DEGRADATION IN STEAM GENERATORS

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Abstract

Karachi Nuclear Power Plant (KANUPP) is a pressurized heavy water CANDU reactor and is in commercial operation since 1972. The gross plant output is 137 MWe with full load steam conditions at the turbine stop valve of 3.85 MPa and 248.1 ^{o}C. KANUPP is equipped with six vertical, re-circulating, U-tube steam generators built by B&W, Canada. The rupture of a steam generator tube is one of the accidents that affect the availability and safety of nuclear power plants. To reduce the probability of leakage in the tubes, KANUPP has implemented a maintenance program that consists of water lancing and inspection of vessel welds, internals and tubes by eddy current test (ET). Besides the inspection program, control measures such as chemistry control, continuous blow down, condenser tube plugging/re-tubing, regular surveillance, etc. are being followed. Steam generator tubes have been plugged due to pitting, denting, and fretting problems. Assessment of degradation in KANUPP's steam generators has been made through inspections including in-bundle visual examination during water lancing, primary side lower & upper internals examination, eddy current examination, rate of tube plugging, examination of removed tube samples, etc. Plugging criteria has also been developed for dented tubes which have reduced number of forced outages due to sudden failures of steam generator tubes during normal operation of the plant. One of the objectives of the water lancing performed was to reduce the degradation rate of tubes (tubes plugged per year). It has been observed that the rate of tube plugging due to denting problem has decreased while rate of tube plugging due to pitting and fretting have increased.

1. Introduction

Steam generators of nuclear power plants are one of the critical equipment as it provides thinnest barrier (tube wall) between primary and secondary fluids. The rupture of a steam generator tube is one of the accidents that affects availability and safety of nuclear plants. Accumulation of sludge and corrosion products on the outside of the tubes, especially at the connections with the tube sheet and the tube support plates, results in tube degradation. Mechanical cleaning method (water lancing) is used to reduce deposits in order to slow down the tube degradation process. Plugging of tube is the initial response towards a degraded tube. In-service inspections of SG tubes are performed in outages to assess tube condition. Degraded tubes identified during inspection are plugged in the outage.

2. Design of KANUPP's Steam Generators

KANUPP is equipped with six vertical, re-circulating, U-tube steam generators (SGs) built by Babcock and Wilcox Canada Limited. Each steam generator has 1355 tubes and an integral preheater that is located at the cold leg of the tube bundle. The preheater contains 19 segmented baffle plates made from carbon steel. There are six carbon steel lattice bar support plates and a 90-degree U-bend support. The design temperature and pressure for the primary side of the steam generators are 316ºC and 11.13 MPa respectively. The design temperature and pressure for the secondary side of the steam generators are 260ºC and 4.82 MPa respectively. The tubing material is in accordance with ASTM B163/N04400 and SB-163/N04400 of Section III of the ASME B&PV Code. Specific alloy used for tubing is nickel-copper alloy (63Ni-28Cu-2½Fe)

that is commercially known as Monel 400 or Alloy 400. The tube outside diameter and nominal wall thickness used to establish the acceptance standards are 12.7 mm and 1.24 mm respectively.

3. Water Lancing History

First campaign of water lancing was performed in 2000. Three hand holes were installed first time in each SG to provide access for lancing tool. Water lancing was performed at 20.7 MPa using rigid lance technology and about 84 kg of soft sludge was removed.

In order to remove the hard sludge from tube sheet and first tube support plate, second campaign of lancing was performed in the outage of 2010 using inter tube lance technology. This water lancing campaign was performed at 68.9 MPa and found more effective. About 135 kg sludge was removed and tube to lattice bar sludge accumulation was reduced substantially.

4. Degradation Mechanism in Steam Generator Tubes

Fitness for Service Assessment

Plugging of tube is based on the following criteria:

- With wall loss > 40% of wall thickness (as per CSA and ASME codes).
- Severely dented tubes with < 0.25" ID at first tube support plate using stabilizer bars.
- Where doubtful signal exist and cannot be characterized for dis-positioning (in the absence of specialized techniques)
- In case of tube leakage, the first indication is increase in radiation level of secondary side fluid due to the ingress of radioactive contamination from primary side. Subsequently leaky tube is identified by primary pressure test and plugged.

Plugged Tube Data

To date, a total of 352 SG tubes have been plugged; this constitutes 4.3% of all of the tubes in the KANUPP steam generators. Details are as under:

Year	Leak	Pit	Dent	Fret	Other	Total
1990	1					1
1993					1	1
1996		6			1	7
1998		12			1	13
1999			26		2	28
2000		18			2	20
2003		2	6		4	12
2006		11	6			17
2007	2	15		4		21
2008	1	8				9
2009	2	41	3	8	5	59
2010	2			2	7	11
2011		127	1	16	6	150
2012	3					3
2013						
Total	11	240	42	30	29	352

Pitting has been observed in the sludge pile of hot-leg region above the tubesheet. Denting has been observed in the hot-leg region, at the first lattice-bar tube support above the tubesheet. Fretting has been observed in the cold-leg region and is associated with wear at the top baffle plate of the preheater.

Regression curve (Fig-1) drawn for evaluation of residual life based on tube plugging data under the present degradation modes shows that 10% tubes would be plugged beyond 2020 and SGs are likely to operate safely subjected to verification of data by inspection after every two years.

