Nondestructive Testing Technology and Optimization of On-Service Urea Reactor

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Abstract. The paper analyses possible types, shapes and locations of defects in a life cycle according to such factors of a urea reactor as material, structure, manufacture approach, work environment, operating medium and failure mode. Then suitable nondestructive testing methods are chosen to test a urea reactor on service on the basis of characteristics of various nondestructive testing methods. And test procedures are optimized which not only ensure urea reactor safety operation, but also reduce test time and minimize plant stand-by loss caused by a test.

Keywords: Urea reactor, Defect, Nondestructive testing, Optimization.

1 Introduction

A urea reactor is a key equipment in a urea production, it works under high temperature, high pressure and strong corrosion which may bring about defects such as stress corrosion crack and fatigue crack, and even worse, it may cause accidents such as cylinder crack, leakage, or even explosion [1]. Therefore, even if a urea reactor design, manufacture and installation quality totally meets all codes and standards, there can still be some potential safety hazards when process run for a period. It will bring about accidents if not eliminate the failures timely, the common practice to insure urea reactors safe operation is to have a complete detection and mending at regular intervals besides real-time monitor.

2 Urea Reactor Operating Conditions and Characteristics

2.1 Urea Reactor Operating Conditions and Characteristics

Operating pressure $\leq$ 22MPa;
Operating temperature $\leq$ 200℃;
Working medium: liquid ammonia, CO_2 and methylamine, etc.

D. Li, Y. Liu, and Y. Chen (Eds.): CCTA 2010, Part IV, IFIP AICT 347, pp. 255–259, 2011.

2.2 Working Characteristics

High temperature, high pressure and strong corrosion.

2.3 Structural Characteristics

Most on-service urea reactors are weld-shrunk multilayered cylinder consisting of liner layer, blankoff plate layer, inner cylinder and layer plate [2]. A urea reactor cylinder has 14 layers with a total thickness of 110mm. Generally liner material is 316L stainless steel with 8mm thickness and blankoff plate material is Q235-A carbon steel with 6mm thickness and inner cylinder material is 16MnR low alloy steel plate with 12mm thickness and layer plate material is 15MnVR with 6 to 8mm thickness.

3 Urea Reactor Regular Defect

3.1 Manufacture Defects

There is merely design defect of urea reactor because it is a high pressure vessel and design organizations must have pressure vessel design qualification, besides, weld-shrunk multilayered cylinder technology is a proven technique. Defects are mainly caused by a slipshod manufacture process.

Manufacturing defects are as follows [3]:

(1) That unreasonable structure and discontinuous shape size are easy to result in problems such as stress concentration.
(2) Defects such as cracks inside weld joints, incomplete fusions, incomplete penetrations, slag inclusions and gas cavities, etc.
(3) Defects such as cracks outside weld joints, incomplete fusions and undercuts, etc.
(4) Defect that bead weld layers don't joint with base materials.
(5) Reheat cracks under bead weld layers.

3.2 Application Defects

Affected by factors such as inside medium, outside ambient medium, leak detection medium, compressive load and temperature load, urea reactor working environment is severe bad, as a result, defects are brought about as follows:

(1) Liner and weld bead corrosion thickness decrease, intercrystalline corrosion, selective corrosion, stress corrosion, crevice corrosion, pitting corrosion and cracks may be accompanied with corrosions mentioned above caused by methylamine.
(2) Veneer sheet and weld bead corrosion crack caused by methylamine.
(3) Veneer sheet and weld bead stress corrosion cracking caused by outside ambient medium and leak detection medium.
(4) Fastener cracks.
(5) Cracks in discontinuous shape size surface caused by stress concentration.

4 NDT Application in a Urea Reactor Periodic Inspection

Nondestructive Testing (NDT) detects various materials, components and structures subsurface and external defects, making a judgment and evaluation on defect type, quality, quantity, shape, location, size, distribution and changes according to textural anomaly insides material or changes of heat, sound, electricity and magnetism caused by defects, without damaging the equipment [4].

4.1 Penetrant Testing

Penetrant Testing (PT) is one of the earliest nondestructive testing methods and based on capillarity to reveal open defects on a non-porous material surface. Infiltrate the penetrant into open defects on a workpiece surface, remove the surplus penetrant, and then show defects with the help of developer.

Main detect positions and requirements PT is in a urea reactor are as follows:

(1) 100% PT on a lining layer soldered joint surfaces.
(2) 100% PT on girth joint capping plate corner joint surfaces and connector capping plate corner joint surfaces.
(3) 100% PT on joint surfaces between an adapter tube and a weld overlay, an adapter tube and a lining layer as well as internal parts and a lining layer.
(4) 100% PT on joint surfaces between an adapter tube and an end plate, an adapter tube and a main body, an adapter tube and an adapter tube.
(5) A random PT on a weld overlay focus on appearances where may have problems.

Penetrant Testing is accepted according to JB/T 4730-2005 first class, and any surface blowhole is not allowed.

