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Urea Reactor Liner Leakage - A Case Study

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Abstract

The multi layered spiral coiled urea reactor with inner liner of 316L (Mod) and 40000 mm TL to TL (tangent to tangent length) leaked during hydro-test after ATR-2019 which in turn resulted in the failure of the outer carbon steel shell of 8 mm. This study briefs about the extent of damage, refurbishment procedure and inspection techniques that were carried out during the repair work so as to ensure better reliability of the equipment during normal running hours.

Key words: Urea plant, urea reactor, liner, 316L (Mod), reactor leakage, dye penetrant test, magnetic particle test, ultrasonic test, ferrite content test

1. Introduction

National Fertilizers Limited (NFL) was incorporated on 23rd August 1974, is a public sector undertaking. NFL has five gas based ammonia-urea plants *viz.* Nangal & Bathinda plants in Punjab, Panipat plant in Haryana and two plants at Vijaipur (District Guna), in Madhya Pradesh. The Panipat, Bathinda and Nangal plants were revamped for feedstock conversion from fuel oil to natural gas, an eco-friendly fuel during 2012-13/2013-14. Vijaipur plants of the company were also revamped for energy savings and capacity enhancement during 2012-13, thus increasing its total annual capacity to 20.66 lakh metric tonnes (LMT) from 17.29 LMT, an increase of 20%. NFL currently has a total annual installed capacity of 35.68 LMT (re-assessed capacity of 32.31 LMT) and is the 2nd largest producer of urea with a share of about 16% of total urea production in the country.

Urea is produced from a highly exothermic reaction of ammonia and carbon dioxide to form ammonium carbamate, with slightly endothermic dehydration of the ammonium carbamate. The principal variables which affect the reaction are temperature, pressure, feed composition and residence time. The conversion of ammonium carbamate to urea takes place only in the liquid phase, therefore high pressure is required. Urea synthesis is favourable with high temperature and pressure. The reaction condition is about 190 °C and 155 kg cm^{-2}. Conversion of urea decreases by the presence of water and increases by the presence of excess ammonia. Urea synthesis is achieved in vertical, high pressure plug flow vessel called urea reactor **(Figure 1)**, which has sufficient volume to allow the synthesis reaction to approach equilibrium condition closely. Residence time of the urea reactor is 45 minutes at design throughput.

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Due to corrosive nature of the reactant and products in the urea reactor, suitable protective lining is employed on all the contact parts. The reactor in Vijaipur plant is lined with 316L (Mod). Addition of small quantity of oxygen in the carbon dioxide tends to passivate the liner, so that satisfactory life of the reactor is obtained. This paper discusses the constructional details of reactor, reactor failure, repairing methodology, inspection techniques and the successful completion of the repair activities.

