WATERWALL TUBE BOILER DAMAGE ANALYSIS IN A 150 MW STEAM POWER PLANT

By Agung Mataram

WORD COUNT	3738	TIME SUBMITTED	08-APR-2023 03:07PM
		PAPER ID	98488344

WATERWALL TUBE BOILER DAMAGE ANALYSIS IN A 150 MW STEAM POWER PLANT

By
Lugantha Perkasa[1)], Agung Mataram[2)] & Irsyadi Yani[3)]
[1,2,3]Mechanical Engineering, Sriwijaya University
Email: [1]Luganta.perkasa@gmail.com, [2]amataram@unsri.ac.id & [3]yani_irs@ft.unsri.ac.id

Abstract

Steam Power Plant which uses environmentally friendly types of boilers such as CFB (Circulating Fluidized Bed) type boilers. Failure of the boiler pipe has a big impact on the process or the losses it causes. This study will analyze the failures that occur in the boiler tube waterwall of PT. DSSP Power South Sumatra which suffered damage by testing chemical content, hardness test, tensile test, metallographic testing, and Scanning Electron Microscopy (SEM) testing. The test results show that the composition contained in the boiler tube waterwall is not in accordance with the standards, there are some elements that are lower than the specifications. The mechanical properties of watertube boilers are still in accordance with the standards. Leaks that occur in pipes are caused by creeping cracks and causing fatigue so that the damage begins with 'thermal fatigue' which causes cracks in certain weld seams. These open cracks produce leaks which cause the discharge of high velocity fluids which hit adjacent surfaces creating an 'erosion' failure which then results in thinning of the walls of the tube. The thinning of the walls then causes another leak. Therefore, a series of erosions occurred which resulted in several leaks. The fact is that the failure is preferably located in the area of the weld seam which makes it the root cause of the failure.

Keywords: Watertube Boiler, Thermal Fatigue, Leaks & Erosion.

INTRODUCTION

A steam power plant (PLTU) is one of the suppliers of electricity that has great potential in providing energy and is an alternative to meeting electricity needs. In a steam power plant or PLTU, a boiler plays an important role as a steam generator. A boiler is a device used to convert water into steam by heating it using coal as the main ingredient (Chudhoifah et al., 2020).

Material selection, treatment and maintenance processes for boilers that are subjected to workloads of pressure and at high temperatures are of great concern, this is because they are very susceptible to overheating, pitting corrosion, creep, erosion, thermal fatigue, corrosion fatigue and stress corrosion cracking which results in lowering life. wear components from planned to cause failure in boiler pipes (Adrian et al., 2016; Aini et al., n.d.; Lusiana et al., 2019).

One of the Steam Power Plants that uses an environmentally friendly type of boiler, namely the CFB (Circulating Fluidized Bed) type boiler. The use of this CFB type boiler is due to its advantages such as fuel flexibility, low NOx emissions, high sulfur capture efficiency and lower emission control costs compared to other types of boilers (Gao et al., 2017; Qi et al., 2017). However, behind its advantages, this CFB type boiler has disadvantages, one of which is the frequent occurrence of high erosion in the combustion chamber, cyclones and associated pipes due to high gas velocity (Cai et al., 2018; Miller, 2017). As in previous studies (Sahlan, 2013), the waterwall tube rupture in this CFB type boiler is caused by surface erosion or depletion due to abrasion by the bed material contained in the combustion gas stream continuously during operation.

In recent years, several studies regarding boiler pipe failures have been carried out. As

ISSN No. 1978-3787 (Cetak)
ISSN 2615-3505 (Online)

with previous research (Duarte et al., 2017), studying the behavior of leakage failure in waterwall tube boilers which is caused by pitting corrosion, residual tensile stress that comes from the rest of the tube bending process and the selection of inappropriate steel materials causes susceptibility to stress corrosion cracking. Meanwhile (Xiong et al., 2020) studied the behavior of high temperature corrosion in a 300MW water-cooled wall tube boiler which is caused because the material experiencing corrosion contains a lot of iron and sulfur elements which can be classified into sulfide corrosion. Another study analyzed the abnormal corrosion of the economizer tube in a waste-heat boiler (Ding et al., 2017), which showed that the tube material did not meet the requirements of ASTM A106 Gr.A and the occurrence of sulfuric acid dew point corrosion which was identified as coming from waste Liquid Methyl Methacrylate (MMA).

