer damage if due precautions are not taken during all stages of fabrication. For example, stainless steel which resists corrosion by some of the very corrosive acids can fail if during transport or storage it comes into contact with sea water or other chlorides. In spite of possessing superior mechanical properties, stainless steels are susceptible to work hardening and hence hammering or other forms of impact should be avoided. Such factors become very important when these materials are used for critical equipment.

4.02 In the case of many of the materials, certain standard procedures may be prescribed for general guidance. But, as the conditions of working may vary from shop to shop and the equipment available may also vary, it would be desirable to establish the correct technology to be adopted based on specific studies made. These tests and process developments should take into account the actual conditions of the shop. The recommendations made would necessarily depend on the results obtained on mechanical tests on the test pieces, studies on changes in the grain structure of the material, as a result of welding and other operations and tests for corrosion resistance etc. Steps are required to alter the structure suitably to meet specific requirements also should form a part of the development of technology to be adopted.

4.03 This is to ensure that whatever changes are likely to take place in the material during fabrication will be known in advance and that the processes followed during and after fabrication will be such that the finished product retains or develops the qualities that are required for the satisfactory operation of the equipment. There is very little room for arbitrary decisions in this area.

5. Fabrication

5.01 It has been mentioned earlier that materials can suffer from work hardening or increased susceptibility to corrosion if proper precautions are not taken in handling. This factor needs to be constantly kept in view and care exercised to avoid acts of omission or commission that may lead to such deterioration. Manufacturers of the raw materials and the technologists, who detail the processes to be adopted for fabrication, may specify the recommended procedures to be followed. It is essential that these directions are closely and scrupulously followed. This may appear to be a superfluous advice but this warning is being sounded as there have been cases of defective equipment being produced in spite of the availability of proper materials and good workmen. The poor results in these cases could be traced to a lack of appreciation of such not so obvious but important requirements.

5.02 The care required to be exercised cannot be ensured without the education of the workmen and the supervisory staff. The development of an attitude that fabrication of equipment for critical services requires a different approach to what may be acceptable in the fabrication of structures or similar items is possible only if the persons responsible are fully aware of the strengths and weaknesses of the materials they handle.

5.03 At least some of us may know competent and dynamic technicians who may have, in addition, the required capacity to organise new operations but who have an exaggerated opinion of their knowledge combined with an utter contempt for anything theoretical or found in books. While they could be very successful in some types of work they can be responsible for disasters if their enthusiasm and prejudices are given free play in the manufacture of equipment for an ammonia plant. Seeing such people in action and having, later on, to see the effects of such attitudes on the equipment are what have prompted these statements.

5.04 Careful handling is required from the stage the materials are taken into the shop; Correct marking out, proper cutting both in regard to the method adopted and accuracy, edge preparation including cleaning of the cut edges are all operations to be executed perfectly if the final product is to have the required high quality. The same applies to rolling of plates to exact dimensions including the production of shell sections with the minimum of "out of roundness". These are not being particularly mentioned as these [illegible] generally be obvious and hence taken care of.

5.05 During the preparation of the surfaces before welding, it should be ensured that the surfaces being welded together are not contaminated by other materials. Small areas where inferior material has entered the work can be starting points for failures due to corrosion or other factors. It is strongly recommended, particularly when handling stainless steel and other similar materials, that grinding wheels, brushes and other equipment used are exclusively set apart for the particular job so that particles of inferior materials from other jobs are not transferred to the higher quality work being done. Contamination by oil or grease also is to be avoided, the importance of this being greater when handling materials such as stainless steel.

5.06 One of the important areas where close attention is called for is in regard to the heating of the job - where necessary - before welding. Many alloy-steels require preheating to certain temperatures before welding is started and these temperatures have to be maintained during welding. Equipment and procedures adopted for this preheating have to be such that one can ensure uniform heating to the temperatures required for the particular type of material. Efforts are required to be put is to see that over-heating does not occur at any particular part of the equipment being fabricated.

9.07 Welding itself, obviously, has to be done strictly in accordance with the recommended procedure. Apart from using proper pre-heating procedures, where required, and the proper quality of electrodes, the actual welding itself has to be done adopting speeds, current intensities, etc., which are conducive to the development of a good quality weld without cracks or causing undue stresses. Even where automatic welding is used, constant attention will have to be given to see that the welds are uniform and fault free. Effective cleaning between different runs of welds is a normal requirement and should be insisted upon in all cases.