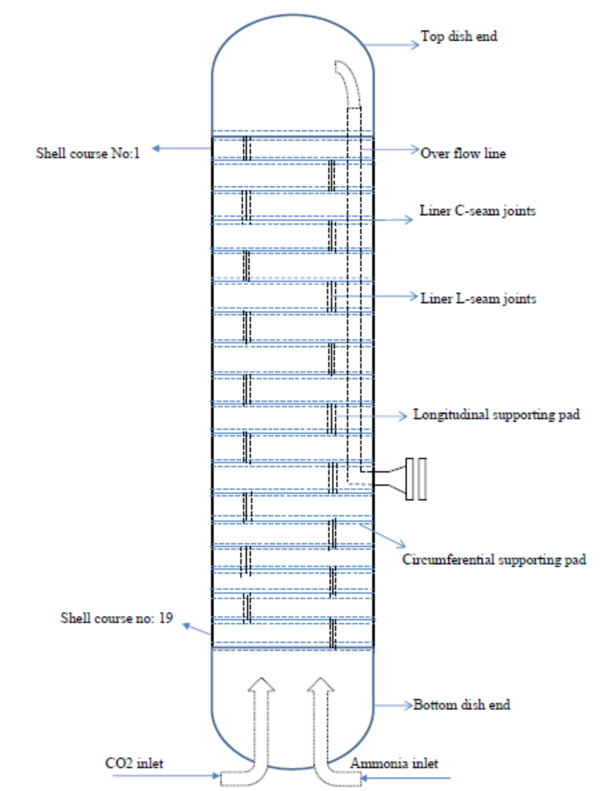

Figure 1. Urea reactor

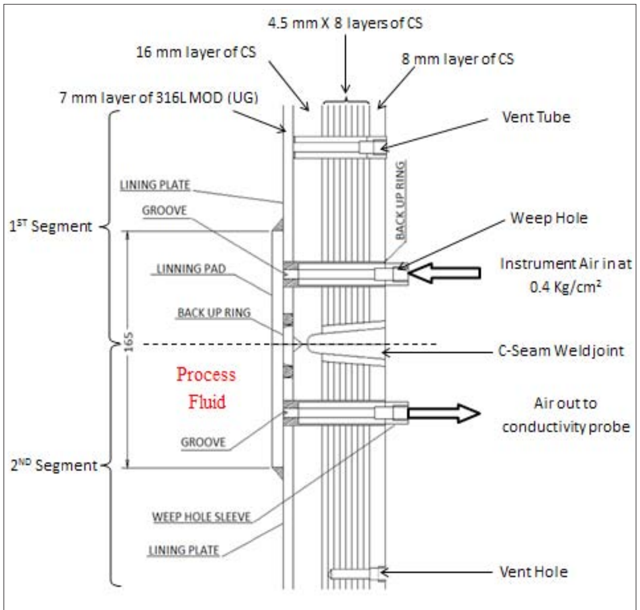

Figure 2. Reactor shell structure

The preventive maintenance of critical pressure vessels such as urea reactor is generally carried out in the annual shut down so as to increase the life expectancy of the equipment.

2. Problem Description and Analysis

NFL Vijaipur-I plant, was commissioned in 1987, has two urea streams (11 & 21) based on Snamprogetti (now Saipem) ammonia stripping process with reassessed capacity of 2620 MTPD. These two streams were revamped in 2012 to capacity of 3030 MTPD. Urea reactors (11/21R1) were supplied by M/s. Mitsubishi Heavy Industries Japan in 1986 and it has served more than 32 years.

2.1. Design Parameters

Design Pressure	:	170 kg cm^{-2} (abs)
Operating Pressure	:	160 kg cm^{-2} (abs)
Design Temperature	:	200 °C
Operating Temperature	:	188 °C
Internal Diameter	:	2,054 mm
Height (TL to TL)	:	40,000 mm

2.2. Construction Details

Urea reactor is a multilayered carbon steel vessel with AISI-316L (Mod) liner. The carbon steel shell is of 60 mm thickness comprising of 16 mm CS plate subsequent to 8 x 4.5 mm coil sheets of CS and extreme outer layer of 8 mm CS **(Figures 2** and **3)**. The vessel is made up of 19 cylindrical shell courses each of 2100 mm length. The top and bottom are hemispherical dish ends having 3 petals each. The entire vessel is lined with AISI-316L (Mod) having a thickness of 7 mm. The segmental circumferential and longitudinal weld joint of liner is further protected using pad of AISI-316L (Mod) with a thickness of 7 mm and width of 165 mm **(Figure 4)**.

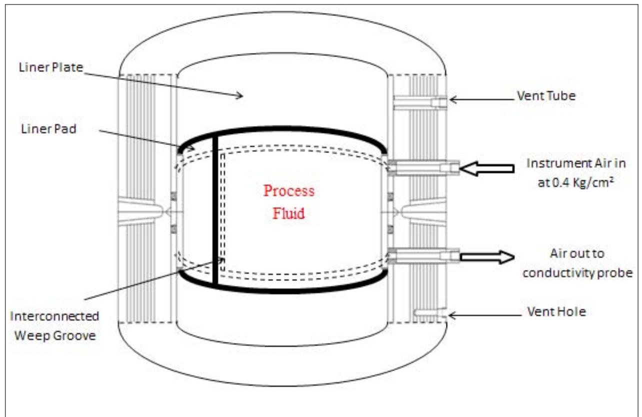

Figure 3. Reactor shell cross sectional view

The carbon steel shell is only for pressure retainment. In case of any internal liner failure, it will result in highly corrosive carbamate solution coming in contact with the carbon steel shell behind the liner, which will corrode the CS shell and would result in

