

Refinery Reliability Through Advanced NDT Methodologies

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Abstract

NDT and equipment health assessment with regular condition monitoring in Oil Refinery has helped in achieving high degree of reliability of Refinery equipments. Such advanced Non-Destructive Testing for reliable inspection and Interpretations of service damage in the equipments over a period have provided adequate fitness for purpose and plant safety. Special advanced NDT'S like **TOFD, IRIS, AUS LFET, AET, RFET, OLCM** etc. have been adopted at regular intervals during plant turn around shutdown at Gujarat Refinery. All these special NDT's have been found successful and implemented for maintaining Reliability, quality, Safety, Life extension, Predictive maintenance of refinery equipments. The need for such NDT's is derived from complexity of refinery which includes operation of secondary processing units at High temperature & pressure like FCCU, **Hydro cracker, DHDS, CRU** etc. These process plants handle hazardous and corrosive service environment like H₂, wet H₂S, CO, erosive catalysts, Hydrogen gas causing material degradation by Low temp. / High temp. Hydrogen induced cracking, sulphur corrosion, Naphthanic acid corrosion, etc. There is narrow gap between design and operating limits in present time along with processing of cheaper feed having inferior quality, optimum construction material on cost economics basis

1. Introduction

Need to adopt advanced NDT methodologies in Refinery is basically due to the fact that hydro cracker or hydrotreating plant is a very sophisticated and complex secondary processing unit and the reaction sections operate at a relatively high Pressure (in the range of 170 kg/cm²). Hydrogen has a very wide range of "explosive limits". Concentrations (by volume) of 4% to 75% hydrogen in air can explode. Also the ignition temperature is lower than for hydrocarbon gases. New units are designed with a narrow gap between design and operating limits. e.g. Hydrogen reformer tubes parameters are as below:

S.No.	Tube Part	Design Pressure (Kg/Cm ² g)	Operating Pressure (Kg/Cm ² g)	Design Temp. (°C)	Operating Temp. (°C)
1	Inlet	30.9	27.8	675	650
2	Main tube	27.5	24.8	990	975
3	Outlet	26.7	23.8	955	930

Material - Centrifugally or static cast 25Cr 35Ni Nb Ti,

Corrosion allowance – Nil.

Equipment with severe operating conditions, sophisticated metallurgy and critical services are given below:

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S.N	Equipment	Design Pr. (Ka/cm ² a)	Design Temp (deg)	Service	Metallurgy
1	Reactor	190	454	HC +H2	F22+SS30 9L + 247 weld O/I
2	Reformer	30	990	HC+H2	25Cr 35Ni Nb Ti
3	REAC	180	204	Effluent/ off gas	SA 192
4	Breach Lock Shell Tube	182 198	432 432	Feed Effluent	F22 + SS 347 SS 321
5	RG Cooler Shell Tube	48 28	253 860	BFW/Steam Reformed gas	387 Gr 12 Cl2 T12
6	PSA Vessels	23	70	H2 in cyclic loading	CS

Availability of opportunity feed stocks and flexibility in processing, require compatible design and stringent inspection methodologies. With the changed competitive scenario, requirement of longer uninterrupted run length have become essential for survival. Post APM Business environment require strategic decisions for investment. Strict and stringent pollution as well as safety norms have resulted in increased concern for operating reliability. Refineries built away from human inhabitant became part of the thickly populated surroundings resulting in potential risk to human life and property. Critical and high-risk equipments like thick wall Reactors, weld overlaid pressure vessels, micro-alloyed cast Reformer tubes etc. demand advanced monitoring techniques. Scientific advancement in NDTs overcome many limitations in conventional NDT methodologies. Ageing of equipment affects the probability of defect growth and thereby reliability.

First Indian hydrocracker unit was commissioned in 1993 which is now 13 years old. World wide accident record of

Hydrocracker units is a warning signal to act in time. History teaches us, but it teaches only hard lessons. Few of the major incidents and consequence are elaborated here.

In January 1997, Tosco Refinery, California, US, Total loss \$22,000,000 (Excluding Production loss & Penalties) took place. Some of the Thermocouples in reactor were out of order, due to some temperature excursion, hydrocracking reaction accelerated, causing further increase in temperature. The phenomenon initiated an uncontrolled chain reaction. Operators did not follow required emergency shut down procedures prior to the accident, assuming the high temperature indication as false. Effluent line from a reactor in the hydrocracker unit failed due to excessively high temperatures. The 12-inch effluent line pipe was bulged at many locations and was ruptured at straight run of pipe, not at a weld. Reason for failure was short-term high temp creep of 1-1/4% Chromium, 1/2% moly steel at temp. above 704 °C.