9.08 With the advent of ammonia processes based on the partial oxidation of fuel oil, coal and other feed stocks, large oxygen plants are required as part of ammonia plants. The manufacture of equipment for air separation plants and liquid nitrogen wash plants also, therefore, may come within the purview of ammonia plants. These have their own peculiarities of requirement of equipment considering that many sections operate at extremely low temperatures. Precautions indicated in the earlier paragraphs are valid with equal if not greater force in the case of fabrication of equipment for the air separation and similar plants. In these plants, aluminium alloys are used in many sections by most designers and this requires special training for welders and special procedures and precautions during fabrication.

5.09 Assembling of completely fabricated equipment or some parts of equipment are after required. This has, obviously to be done with sufficient precision to ensure that, during operation, problems on account of leakage of process fluids under high pressure or mechanical defects due to improper assembly or alignment do not cause interruptions in operation or lead to the development of dangerous situations. A failure of a gasket even at the time of hydraulic testing of a high pressure equipment resulted in an operator suffering a serious injury due to the water jet piercing his body as if by a sharp instrument.

5.10 The next operation requiring careful attention is the stress relieving of fully fabricated equipment or major components. The use of higher thicknesses in the plate and other materials, alloy steel and alloys call for careful control of the heat treatment operations. The properties of these materials are affected by heating and cooling and they call for individually designed heating-soaking-cooling cycles. Extreme care in the post-weld heat treatment is essential without which the final product may be rendered unsuitable.

5.11 Furnaces and auxiliary equipment capable of handling large sized process equipment are generally used for this final heat treatment operation. Underheating or overheating can alter the properties of materials to undesirable levels. Similarly the rate of heating and cooling have to be kept within the recommended limits to ensure that the structure of the material and dimensional accuracy of the fabricated equipment are kept as desired.

5.12 An important requirement that has to be met is the maintenance of a uniform temperature over the entire equipment being heat treated. This would require that the furnace and the system of burners are such that the input of heat into the system is uniform and the circulation of the hot gases eliminates hot spots and cold areas. Deformation of the equipment and, in extreme cases, structural damage to the material can result if conditions are not prevented from going out of control. Temperature measurements are to be provided for from a large number of points on the equipment. The temperatures at different points are to be constantly monitored and corrective action taken with minimum delay if there is any tendency to deviate beyond the permissible limits. Automatic controls and recording of temperatures continuously are desirable if not essential.

5.13 It may be worthwhile mentioning at this stage that a piece of equipment [redacted] had to be rejected recently on account of local overheating resulting in distortion of the equipment. Deterioration in the physical properties in the material was also noticed at the location which was subject to overheating. Even where there is no serious overheating as such, an appreciable difference in temperatures between two sides of a pe piece of equipment or two different areas along the length of the equipment could lead to distortion.

5.14 With the inevitable increase in the sizes of ammonia plants, it is being found necessary to shift some of the work that has, up to now, been done in the fabrication shops to the plant sites due to the sizes of the individual equipment being too large for transport over sections of the route between the fabricators' works and the site of erection of the plant. Generally, the conditions of work at a plant construction site are bound to be less conducive to the production of quality equipment and hence greater care is required in the organisation and execution of such work. The precautions recommended for shop fabrication apply with equal force for site fabricated equipment and this would require considerably greater efforts to be put in. During the entire process of assembly and welding, additional protection to counteract the undesirable effects of exposed locations will have to be provided.

5.15 Stress relieving of such large equipment at construction sites is a specialised work. Where it is a matter of stress relieving of one or two welded joints only, comparatively simple methods are available involving the use of bands of electric resistance heaters or gas fired burners designed to give uniform heating around entire welded seams. Temperature measurement and controls at a number of points around the circumference are required to be maintained. Suitable insulation has to be provided to minimise heat losses and achieve the recommended rates of heating, soaking and cooling.

5.16 In some cases, where an entire vessel weighing hundreds of tonnes is to be stress relieved at site, the problems become greater. But here again, there have been some recent developments enabling heat treatment of such vessels to be done effectively. The vessels are completely insulated and specially designed burners, one or two of which are capable of supplying the necessary heat, are used. The design of these burners is such that a high degree of turbulence is created which helps in ensuring uniform heating of the entire vessel. This, of course, is a very specialised job and, as such, requires special skills. To obtain and maintain proper temperatures over the entire vessel would require careful planning and constant attention during the entire heat treatment period.

5.17 Mention has been made in the earlier parts of this paper that to cater to the requirements of the larger capacity ammonia plants, new technologies had to be developed for the manufacture of high pressure vessels. A brief review of the more usual methods may be made at this stage.

5.18 The earlier practice of using single forged vessels offered a satisfactory solution for comparatively small capacity plants. These, however, could not be made in sizes large enough to meet the requirements of the modern high capacity ammonia plants. Ingots are to be cast as the first step, which are then pierced and subsequently forged to the required dimensions. These ingots have to be three or four times as heavy as the finished forgings. The handling facilities in the foundries and the forging shops soon proved to be a limitation which prevented larger high pressure vessels being made of forged construction. Presses also would have to be much higher in capacity if very large forging is to be manufactured.