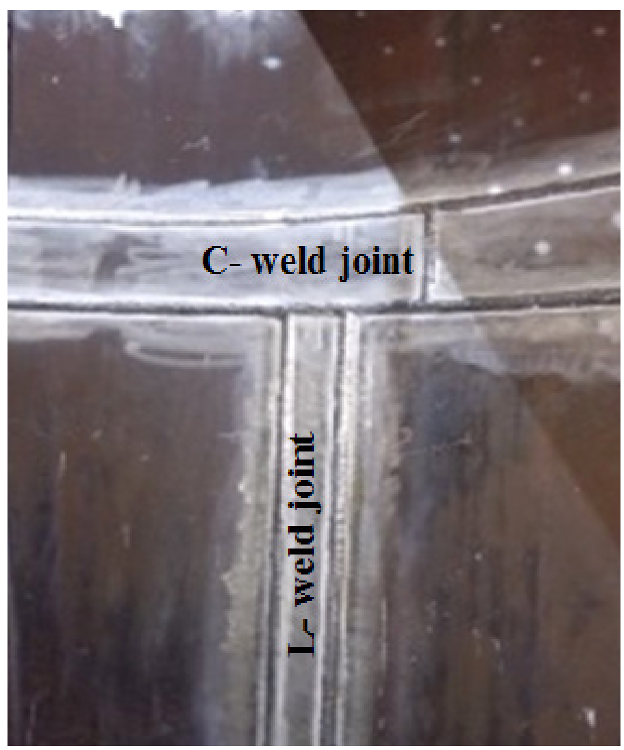

Figure 4. Urea reactor from inside showing C-weld & L-weld joint

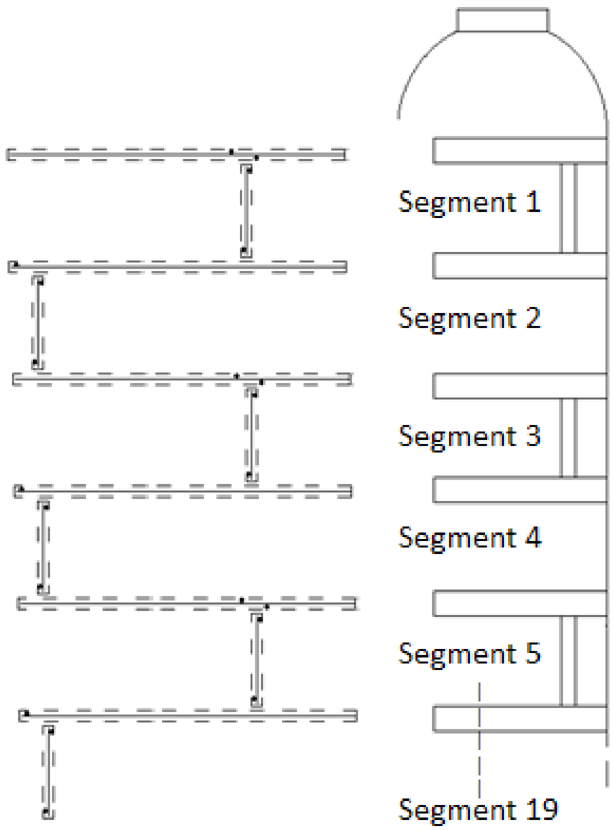

Figure 5. Weep tube location & orientation

lethal effects. Hence, weep holes are provided to detect the leakage from the welding joint at earlier stage **(Figure 5)**. Behind the welding joint of the liner pad groove is provided to which the weep tubes are connected. Each welding joint is provided with 2 weep tubes, one as inlet for instrument air, which will push any leaked fluid through the groove towards outside from the second weep tube connected with conductivity probe. Conductivity probe will show reading variation in the control room based on the changes in the resistance of the flowing fluid. There are total of 20 circumferential weld joints having 40 weep tubes, 19 longitudinal weld joints having 38 weep tubes, 3 weld joints for both top and bottom dish end each having 12 weep tubes in total and 2 weep tubes of the outlet line, 2 weep tubes for the top man hole cover and 2 weep tube for the top neck (total weep tubes = 96 out of which 48 are provided with conductivity probe).