In April, 1989, Richmond, California, United States, Loss \$112,000,000 (Excluding Production loss) took place. A 2-inch line carrying hydrogen gas at 210 Kg/CM² failed at a weld, Weld was probably not stress relieved and hydrogen embrittlement caused the rupture, resulting in a high pressure hydrogen fire. Unit was in hydrogen purge cycle before shutting down. The fire resulted in flame impingement on the insulation of the skirt for a 100-foot high reactor in a hydrocracker unit. The 7" thick steel skirt subsequently failed. The falling reactor damaged air coolers and other process equipment, approximately 25 percent of the refinery throughput capacity, was lost for a period of five months and restoration of the hydrocracker itself required nearly two years.

In March, 1987 Grangemouth, United Kingdom, Loss \$107,000,000 (Excluding production loss) occurred. Hydrocracker

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unit was undergoing startup and was under hydrogen pressure and circulation. The hydrogen leak-off from the high pressure separator at 105 Kg/cm² to the low pressure separator at 10.5 Kg/cm² being regulated by two control valves in series. When the control valves were placed in manual mode, they opened fully and over-pressured the low pressure separator, whose relief valves were not sized for such an occurrence. The 30-foot tall, 10-foot diameter separator exploded and disintegrated. One piece weighing three tons was thrown 3,300 feet.

In December, 1984, Las Piedras, Venezuela, Loss \$89,000,000 (Excluding Production loss.) took place. An 8-inch Hot oil line in a refinery hydrogen unit with previous history of vibration failed due to Fatigue cracks. Hot oil at 50 Kg/cm² and 343°C sprayed across the roadway into the hydrogen units where ignition occurred. Intense fire around the pipe rack in the hydrogen plant caused a 16-inch gas line to rupture, adding a second blow torch to the fire. In successive order, more pipes ruptured with explosions. Damage was extensive. The three hydrogen plants and the four HDS units were heavily damaged or destroyed.

In November, 1990, Chalmette, Louisiana, United States, Loss \$25,000,000 (Excluding Production loss) happened. Cracks in internal lining of a heat exchanger resulted in shell leak and subsequent formation of a vapour cloud. Vapour cloud was ignited by a heater. The subsequent fires in this unit burned for 10 to 12 hours before they were extinguished. The hydrocracker unit was shut down for approximately three months for repairs. However, the fire damage was limited to the hydrocracker unit and the refinery was brought back on-line within one week.

2. Discussion

Preferred NDTs for critical equipment:

Sl No	Equipment	Preferred NDT	Remarks
1	Reactor	TOFD/UT	Detection and monitoring of cracks /defects at very initial stage
2	REAC	IRIS	Evaluation of quantitative wall loss due to Ammonium Bisulphide
3	Reformer	AUS/H-SCAN	Early detection of creep voids
4	PSA Vessels	SWUT	Identification of fatigue cracks at shell weld joints and skirt to shell weld joints.
5	Critical	Exchangers	ECT/
6	RFET	Speedy scanning for qualitative wall loss. RFET for Ferromagnetic material	Furnace Tubes
7	Metallo-	graphy	For degradation of alloys-reference for future
8	RG Cooler	Fibroscopy	For inspection of difficult to access locations

Due to complexity, integrity assessment of critical equipment in hydro cracker units present a great challenge. Critical requirements of integrity assessment system are:

- Very high reliability and accuracy
- High probability of detection (POD)
- Low false call rate (FCR)
- High repeatability
- Variable speed for scanning and mapping operation.
- Easy record keeping and tracing

Hydrocracker units are subjected to various degradation mechanism like High Temperature hydrogen attack, Hydrogen/Temper Embrittlement, High Temperature Creep, Ammonium Bisulphide attack, Localised erosion, corrosion, Sigma phase formation, service induced defects.