5.19 To overcome the problem, alternative technologies for high pressure vessel manufacture were investigated and some methods have been developed. One of the earlier developments is the manufacture of vessels with a fabricated shell of medium thickness as the core over which a number of specially formed strips were wound. These strips were heated before being applied tight over the preceding layers and on cooling these caused a pre-compression of the inner layers. Theoretically, any thickness could be achieved by merely increasing the number of layers. The size, however, is subject to limitation by the capacity of the grooving lathes and the winding lathes. This method, which, to some extent, is still used in some industries, has, more or less, gone out of use as far as the manufacture of ammonia converters and other similar equipment are concerned.

5.20 A second method of fabrication of high pressure vessels is by building up the thickness by means of the use of a number of concentric shells of about 50 mm thickness. The shells are made to exact dimensions with each succeeding outer shell having an inner diameter slightly less than the outer diameter of the preceding inner shell. Each of the outer shells is heated and the expansion of the shell so caused facilitates the insertion of the inner shell smoothly. On cooling, the outer shell shrinks and causes a pre-compressive load on the inner layers. Many high pressure vessels have been made by this method and are in successful operation in many parts of the world.

3.21 There is another method, which is quite popular and, like the previous method, does not suffer from any limitations in regard to size or weight of vessels that can be fabricated, except the limitation imposed by the handling facilities at the shops and the sites and capacity of the transportation system between the shops and the plant sites. In this method, an inner shell with a thickness of the order of about 25 mm is made of welded construction and thoroughly checked for good quality by the usual methods of quality control. On to this inner shell, layers of about 6 mm thickness are added by wrapping. Each of these layers is made up of 2 or 3 sections depending on the diameter of the shell. These are prepared with dimensions to close limits and wrapped on to the shell. A tight application of the layer on to the preceding layer is achieved with the help of a hydraulically operated tension belt arrangement and the longitudinal joints are welded together. The shrinkage of welds at these joints induces a compressive load in the inner layers. By this method, any vessel thickness is possible by suitably increasing the number of layers.

3.22 Individual sections, thus manufactured, are usually 3 metres to 4.5 metres long depending on the shop facilities. Any length of the finished equipment can be obtained by welding together the required number of sections.

3.23 A recent development on similar principles is the manufacture of thick vessels using plates of about 4 mm thickness wound over an inner shell as a continuous coil. The application of the coil is done using equipment with a tensioning device which causes a certain amount of pre-compression of the inner layers and the vessels so manufactured act, more or less, like a multilayer vessel described earlier. Here longitudinal welding is required only at the start of the coil and at the finish. The length of each section that can be made by this process at present, is limited to less than 2 metres by the width of coils that can normally be made available by steel producers and results in a larger number of circumferential joints for the same length of vessel as compared to a vessel manufactured by the multilayer process described earlier.

5.24 While these processes have the advantage that vessels of practically any size can be manufactured to suit the requirements, the effective inspection of the welding - both longitudinal and circumferential - by the usual methods, such as by radiographic examination, poses serious problems. In the case of longitudinal welding, the welds are staggered and location of faults in a 6 mm thick weld in one of a large number of layers is difficult. Similarly, the radiographic examination of the circumferential joints also is difficult as the total thickness is made up of a number of layers. Due to possible small gaps between the layers, the radiographic pictures can be misleading.

5.25 The quality of the fully fabricated equipment, therefore, depends, primarily, on the ability of the individual welders and the effectiveness of the welding equipment. Operators and equipment employed for such manufacture have, therefore, to be constantly checked for reliable high level performance and work done by them kept under close scrutiny. As individual layers are only of the order of 6 mm in thickness, there should, normally, be no problem in achieving good welded joints by manual or automatic welding, but just the same constant care is required to be exercised at every stage of fabrication.

9.26 Most of the points mentioned so far have referred to the precautions to be taken to ensure that the equipment, when fully fabricated, will have the required physical properties to ensure safe working under the actual conditions of operation of the plants. This, of course, is a primary consideration, but certain other aspects also have to be closely watched to achieve the desired operating results. This would refer to the stage at which assembly of equipment is done.

9.27 A good example of the need to ensure accurate assembly is the case of the installation of trays in columns used for absorption, distillation and other similar operations. It may not be quite obvious to a fabricator that the successful operation of a column with trays is largely dependant on the care with which the trays are assembled in the columns. Even a very minor deviation from the horizontal, of the trays, after the columns are erected, can cause a marked reduction in the efficiency of the equipment and consequently the performance of the plant as a whole, though even a substantial deviation in this regard may not weaken the equipment from the purely structural point of view. This is just one example. Similar reduction in performance can be caused by improper assembly of heat exchangers, agitators or other mechanical devices and, as such, all these operations also require effective scrutiny and application of stringent quality control measures.