Coil layered shell course is provided with one vent tube and three vent holes for each of the longitudinal segments. Vent tube is terminated at the back side of liner plate and vent holes are terminated at the back side of 8th coil layer, these are interconnected **(Figure 6)**. These vent holes and vent tubes are provided to release welding fumes during fabrication of equipment.

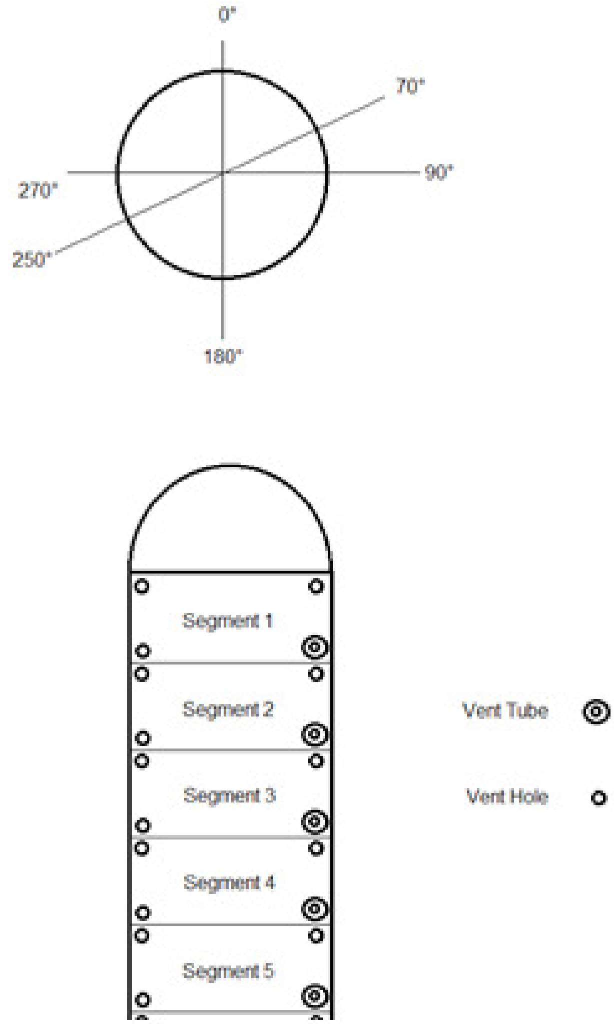

Figure 6. Vent tube & vent hole location & orientation

During transportation these were plugged to avoid equipment damage.

2.3. Repair Activities in 2019 Annual Turn Around

During every shutdown, various NDTs and measurement are carried out as a part of extensive and stringent inspection. During inspection, it was observed that the welds of circumferential and vertical seam, cleats of tray support rings (TSR) were in eroded/corroded condition and spongy. Repair activities like overlay welding of the joints of circumferential and vertical seams cover strips and addition of cleats to tray support rings were also carried out to ensure the reliability of the equipment.

During annual turnaround of May 2019, 11R1 (11 stream urea reactor) about 200 meters of circumferential and vertical seam cover strips liner joints from top of the reactor got welded using SANDVIK make 25:22:2 LMn filler wires. Additional