3. Time of Flight Diffraction (TOFD)

3.1 Application In Hydrocracker reactors

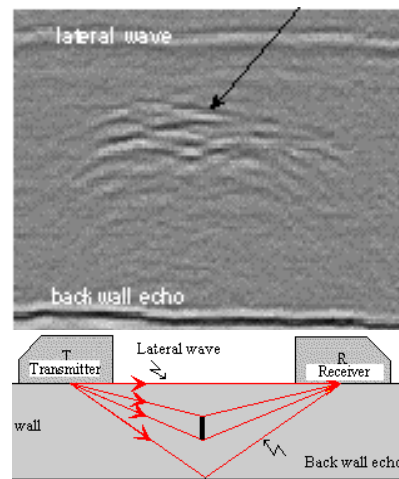
The Hydrocracker reactors, installed during Dec'93, are thick pressure vessels constructed of alloy steel SA 336 F22 CI3 , 223 mm thk as base metal and internal weld overlay of stainless steel SS 309 L and SS 347, 7.5 mm thk. The design temperature and pressure are 454 deg C and 190 kg/cm² respectively. Severe operating conditions and hydrocarbon, hydrogen service makes it most critical equipment in hydro cracker. Under these conditions a micro crack or a fabrication defect can grow to dangerous proportions in very short time and may cause a catastrophic failure. Early and accurate detection of defect is most important in health assessment of these reactors. The primary concerns for I & II stage Hydrocracker Reactors after about 10 years of service are like Growth of fabrication defects, Temper embrittlement, Weld overlay disbanding, Hydrogen embrittlement ,High temperature Hydrogen attack. For detection of these defects and overall integrity assessment of the Reactors, a combination of TOFD and manual pulse echo ultrasonic examination are best suitable.

The basic principle - Time of Flight Diffraction (TOFD) is an ultrasonic technique to measure the time differences of ultrasonic signals diffracted by the extremities of the defects and to provide an exact statement of defect size and position. The objective of TOFD is to monitor the detected flaws periodically for signs of growth. It uses two separate transducers,

one acting as transmitter and the other as receiver in a directly opposed configuration.



TOFD set up and D- scan image-showing defect on the weld



TOFD scan in progress

Premier inspection agencies have approved procedures for TOFD Technique and its validation ASME Sec V Article 4 App E, Case no. 2235 / 1996 (Accepts TOFD in lieu of radiography > 4")

The British Code for TOFD and BS 7706, CEN / 138 / WG. Oil majors like Exxon, BP, Shell, Fluor Daniel, Texaco, Chevron etc. recommend TOFD to replace radiography for examination of welds during fabrication and after hydraulic testing. Advantages of TOFD technique are that it 'sees' literally everything – like an

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ultrasonic microscope with higher accuracy over any other conventional UT or radiography. Provides a 'fingerprint' and best possible repeatability to monitor defect growth and to distinguish pre-service / in-service defects. Old and new computer records of TOFD scans can be compared very easily. Not dependent on the defect orientation, highly reliable for detection of planar defects and crack unlike other NDTs. Present day trend is to use TOFD for in-service (on-stream) integrity assessment of thick wall pressure vessels. No radiation hazard as in case of RT. For thick wall vessels like Reactors, RT requires very high source strength and time. All other Shut down activities in the vicinity are to be suspended. Instantaneous detection and sizing of defects with real time data acquisition, thus saving time and cost. Better probability of detection compared to conventional NDTs. Can also be performed at elevated temperature conveniently up to 200° C

4. Internal Rotary Inspection System (IRIS)

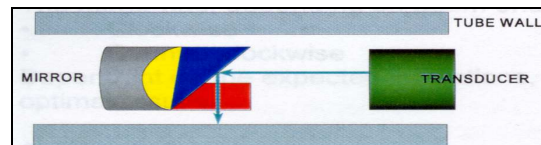
4.1 Application

Used for detecting corrosion/metal loss in Reactor Effluent Air Coolers. These are notorious for Ammonium bisulphide corrosion. High accuracy and reliability of IRIS makes it ideal technique for the job. Process Licensers also recommend the use of this technique.

4.2 Principle

An advanced technique for accurate thickness measurement of tubes in air fin coolers, heat exchangers, boilers etc. Developed in late 50's by Shell Oil for inspection of their Fin-Fan cooler tubes. Now it is proven technique used world-wide for inspection and integrity assessment of Air fin coolers. Petroleum giants like Exxon-mobil, Shell, BP, KNPC, ADNOC, Flour-Daniel etc. are employing this technique regularly.