6. Quality Control

6.01 From what has been stated, it will be obvious that effective quality control of a very high standard is essential in the manufacture of critical equipment for ammonia and other plants. It has been indicated under the different major operations that checks for quality of materials, sound welds, possible changes in the grain structure of the material and other relevant factors, should be made at the appropriate stages of fabrication.

6.02 To enable this to be done, the quality control department has to be well organised. The staff of this important department should consist of engineers and metallurgists, who understand the importance and implications of each procedure. They should be able to extend technical assistance to the production staff in the shops and also educate them on the consequences of a any deviation from the recommended procedure.

6.03 An important link in the set up for quality control is the laboratory which plays a very essential part. The work of the laboratory, on the one hand, includes testing of raw materials and test coupons attached to the job during welding and helping to assess the quality of the materials and the work done. On the other hand, the laboratory has also to make critical studies of the effect of welding and other operations on the material, carry out the trials and recommend detailed procedures to be followed during the different stages of fabrication as pre and post welding heat treatment, in order to achieve the desired properties of materials in the fully fabricated equipment. Many of the above jobs have to be done in cooperation with the technology development group who may form a part of the production department. The laboratory facilities therefore will have also to play their part as a close associate of the production technologists' group.

6.04 With these responsibilities to be discharged effectively, the organisation of the quality control wing - both in terms of equipment and competent men - assumes considerable importance. Equipment for the testing of materials for tensile, compressive, shear, bending, hardness and impact are essential. Facilities for these tests to be conducted at temperatures ranging from very low, as for equipment for Air Separation Plants, to very high temperatures are required.

6.05 Equipment for metallographic examination of specimens with the auxiliary equipment for preparation of specimens are required for studying the changes in structure of the material due to various operations. Controlled temperature furnaces to reproduce different heat treatment cycles represent another item of equipment. Besides these provisions for tests for corrosion resistance of raw materials and fabricated test pieces under different conditions have to be provided.

6.06 For the inspection of materials and equipment at the shops, radiographic equipment, ultrasonic testing equipment and facilities for hydraulic or other testing are also obviously needed.

6.07 To make effective use of these equipment and facilities good, qualified and trained inspectors are required. In addition to a sound knowledge of the technical aspects of their work, the ability to spot deviations and enforce the standards strictly are essential. These engineers have to be trained to think and act as if the safety of the plants is entirely their responsibility and any slackness on their part could mean disaster - which is true.

6.09 The quality control group should also be invested with the appropriate authority and should be made to feel that they can act without fear or favour so long as they are aiming at getting equipment of first class quality. In fact, many experts recommend that the quality control department should be made responsible only to the Chief Executive and should be independent of all other departments. This is quite understandable in the light of the importance of their job.

7. <u>Training</u>

7.01 Another aspect that would have been obvious is regarding the need for training of different categories of workmen for different operations. Extensive training, particularly, in areas like welding, have to be given to train up persons to reach a standard of competence required to produce consistently good results in work. These trained persons should normally not be allowed to work on jobs requiring less skill or which are generally of a lower category of work. Frequent tests and records of ability to produce high quality work have to be maintained for each of the technicians. In case a welder, for example, is put on some lower category of job for some time, he should be given thorough tests to get an assurance of his ability for doing higher categories of work before he is actually allowed to work on such jobs requiring a higher standard of work.

7.02 Supervisory staff also require to be educated on the reasons for different stipulations made in the design or production technology sheets. It should be emphasised to them that deviations from the recommended procedures can often result in a considerable reduction in the quality of the work and they should be made to realise the possible consequences of such a reduced quality product. The entire approach to the fabrication of equipment for plants, such as for the production of ammonia, has to be based on a fanatical adherence to a high standard of workmanship. It should be made absolutely clear that in the fabrication of equipment for operation under critical conditions, there is no room for a second class job and the consequences of unsatisfactory workmanship even in a small part of an equipment could be very serious leading, apart from loss of production, to loss of life and valuable property.

SUMMING UP, it may be briefly stated that the maintenance of a high standard of quality in equipment for this group of industries is not just part of one's work but the basic philosophy from which all other details derive. It may be mentioned here that once the proper systems get going and every one has got over the initial reluctance to put in that little bit of extra effort which makes all the difference, it will be found that it is almost as easy to do a first class job as it is to do a sub-standard job and, in the overall analysis, it may be found to be much less costly if the job had been started and done right the first time.

---

76. 02. 02