Survey: Cat Tubes: Strategy of Replacement

After discussions, we can organize / select the information that is most relevant to use for the survey.

1. Main production from SMR plant
    a. Hydrogen
    b. Methanol
    c. Ammonia
2. Design of SMR
    a. Top-fired
    b. Side-fired
    c. Bottom-fire
3. Overall Reformer size
    a. Number of rows x Number of tubes per row
4. Cat tube design practices. (Materials used for SMRs Cat tubes are not include in API 530).
    a. API 530 general practice
    b. Based on average creep rupture properties reported by suppliers
    c. Based on minimum creep rupture properties reported by suppliers
    d. Using minimum creep rupture properties determined using lot-centered approach
    e. Internal Pressure stresses
    f. Consideration of thermal stresses. Effect of tube thickness, which minimum thickness.
    g. Design temperature
    h. Use of safety factors associated with creep materials properties, stresses, and/or tube metal temperature. Describe.
    i. Design Service life of 100K; 150K; or 200K hours
    j. Others
5. Materials
    a. HP
    b. HP-modified
    c. HP-Microalloy

   d. HP-Microlloy Special

   e. Use of high-emissivity coatings on radiant section refractory or OD of catalyst tubes

   f. Others

6. Operation Parameters

   a. Turnaround interval (years)
   b. Burner type (e.g. premix, low NOx, other) and potential advantage / disadvantage regarding integrity/life of tubes
   c. Process Monitoring and Control.
      i. On-line monitoring
         1. Operating temperature, pressure and flow rate
         2. Approach to equilibrium, Methane slip
         3. Monitoring the firebox vacuum, oxygen, and temperature
      ii. Performance Monitoring
         1. Drops in Pressure
         2. Carbon formation: S/C (Steam / Carbon) control and optimization
      iii. Firing Control
         1. Firing parameters
         2. Over-firing protection
         3. Imbalanced Firing
      iv. Reformer limited by
         1. TMT
         2. Firing
         3. others

7. Tube Metal Temperature Monitoring Technique / Correction Method / Degree of Uncertainty in end of row and at the bottom of the furnace).

   a. Optical Infrared pyrometer / Operator round frequency /Operator training
   b. Gold Cup Pyrometers / Frequency / Operator training
   c. Infrared Camera / Operator round frequency / Operator training
   d. Online TMT camera
   e. OD thermocouple
   f. ID thermocouple
   g. Tube growth management
   h. Visual (bowing, hot spots, color/roughness of tubes, flame impingement)

8. Tube inspection technique, variable, and replacement criteria
   a. Baseline inspection before start operation
   b. Laser ID profilometry, ID growth (strain), replacement criteria
   c. Laser OD profilometry, OD growth (strain), replacement criteria
   d. OD Eddy Current, Cracking, replacement criteria
   e. Visual Inspection (surface color and roughness, bowing), replacement criteria
   f. Ultrasonic Attenuation

   g. Radiography
   h. Combined NDE Technique Crawlers (describe combination of techniques)

9. Creep testing methods
   a. Omega method
   b. Creep rupture test
   c. Microstructural analysis
   d. Others

10. Failure Mechanisms controlling tube replacement
    a. Creep
    b. Hot spots due to flame or catalyst irregularities. Bulging / replacement criteria.
    c. Bowing or deflection of tubes / replacement criteria
    d. Tube casting defects
    e. Brittle fracture due to steam droplet carryover
    f. Others

11. Weld Repair or Tube section Replacement practices
    a. Weld Repair of base material or welded joint after service
    b. Replacement of section (s) from cat tubes

12. Overall Strategy for Cat Tube Replacement

    a. Typically based on individual tube replacement (harvesting), partial, or full replacement (reharp)
    b. Trace tubes in reformer based on suppliers and/or production heats
    c. Based on historical method or predictive approach
    d. Historical temperature and pressure exposure and excursions; severity and frequency of start-ups/shutdowns, etc.; inspection records; notable events and/or fires; Design and/or service changes; Anticipated date of next turn around (T/A) opportunity or desired T/A interval. (elastic stresses and creep stress relaxation or plastic if high Dt/dt), etc.
    e. Based on fixed service life (100k hours; 150K hours, 200K hours; etc.)
    f. Sequential replacement of tube population of a SMR to be completed in a given span of years
    g. Based on control of number of tube vintages in the reformers
    h. Based on Creep life (plan replacement in advance of TA)
       i. Creep life based on time. Creep life based on remaining lifetime (LMP). It does not account for through-thickness thermal stresses, inspection results can't be used, based on short-term creep rupture testing, aging effect on creep performance are not considered

   ii. Creep life based on strain (creep ductility) (R5 methodology). If material have good creep ductility, through thickness stress effect is minimum

   iii. Creep life based on strain, Omega method. API 579-1/ASME FFS-1, Fitness-For-Service

i. Based on cat tube inspection results

j. Based on Continuum Damage Mechanics (CDM) models. Models include microstructural aging and creep damage. Models includes material behavior at high stresses (start-ups) and low stress state (steady state regime)

k. Replacement strategy based on temperature monitoring, baseline data, periodic crawler inspections, operating experience, and some decent CDM based material models.

l. Combination of listed factors or any additional considerations (describe)