A computerized ultrasonic inspection system best suited for integrity assessment of air fin cooler tubes, which are inaccessible from external sides because of fins. It consists of a high frequency, high-resolution transducer and 45 deg mirror mounted on a small water driven turbine. The mirror rotates at high speed and reflects the ultrasonic beam around the tube circumference to perform a 360 deg scan of the wall thickness.



IRIS principle

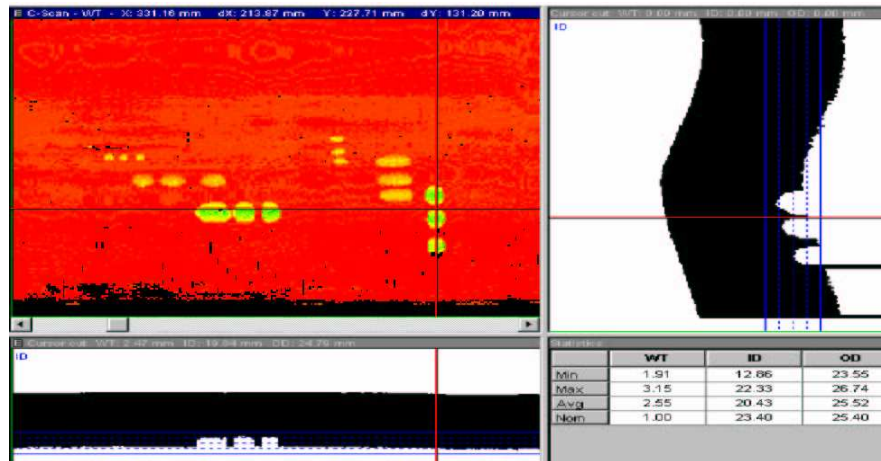


IRIS test head with centering spider

4.3 IRIS Output

The primary operation produces large quantities of H₂S, which is a toxic material. Thus essentially all gas streams and most liquid streams will contain H₂S in varying amounts. The Iso-cracking catalyst contains nickel; thus formation of nickel carbonyl is possible under high temperature-low pressure conditions, nickel carbonyl is highly toxic. There is no possibility of significant nickel carbonyl formation during normal operations but it may formed during emergency shutdown, if recommended procedures can not be followed.

There are 18 flat bottom holes (FBH) on the OD of a calibration tube. The Nominal wall is 2.55 mm, tube OD is 1 inch. Output is in the form of ID surface, OD FBH.



4.3 Advantages

High level of accuracy, as low as 0.05 mm size defect can be detected reliably. Only suitable and reliable NDT method for examination of finned tubes. Magnetic flux leakage and Eddy current testing are also used, primarily for initial sorting. However, these methods pose difficulty in interpretation. Unlike MFL or ECT, IRIS is suitable for ferrous as well as non-ferrous and even non-metallic tubes. Test results are recordable in soft as well as hard formats. The output display is user friendly. Accurate measurement even at support / baffle plate locations. The equipment is transportable and lightweight.

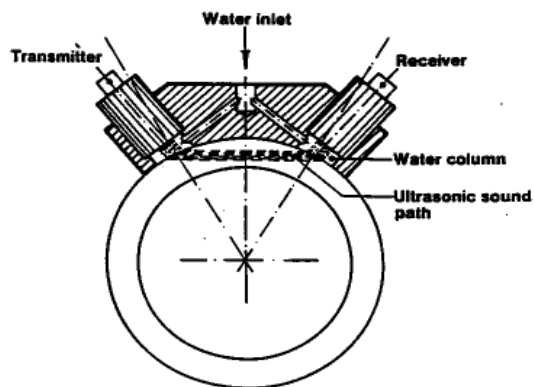
5. Through Transmission Ultrasonic Scanning (AUS)

5.1 Application

In service defects in reformer tubes are originated in the form of Creep voids coalesce to form mid-wall fissures. These subsequently propagate as cracks to inner / outer surface. AUS is the best suitable and most widely used technique for detection of above defects at early stage. Licensors like HTAS and Linde recommend a frequency of 2 years or less for such examination depending upon tube grading and operating severity.