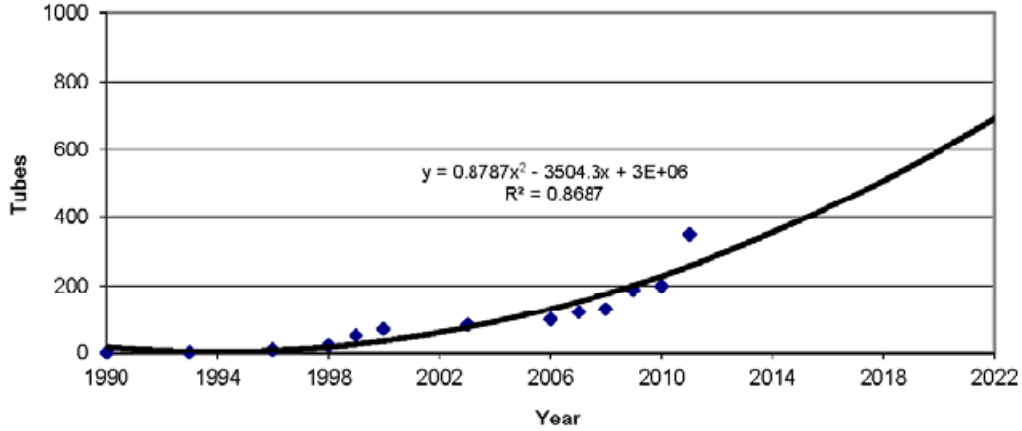

Fig-1: Prediction (polynomial) of Total Plugged Tubes in Six SGs at KANUPP

Metallurgical Examination of Removed Tube Samples

Pieces of two tubes from sludge pile were examined to verify the results of field non-destructive examination and to conduct an overall assessment of degradation. The metallurgical examination report concluded the following:

- Material analysis conformed to ASTM B163-08 for Alloy UNS N04400 tubing.
- Loss of wall (44-49%tw) was observed around the entire circumference lying within the sludge pile. Loss of wall measured by metallurgical examination was consistent with field NDE inspection and laboratory UT inspection results. The examination revealed that the wall loss was due to general corrosion.
- No evidence of inter-granular attack (IGA), localized pitting, or cracking was observed on the tubes.
- High concentrations of chloride (up to 22.5 wt %) were present at the tube outside surface likely due to occasional seawater ingress from condenser leaks.

Circumferential and Axial Cracking of Tubes

In the most recent outages, about 35% of the tubes in sludge pile areas of hot leg were inspected with state-of-art X probe to observe the presence of circumferential and axial cracking at top of the tube sheet and no cracking of tubes was observed. It is, therefore, concluded that there is no chance for rupture of tubes due to circumferential & axial cracking.

5. Degradation in Other Components of Steam Generators

Primary Internals

Visual examination of primary side internals revealed that divider plate assemblies (plates, bolts, nuts, locking tabs, etc.) are intact in all SGs.

Tube Support Plates

Carbon steel tube support plates are showing some degradation, especially at the first support plate above the tubesheet. After the water lancing campaign, it was reported that the tube to lattice bar sludge accumulation has been reduced by a substantial margin.

Upper Internals

Inspection of upper internals of three SGs was performed during the outages of 2006, 2009 and 2010-11. The inspection extent was from upper man way to U-bend including dismantling, inspection and reinstallation of dry pan, scrubber section, partition plate, cyclone and U-bend region and revealed satisfactory condition of upper internal components. No noticeable degradation or flow accelerated corrosion was observed.

6. Mitigation for Degradation

To manage pitting and denting, mitigating actions includes water lancing, chemistry control, continuous blowdown, condenser tube plugging/retubing, etc. Two water lancing campaigns have already been performed while third is planned for upcoming outage of 2013-14. Secondary side water chemistry is periodically monitored at KANUPP and further improvements, as suggested in [1], are also under consideration. Condenser retubing is being performed in appropriate long outages whereas tube plugging is based on comprehensive inspection and leak search in short outages.

7. Conclusion

a) Internals examination of KANUPP SGs revealed that there is no indication that these represent a safety risk in short term and the SGs have safely operated for seven years since the condition assessment of 2006. It would appear that part of this success is due to the frequent tube inspection campaigns undertaken since 2006. From the results of subsequent inspection campaigns, it appears that the rate of tube plugging due to tube denting has decreased; but, the rate of tube plugging due to pitting and fretting have increased.

b) Removed tube material analysis revealed that:
   - Elemental composition for both tube samples after 39 years of service conformed to the expected values for ASTM B163-08 for Alloy UNS N04400 tubing material.
   - The examination revealed that the wall loss above the top of the tube sheet under sludge pile was due to general corrosion on outer surface. There was no evidence of intergranular attack, localized pitting, or cracking in the two tube samples.
   - The examination provided information on the specific condition of the two KANUPP SG tube samples and generally confirmed the field inspection results regarding location and extent of degradation, i.e., the results from the laboratory UT analysis agreed reasonably well with the findings from the field NDE inspection.

8. References

1) Nabeel Malik, KANUPP Waterlancing and Steam Generator Services, April 2011
2) Gubbala Narayana Prasad, Chemistry Assessment of KANUPP Steam Generators, May 2010.