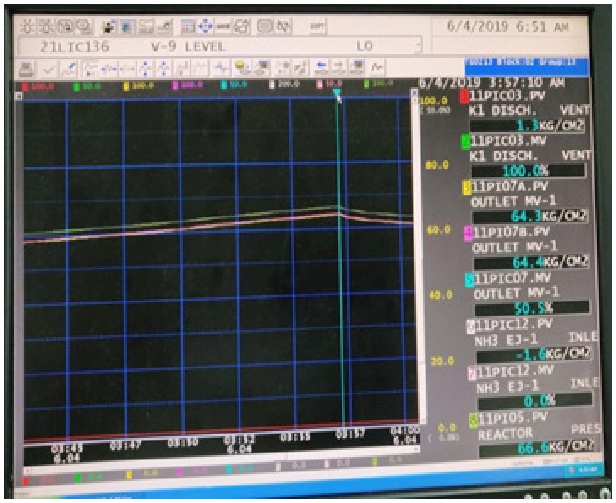

Figure 7. Pressure trend on DCS

32 numbers TSR cleats were also welded for strengthening. DPT of newly weld joints, ferrite content on liner and pad plates were found normal. All weld repairs were cleaned/pickled with acid solution (4 vol% HF acid and 20 vol% nitric acid). Liner joints soap solution test at the inside of the reactor was carried out with 0.4 kg cm^{-2}(g) instrument air pressure from outer weep hole.

2.4. Leakage and Observations

Subsequent to repairs, HP loop hydro test was initiated. It was observed that HP loop pressure was not increasing beyond 65 kgcm^{-2}, rather started decreasing **(Figure 7)**. It was noticed that condensate was coming outside from 1st segment (L-seam) of the reactor from inside the insulation. Immediately insulation was removed and it was noticed that the outer shell plate of 08 mm got ruptured from its vertical weld joint (400 mm in length) at 1st segment (L-seam) **(Figure 8)**.

Figure 8. Condensate coming out from vertical weld joint at 1st segment (L-seam)

Figure 9. Condensate coming out from TSR 1st tray

Hence, HP loop was depressurized and draining was carried out and top manhole cover was removed for internal inspection. Simultaneously, tray manways were opened from 1st to 5th tray. To detect the leaky portion inside the reactor, DM water was supplied through flexible hose from outer ruptured portion of the shell course and thorough physical (visual) inspection was carried out inside the reactor. It was found that water was coming out through 1st tray's TSR's newly welded cleat **(Figure 9)**. After insulation removal, it was also noticed that there was bulging on outer (8 mm) layer at the first and fifth segment from the top of the reactor **(Figure 10)**. Vertical joint of 1st segment outer shell 8 mm layer welding was found in ruptured condition and bulging of longitudinal pad plate of 5th segment was also noticed.

Figure 10. Bulging of outer shell

Figure 11. Temporary scaffolding erected around and for complete length of reactor

Figure 12. Outer 8 mm shell removal of 1st and 5th segment

2.5. Reason for Failure of Vertical Welding Joint of 1st Segment

System hydro-test water entered through the damaged portion of newly welded TSR cleat of the first tray into the coiled layers and reached up to the last layer of 8 mm. As the vent holes and vent tube of the segment were in plugged condition, this resulted in pressurization of the outer shell course, causing rupturing of the 8 mm outer layer vertical joint. The coiled layer welding remained intact, otherwise it could have un-winded.

3. Repair and Maintenance

After thorough inspection of internal and external damage as well as consent and repair procedure approved from M/s. Saipem, rupture repairing company was contacted for rectification/repair of the reactor within minimum possible time at NFL Vijaipur site itself.

3.1. Repair Procedure

Temporary scaffolding was erected from ground floor to top of the reactor for approaching all vent tubes and vent holes as well as to carry out the job **(Figure 11)**. Subsequently, whole insulation was removed from reactor. All the vent holes and vent tubes plugs were de-plugged. All vent tubes' depth was measured, which was found in the range 62 mm and depth of vent holes was found as 40-42 mm. Further cleanliness of the vent tubes and connected vent holes of each segment was checked with instrument air pressure at 0.3 kg cm^{-2}g and found at clear condition.

Maintenance jobs executed to rectify the damaged portion of reactor are as follows:

i. The outer shells (8 mm) of first and fifth segment were removed and replaced with new semi-circular shells made of 16 mm CS plate (SA516 Gr70) in NFL Vijaipur workshop **(Figures 12** and **13)**.

ii. The TSR leaky point was removed in rectangular shape of size 300 x 200 mm **(Figure 14)** to ensure that the internal layers of the reactor is not damaged and replaced with new patch plate, with separate weep hole for monitoring patch plate liner and welding.