5.2 Principle

Attenuation and scattering in UT signals are observed, if creep voids and fissures are present in reformer tubes. The amount of scattering is a function of the extent of damage. In this technique, transmitter and receiver ultrasonic probes are fitted in such a manner that the ultrasonic signal passes tangentially through mid-wall of the tubes. An Ultrasonic Flaw Detector measures the loss of signal due to attenuation / scattering in dB values. Based on the results obtained, the tubes are graded as A, B, C or D in relation to the residual life



5.3 Advantages

AUS can detect even mild initial stage creep, not detectable by radiography. Catalyst unloading is not required to

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perform AUS unlike radiography (RT), laser profiling (LOTIS) and Eddy Current Testing (ECT). Faster Inspection of the tubes is possible, thus requiring lesser downtime. No radiation hazard.

6. Eddy Current and Remote Field Eddy Current (RFEC)

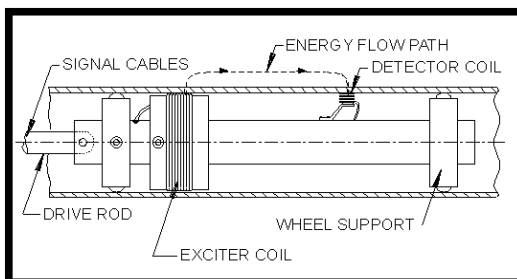
6.1 Application

Used for scanning and condition assessment of critical exchanger tubes.

6.2 Principle

A known energy flux is induced into the material to be tested with an Exciter coil probe by generating a magnetic field which penetrates the material causing eddy currents. Any defects or irregularities in the grain structure disturb the energy flow leading to indications on the oscilloscope.

The RFEC tool uses a relatively large internal exciter coil. A detector coil is placed near the inside of the pipe wall, but axially displaced from the exciter by about two pipe Dia. At the outer wall, the field spreads rapidly along the tube with little further attenuation. These fields re-diffuse back through the pipe wall and are the dominant field inside the tube at remote field spacing. Anomalies anywhere in the indirect path cause changes in the magnitude and phase of the received signal, and can therefore be used to detect defects.



6.3 Advantages

Eddy current technique is fast compared to IRIS. Records can be preserved in soft form. Eddy current is suitable for non

ferromagnetic material and RFET is for Ferromagnetic so complete material range is covered. Faster Inspection of the tubes is possible, thus requiring lesser downtime. No radiation hazard.

7. Laboratory Analysis of ageing Reformer tubes

Needs to be taken-up after about 8 to 10 years of service on cut representative samples. Recommended tests are Visual/Macro Observations, Detailed Micro-structural Analysis including under SEM, Physical destructive Tests, ASRT(Accelerated Stress Rupture Tests) at Operating Temperature and H-Scan as latest technique.

8. Laboratory Analysis of Carbon ½ Moly Ckts in Hydrogen Service

Recent research showed C -1/2 Mo material shall not be used in Hydrogen Service (also included in recent API 941-Steels for Hydrogen Service at elevated Temperature and Pressure in Petroleum Refineries & Petrochemical Plants) and process licensors are not recommending use of this material now-a-days. If this metallurgy is used in the plant, test are advisable after about 6-8 years of service, on representative cut samples for recommended tests like Cross Sectional Micro analysis for de-carburisation, EDAX Analysis, Micro structural Analysis including under SEM, Physical destructive Testing including Hot Tensile Tests. Latest equipment are now based on Phased Array Ultrasonic technique. In future, this will permit customized weld inspection, multi-angled TOFD, advanced imaging, like doctor's ultrasound and detailed inspection.

New Methodologies like RBI and RCM are Risk-based Inspection (RBI) was always in practice e.g. Transfer line gets more importance than utilities RBI makes it more simple. More relevant for Stationary equipment. Reliability Centered Maintenance (RCM) based on failure

pattern analysis during life of equipment. The technique is found more appropriate for rotary equipment. New software are on anvil to utilize plus points of both RBI and RCM techniques.

9. Conclusion

In reference to critical item of equipment like reformer tubes, reactor shell and breachlock exchangers in Hydrotreating unit, tube condition cannot be determined by one stand-alone technique, as the degree of damage within a particular tube may not lend itself to that specific NDE technique. The reliability of NDE evaluation of reformer furnace tube condition can be improved by combining a variety of advanced NDE techniques that individually monitor differing physical parameters. The advantages and disadvantages of each technique, when compared against each other, reduces the occurrence of false calls, improves tube condition assessment and can increase overall reliability of equipments and improved safety of refinery equipments.

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