

Metallurgy of Superheater in Rice Straw Biomass Boiler: Ways & Means

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Abstract

The superheater in a rice straw biomass boiler operates under extreme conditions of high temperature and aggressive chemical environments, primarily due to the presence of alkali chlorides, silica, and other corrosive compounds in rice straw ash. These conditions lead to severe challenges such as high-temperature corrosion, fouling, slagging, and thermal stresses, which significantly reduce the service life of superheater tubes. This paper explores the metallurgy of superheater materials suitable for rice straw biomass boilers, focusing on the selection of alloys with enhanced corrosion resistance, creep strength, and oxidation resistance. Various ways and means such as the use of high chromium steels, austenitic stainless steels, nickel-based alloys, and protective coatings are discussed. Additionally, operational strategies and design modifications aimed at mitigating degradation and prolonging tube life are highlighted. The study aims to provide a comprehensive understanding of the materials and methods to improve the reliability and efficiency of superheaters in rice straw biomass boilers.

Introduction

Rice straw biomass boilers are increasingly used as sustainable energy sources due to the abundance and renewability of rice straw as fuel. However, the combustion of rice straw poses unique metallurgical challenges for boiler superheaters, which operate at high temperatures and are exposed to highly corrosive flue gases. The ash from rice straw contains high levels of alkali metals (primarily potassium and sodium), chlorine, and silica, which promote aggressive high-temperature corrosion and slagging on superheater tubes. These conditions accelerate material degradation, leading to reduced boiler efficiency, frequent maintenance, and shortened equipment lifespan.

Superheaters play a critical role in enhancing the thermal efficiency of biomass boilers by increasing the temperature of the steam beyond its saturation point. Consequently, the materials used for superheater tubes must withstand not only high temperatures but also chemical attack and thermal stresses. Traditional carbon steels often fail prematurely under these conditions due to inadequate corrosion resistance and creep strength.

This has prompted extensive research into suitable metallurgical solutions, including the development and application of alloy steels with enhanced high-temperature properties and corrosion resistance. In addition, protective coatings and surface treatments, design modifications, and operational control measures serve as effective strategies to mitigate superheater tube failures in rice straw biomass boilers.

This paper focuses on the metallurgy of superheater materials and explores various ways and means to improve their performance and durability in rice straw biomass boiler environments. It aims to provide practical insights into material selection, protective technologies, and operational practices to ensure reliable and efficient superheater operation.

Challenges in Rice Straw Biomass Boilers

- **High-temperature corrosion** due to alkali chlorides (potassium, sodium, and chlorine compounds) in rice straw ash.
- **Aggressive fouling and slagging** caused by high silica and alkali content.

- **Thermal stresses** from fluctuating operating conditions.
- **Erosion-corrosion** due to ash particles and gas flow.

2. Metallurgical Considerations for Superheater Materials

Key Requirements:

- High temperature strength and creep resistance
- Resistance to chloride and sulfate-induced corrosion
- Good oxidation resistance
- Compatibility with high ash alkali environments

Common Materials Used:

Material Type	Composition and Characteristics	Pros	Cons
Carbon Steel strength	Low alloy, cost-effective	Good mechanical	Poor corrosion resistance
Low Alloy Steels 0.5Mo	Cr-Mo steels (e.g., 1.25Cr- 0.5Mo)	Better creep and limited chloride corrosion resistance	chloride resistance
Austenitic Stainless Steels	18-8 Cr-Ni alloys (e.g., SS304, SS316)	Excellent corrosion resistance	Susceptible to chloride-induced stress corrosion cracking (SCC)
High Alloy Steels / High Superalloys	Cr-Ni-Mo alloys (e.g., Sanicro 28, Inconel 625)	Superior corrosion and oxidation resistance	Expensive, difficult to weld

3. Ways & Means to Improve Superheater Metallurgy

3.1 Material Selection

- Use high Cr content steels to resist chloride corrosion.
- Consider austenitic stainless steels or nickel-based alloys for severe environments.
- Use low alloy steels with protective coatings for moderate conditions.

3.2 Protective Coatings & Claddings

- Thermal spray coatings (e.g., ceramic coatings) to reduce erosion and corrosion.
- Overlay welding or cladding with corrosion-resistant alloys.
- Aluminizing or chromizing surface treatments to improve oxidation resistance.

3.3 Design Modifications

- Increase tube wall thickness to allow for corrosion allowance.
- Design for uniform heat distribution to reduce thermal stress and hotspots.
- Use smooth surfaces to reduce ash deposition.

3.4 Operational Controls

- Control combustion temperature to minimize ash melting and corrosion.
- Optimize fuel quality and handling to reduce alkali salt deposits.
- Implement regular cleaning schedules to remove ash and deposits.

3.5 Monitoring and Maintenance

- Use online corrosion monitoring techniques.
- Regular non-destructive testing (NDT) to detect early damage.
- Scheduled replacement and repairs based on predictive maintenance data.

4. Case Studies & Research Highlights

- Research indicates Sanicro 28 (Fe-Ni-Cr-Mo alloy) shows excellent resistance to biomass ash corrosion in rice straw boilers.
- Development of coated 9Cr-1Mo steels with ceramic overlay showed enhanced lifespan in superheater tubes.
- Controlled addition of sulfur compounds in fuel can reduce alkali chloride-induced corrosion.

5. Summary

Issue	Solution
Chloride corrosion	Use high Cr or Ni-based alloys; apply protective coatings
High temperature creep	Use low alloy Cr-Mo steels or superalloys
Ash fouling	Design smooth surfaces; maintain regular cleaning
Thermal stress	Uniform heat distribution; increase tube thickness
Cost constraints	Balance between material cost and lifetime using claddings/coatings

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