Figure 13. New outer 16 mm shell installation in progress

Figure 14. Liner plate removed (300 mm x 200 mm) from the leaky point

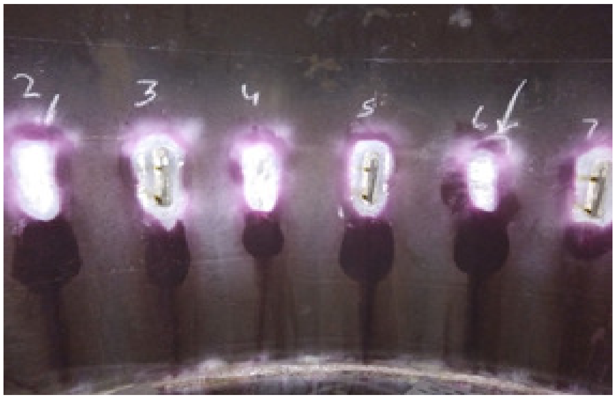

Figure 15. Old TSR and cleats removed and repaired

Figure 16. New TSR and cleats installed

iii. The first to fifth TSR as well as its all cleats were replaced with new one **(Figures 15** and **16)**.

iv. The longitudinal pad plate of the fifth segment was replaced **(Figure 17)**.

Figure 17. Longitudinal pad plate of the 5th segment removed

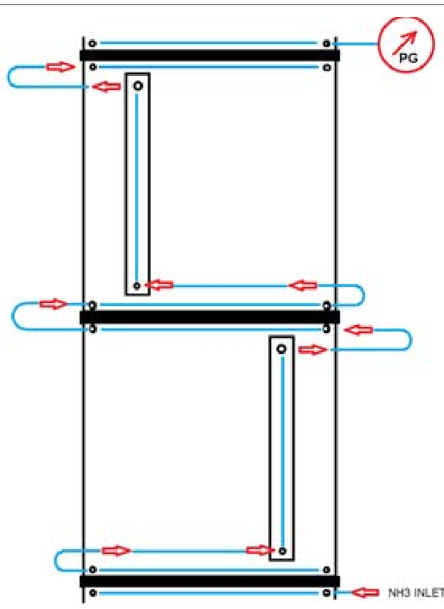

Figure 18. Weep hole tubing group with PG

3.2. Testing and Inspection

On completion of the repair work by M/S L&T, visual test, dye penetrant test, magnetic particle test and ultrasonic test of all pressure seams (L, C and nozzle welds) were carried out on the external surface. Visual test, dye penetrant test, ferrite content test of all the internal attachment welds were carried out followed by air and ammonia leak test for weep holes as well as vent holes/vent tubes system of all segments inside the reactor.

To facilitate air and ammonia leak test, small loops connecting weep **(Figure 18)** and vent **(Figure 19)** system of 2/3 segments each were made to cover up