4.2 Magnetic Particle Testing

Magnetic Particle Testing (MT) is a kind of NDT which shows defects on the surface of ferro-magnetic material and composition metal based on interaction of magnetic leakage field and magnetic power. MT is widely used to detect cracks, crease, interlining and cinder inclusion on or near ferro-magnetic material surfaces.

Main detects position and requirements are as follows:

(1) 100% MT on an external surface of a circular joint between a cylinder and an upper or a lower head.
(2) No less than 50% MT on a cylindrical shell section longitudinal seam external surface and girth joint between sections.
(3) Random inspection on veneer sheets, focus on appearances where may have problems.
(4) Kingbolts should be cleaned one by one, damage and cracks should be checked, MT should be done when necessary. Bolt that there are circular cracks on thread and transition section should be replaced.

MT is accepted according to JB/T 4730-2005 first class.

4.3 Ultrasonic Testing

Supersonic wave attenuates when travels through a medium, and is reflected back when comes to a interface. This is exactly the principle Ultrasonic Testing (UT) used to detects defects. UT has many advantages, such as high sensitivity, good directive property, good penetrability and fast. UT is widely used in urea reactor test because of an ultrasonic flaw detector has small cubage, light weight, conveniently portable and operate and harmless compared with ray.

Main detects position and requirements are as follows:

(1) Bead weld UT: no less than 50% UT on a bead weld; test methods and grade follow JB/T 4730-2005, accept with manufacture conditions.
(2) Deep girth joint UT: a bead should be planished before a test. The planish bead can be test with different focus normal probes and K1 angle beam probes.

UT is accepted according to JB/T 4730-2005 first class.

4.4 Radiographic Testing

Radiographic Testing (RT) is a kind of NDT which is based on the difference absorptivity of ray breakthrough testing workpiece (no matter electromagnetic radiation or particle radiation) to show defects inside a workpiece. Main RT used in industry is X-ray, γ-ray and neutron-ray, besides, X-ray is the most widely used.

Deep girth joint RT can be taken when there are questions after UT or an inspector considers necessary.

RT is accepted according to JB/T 4730-2005 second class.

4.5 Acoustic Emission Testing

Acoustic Emission (AE) is a physical phenomenon which refers to that once an object suffers shape change or external affection, it will soon releases elastic energy and then generates stress wave. Acoustic Emission Testing (AET) is one of the methods that work through detection device to analysis acoustic emission signal and detect defects by the signal [5].

AET should be taken after agreement from testing unit and end user, AET is accepted following the standard which is made beforehand.

5 Detect Scheme Optimization Exploring

Visual testing (VT) is a simplest urea reactor test method, which detects through sight, hear and tactile organs and experiences. It needs other non-destructive testing technologies as supplementary sometimes because VT can only be used in detecting external defects which can be distinguished by a sense organ. MT is used to test a surface and near a surface flaw and has a low requirement of surface finish quality, high defect discovery rate, high flaw detection reliability, low cost and fast working speed. However, it can only be used for a pressure vessel made of ferro-magnetic material. PT is used to test surface split defects and has a high surface finish quality requirement, and flaw detection sensitivity is strongly influenced by defect breadth-depth ratio, defect

types and operating correct or not, therefore PT is usually used in case where MT cannot work (such as fillet weld). RT is more sensitive to capacity defects rather than to some small cracks, especially those crack defects with a transillumination angle of more than 30 degrees. Nowadays RT is considered to be the most suitable Non-Destructive Testing Technology for harmless defects test, but it is of heavy defect detection workload, cost more, and it is harmful to health. UT is of high sensitivity and able to detect extremely harmful planar defects. A lightweight equipment is easy to be operated, so it can make a fast test with a low cost, what's more, it is harmless to health. But there are certain difficulties about defect qualitative and quantitative; therefore it calls for carefulness and experience.

Altogether, optimization non-destructive testing order based on a dangerous defect is VT, MT, PT, UT and RT, according to various non-destructive test applicable occasions and features as well as the theory that a surface defect is much more dangerous than a latent defect.

6 Conclusion

In recent years, Non-Destructive Testing Technology has developed rapidly, and some new testing methods have been brought into use, such as metal magnetic memory test, infrared thermography testing, ultrasonic phased array inspection, laser-based non-destructive testing, etc. Non-Destructive Testing Technology has been extensively involved in the development of national economy, and will get faster development and be more widely used in the future.

References

[1] Lin, L.H.: Nondestructive Testing Techniques for Pressure Vessels. General Machinery (05), 54–56 (2008)
[2] Ding, M.Z.: The urea synthesizes the tower's corrosion and counterplan. Small Nitrogenous Fertilizer Plant (11), 20–21 (2008)
[3] Shi, H.B.: Non-destructive Inspection Technology in Urea Converter Periodic Inspection Application. Petro & Chemical Equipment (01), 23–24 (2009)
[4] Wang, Z.M.: General Knowledge of Non-destructive Inspection. Mechanic industry Press, Beijing (2005)
[5] GB/T 18182-2000: Acoustic emission examination and evaluation of metallic pressure vessels