

INTISARI

Boiler PLTU Unit 3 telah beroperasi selama lebih dari 38 tahun dengan perubahan pola operasi dari *base load* menjadi *start-stop operation* sesuai kebutuhan sistem kelistrikan. Kondisi tersebut menyebabkan komponen boiler mengalami siklus termal yang lebih tinggi dan berpotensi mempercepat degradasi material akibat paparan temperatur tinggi dalam waktu lama. Selain itu, indikasi gangguan sisi gas buang akibat penurunan kinerja *air preheater* dapat menyebabkan distribusi panas tidak merata dan meningkatkan potensi *local overheating* pada *waterwall tube*. Salah satu kegagalan yang terjadi pada *waterwall tube* PLTU Unit 3 ditandai dengan retak memanjang (*longitudinal crack*) dan deformasi *bulging* pada area *fire side*. Penelitian ini bertujuan untuk menganalisis mode dan mekanisme kegagalan serta mengevaluasi umur sisa (*remaining life*) *lower waterwall tube* menggunakan pendekatan *Remaining Life Assessment* (RLA).

Metode penelitian dilakukan melalui analisis karakteristik material dan kondisi operasi aktual boiler. Material menggunakan potongan *tube* boiler yang sejajar dengan *burner* dan mengalami kebocoran. Pengujian yang dilakukan meliputi inspeksi visual, pengukuran dimensi dan ketebalan tube, analisis komposisi kimia, pengujian kekerasan Vickers, uji tarik, serta pengamatan metalografi untuk mengevaluasi perubahan mikrostruktur material. Selain itu, dilakukan pengujian *creep rupture* dipercepat pada temperatur 500–700 °C untuk memperoleh parameter ketahanan material terhadap mekanisme *creep*. Hasil pengujian material kemudian dianalisis menggunakan pendekatan *Larson–Miller Parameter* (LMP) dan dikombinasikan dengan perhitungan tegangan lingkaran (*hoop stress*) berdasarkan tekanan dan temperatur operasi aktual untuk menentukan estimasi umur sisa tube.

Kegagalan yang terjadi berupa *longitudinal rupture* dengan mode kegagalan *creep damage* akibat *longterm overheating*, yang ditunjukkan oleh deformasi *bulging*, penurunan ketebalan, penurunan sifat mekanik, degradasi pearlite, *spheroidization*, serta indikasi pembentukan *void/cavity*. Pada area kerusakan terjadi peningkatan radius maksimum sebesar 19,68% dan penurunan ketebalan dari 8,38 mm menjadi 6,50 mm, disertai penurunan nilai kekuatan tarik maksimum (UTS) sebesar 352,50 MPa dan kekuatan luluh (YS) sebesar 217,44 MPa. Hasil uji material sesuai dengan standar JIS STB 42. Hasil evaluasi RLA menggunakan metode LMP dan *hoop stress* menunjukkan estimasi umur sisa *lower waterwall tube* sebesar 0,66 tahun pada temperatur evaluasi 500 °C. Berdasarkan hasil tersebut, rekomendasi yang diberikan meliputi pemantauan kondisi *waterwall tube* melalui *thickness mapping*, evaluasi deformasi *bulging*, inspeksi metalografi berkala, serta prioritas penggantian tube yang telah mengalami degradasi lanjut.

Kata kunci: *waterwall tube, overheating, creep, Larson–Miller Parameter, hoop stress, Remaining Life Assessment.*

ABSTRACT

The boiler of PLTU Unit 3 has been in operation for more than 38 years, with an operational shift from base load to start-stop mode in accordance with electricity grid requirements. This operational pattern increases thermal cycling on boiler components, which can accelerate material degradation due to prolonged exposure to high temperatures. Flue gas-side disturbances resulting from reduced air preheater performance lead to non-uniform heat distribution, increasing the potential for local overheating on the waterwall tube. One observed failure on the waterwall tube is characterized by a longitudinal crack and bulging deformation on the fire side. The study aims to analyze the dominant failure mode and mechanism, as well as to evaluate the remaining life of the lower waterwall tube using a Remaining Life Assessment (RLA) approach.

The investigation was carried out through analysis of material characteristics and actual boiler operating conditions. Test specimens were taken from waterwall tubes aligned with the burner that exhibited leakage. The experimental procedures included visual inspection, dimensional and wall thickness measurements, chemical composition analysis, Vickers hardness testing, tensile testing, and metallographic observation to evaluate microstructural changes. Accelerated creep rupture tests were conducted at temperatures of 500–700 °C to obtain material resistance parameters against creep. Material test results were analyzed using the Larson–Miller Parameter (LMP) approach and integrated with hoop stress calculations based on actual operating pressures and temperatures to estimate the remaining service life of the tube.

The failure in the lower waterwall tube was a longitudinal rupture, driven by creep damage from long-term thermal exposure, indicated by bulging deformation, wall thinning, reduced mechanical properties, pearlite spheroidization, and intergranular void formation in the affected area, the maximum radius increased by 19.68%, wall thickness decreased from 8.38 mm to 6.50 mm, UTS dropped to 352.50 MPa, and YS to 217.44 MPa, with chemical composition remaining within JIS STB 42 standards, confirming failure was not due to material nonconformity. RLA using Larson–Miller Parameter (LMP) combined with hoop stress estimated a remaining life of 0.66 years at 500 °C, and recommended actions include thickness mapping, bulging evaluation, periodic metallographic inspection, and prioritization of tube replacement in areas showing advanced degradation.

Keywords: *waterwall tube, overheating, creep, Larson–Miller Parameter, hoop stress, Remaining Life Assessment.*