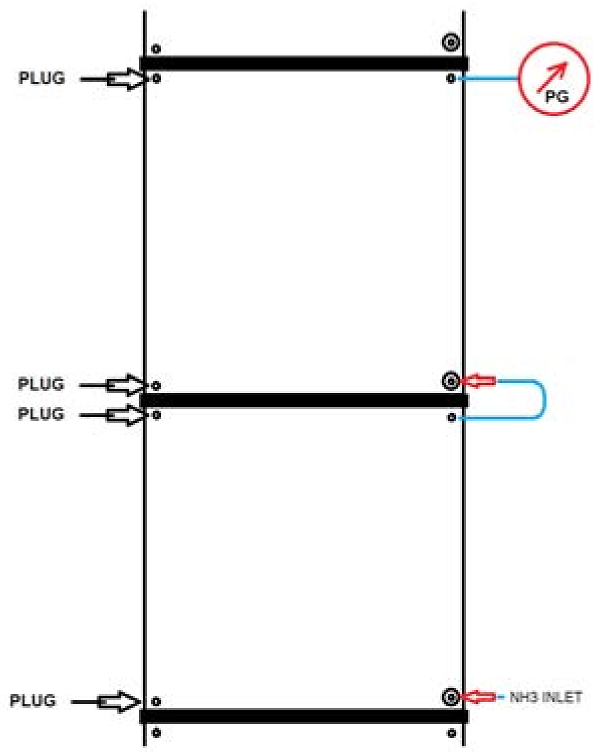

Figure 19. Vent tube/hole tubing group with PG

Figure 20. Ammonia leak test – application of paste on linear, patch plate and weld joints

Figure 21. Fresh urea deposition observed at the 70° top vent hole of 3rd segment

the whole reactor. To ensure that the system loop pressure does not go beyond 0.35 kg cm^{-2}g while carrying out air and ammonia leak test, a solenoid valve with cut off set value of 0.35 kg cm^{-2}g was provided. Hold test was done at 0.3 kg cm^{-2}g to ensure zero leakage from connected tapping and unions. Once the pressure hold test was complete and no pressure drop of air was observed then air leak test was carried out using soap solution for the L and C pads as well as the liner plate.

After air test, the complete system was purged out using nitrogen and then ammonia was charged to carry out ammonia test, the system was kept at hold for 12 hours at a pressure of 0.3 kg cm^{-2}g, to ensure the permeation of ammonia through leakage and cracks. Paste of barium sulphate, phenolphthalein and demineralized water, which changes the color from white to pink in presence of pH change, was applied on the reactor surface for leakage detection **(Figure 20)**.

No defects were noticed. Subsequently, hydro test of HP loop was carried out. During hydro test, physical inspection of weep holes and vent tubes/vent holes was carried out and no abnormalities were found.

3.3. Startup and Leakage at 3rd Segment

Reactor feed in was carried out on 08-07-2019 at 0300 hours and prilling lined up at 0730 hours. Thorough physical inspection of the reactor weep holes as well as vent holes/vent tubes were carried out. Fresh urea deposition was observed at the exit of 70° top vent hole of 3rd segment. It was noticed that fresh urea melt was accumulating at the exit of the said vent hole **(Figure 21)**. Again plant shutdown was taken. After draining/depressurization and flushing of HP loop, reactor manhole cover was removed. Manways up to 4th tray were opened for inspection and repairing the internal defect.

3.4. Repairs at 3rd Segment and Inspection

Grinding of longitudinal and circumferential seam weld joints was carried out keeping weep holes system and vent tubes/vent holes system pressurized with instrument air at 0.3 kg cm^{-2}g. One pinhole was found on C- seam weld joint of 3rd segment. Patch plate was welded over pinhole point **(Figure 22)**, after performing NDT test and clearance received from mechanical team & M/s. L&T for leak test by air and

Figure 22. Ammonia leak test – application of paste on linear, patch plate and weld joints

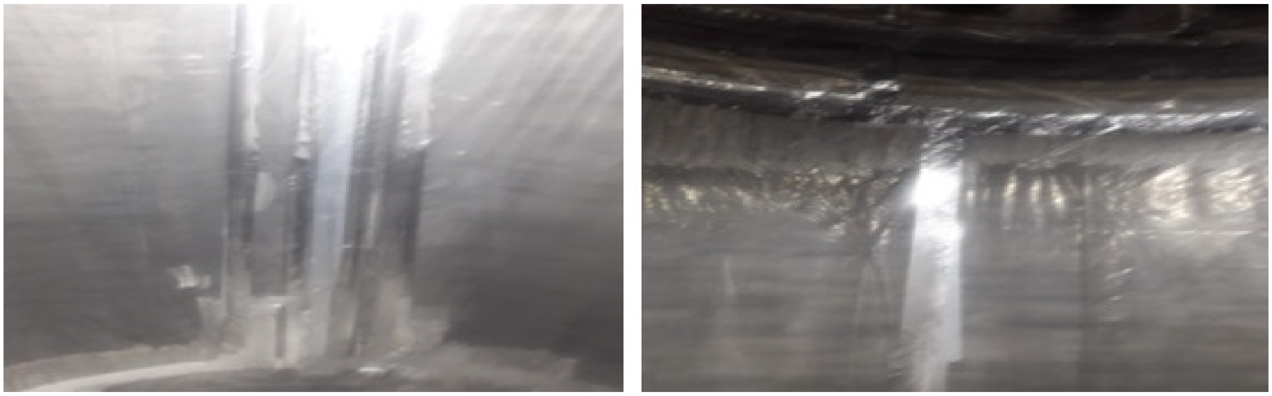

Figure 23. Helium leak test at third segment. Partition of segment carried out using polythene and duct tape

ammonia on 12-07-2019 at 0200 hours. This time air & ammonia tests were performed at 0.4 kg $cm^{-2}g$ for 2nd and 3rd segment and 0.3 kg $cm^{-2}g$ for 4th segment which was completed on 12-07-2019 at 2120 hours. No leakage was found with air and ammonia leak test. Further, hydro test of reactor was carried out but water started coming out through 70° vent tube and 250° vent hole (bottom) of 3rd segment at HP loop pressure of 90 kg $cm^{-2}g$. Leakage rate (number of drops per minute) was measured to detect the leakage source whether it is leaking from inside of reactor or accumulated water from the coiled layer of 3rd segment. Leakage rate was measured while increasing the HP loop pressure up to 145 kg $cm^{-2}g$ and then reducing to 120 kg $cm^{-2}g$ and held at that pressure for 4 hours for measurement of leakage rate. But nothing could be concluded from this. Finally system was depressurized and drained. Air leak test as well as Helium test was carried for 2nd, 3rd and 4th segment on 19th and 20th July.

The same instrument tappings that were used for the air and ammonia test were used for the helium test. First the system was purged with nitrogen and then helium was charged from helium cylinder through the vent hole/tube and weep hole system, the system was kept at hold for 04 hours at a pressure of 0.3 kg $cm^{-2}g$, to ensure the permeation of helium through leakage and cracks. Inside the reactor the segments were divided into smaller isolated portion using sheets and tapes for leak detection **(Figure 23)**. After the hold duration was complete, the leak test was carried out by puncturing the sheet and inserting the analyzer in it. No leakages were detected in the test.

3.5. Plant Startup and Monitoring

Thereafter plant startup activities started with close monitoring of weep holes as well as vent tubes/vent holes system. After smooth operation of plant, instrument air connection was provided on the vent hole /vent tube system and bubblers were kept at the outlet vent tube for analyzing ammonia in case of leakage. Lab analysis of the air sample as well as physical checking of these segments using phenolphthalein was also carried out. Initial samples of the vent hole/vent tube as well as weep hole system were having a higher ammonia (around 300 ppm), which was due to the residual ammonia (used for the ammonia test) residing in the multilayers of the reactor as well as weep hole system. Ammonia content reduced to the level of less than 25 ppm within 4 days. This shows that ammonia was coming from coiled layer as well as weep hole system which was soaked during ammonia test.

4. Conclusion and Recommendation

- Extensive repair work of high pressure equipment shall be carried out by engagement of reputed party in the field of repair of reactors or licenser approved parties.
- Vent tube and vent holes provided to release welding fumes during fabrication of equipment, which are plugged during transportation for avoiding equipment damage, should be de-plugged at site and provided with instrument tubing, free end positioned downward with strainer. It has been done for other urea reactors.
- Physical monitoring of vent hole/tubes during normal plant operation and extensive monitoring after liner repair is must.
- Monitoring of weep hole system for clearance of all connected path, phenolphthalein test for leakage detection and checking of conductivity probe system healthiness should be carried out regularly.
- After repair work, while carrying out hydro test, extensive monitoring of weep hole and vent hole/tube should be carried out.
- Though various tests are available, each having their own advantages and disadvantages, ammonia test is time consuming, but it is recommended to perform ammonia test after extensive repair of equipment. ■