The failure of the boiler pipe has a big impact in the process or in the losses incurred. Therefore, analyzing a failure is an important thing to do to find out the root of the problem in order to reduce failures that occur in the future. Based on the above background, this research will analyze the failure that occurs in the waterwall tube boiler.

LITERATURE REVIEW

2.1 Boiler

Boilers are a vital component in a generating system that produces steam and hot water at pressures above atmospheric pressure which can then be used to drive turbines for power generation or to run factories in manufacturing industries (Drastiawati and Soekrisno, 2020; Kim, 2017). Boilers are usually built according to the requirements adopted from the American Society of Mechanical Engineers (ASME), specifically the ASME Boiler and Pressure Vessel Code.

2.2 Types of Boilers

The following types of boilers are commonly used to produce energy: fire tube boiler, water tube boiler, fluidized bed (FBC), Atmospheric fluidized bed combustor (AFBC) Boiler, Pressurized Fluidized bed Combustion (PFBC) Boiler, Stockers Fired Boiler, Pulverized Fuel Boilers, Waste Heat Boilers, and Thermal fluid heaters.

2.3 Definition of Failure

Based on theory, damage or failure analysis is an activity or effort to investigate the causes of failure of a component (Hill, 2000; Priambodo and Suhardjo, 2019). A tool can be said to have failed when the tool does not meet several requirements, including: Does not meet the planned service life; The efficiency of the tool is unlike when it was first installed; There are many defects (defects) in the tool (eg cracks, corrosion, or other surface defects); When operating there is a potential for hazard.

Failure analysis is an inspection or checking of the material experiencing problems which will result in failure of other engine components. Failure examination is based on procedures and physical evidence, literature studies and also analysis (Kurniawan et al., 2017). Failure analysis is a forensic activity in the industrial world that is carried out in order to reduce or anticipate the amount of damage and failure in a system that affects the efficiency of the production process. The failure of a material can basically be seen physically as the presence of fractures, wear and corrosion which reduces the efficiency of a system.

According to (Orosa, 2012) There are several types of causes of a failure in a system, including the following: Incorrect design; Wrong material selection; wrong in the assembly process; wrong in maintenance (maintenance); unsuitable operating conditions.

2.4 Types of Failure

2.4.1 Corrosion

Corrosion can result in a decrease in the quality of a material, resulting in the material becoming weak and damaged quickly (Yudha Kurniawan Afandi, Irfan

Syarif Arief, 2015). **Figure 1 below shows the corrosion of a component.**

Figure 1.Pitting Corrosion (Duarte et al., 2017)

2.4.2 Fatigue

Fatigue is material damage caused by fluctuating stress which is smaller than the maximum tensile strength or yield stress of the material which is given constant load (Ahmad and Rahmatullah, 2018). Figure 2 below shows Fatigue in a component.

Figure 2. Fatigue (Nusa, 2015)

2.4.3 Tensile

Tensile is a type of failure that reduces the function of machining including limiting the service life and performance of various machine components. This results in an increase in the cost of maintaining a material (Rumendi, 2018).

2.5 Failure Countermeasures

The efforts that can be made to prevent fatal damage to components according to (Syofyan and Adnyana, 2018) include the following: Reducing work stress through design improvements; Increase material / component resistance; and Increase material / component resistance.

RESEARCH METHODOLOGY

3.1 Material

Figure 3. Below is the material used in the research in the form of a waterwall tube cut in a CFB (Circulating Fluidized Bed) boiler at a steam power plant in South Sumatra that has failed. Prior to the testing process, the material will be subjected to a size reduction process using a wire cut machine.

Figure 3. Waterwall Tube Boiler

3.2 Research Method

The research method used in this research is field studies, literature studies and testing of specimens. The things that include research include:

1. Field Study

This method refers to the search for information about the components to be studied along with information about failures that occur in the waterwall tube boiler by going directly to the field, namely one of the Steam Power Plants in South Sumatra, then discussing with the supervisor and the Steam Power Plant in Sumatra. South who are experts in their fields.

2. Literature Study

This method refers to the latest books and research journals on the problem of failure analysis in boiler tube waterwall.

3. Testing

This method is carried out by conducting direct testing in accordance with existing procedures and methods. The tests carried out in this study are: chemical composition test using Optical Emission Spectrometry (OES), Rockwell Hardness Tester to determine the hardness value of tube material, tensile test

ISSN No. 1978-3787 (Cetak)
ISSN 2615-3505 (Online)

using a tensile testing machine, metallographic observation using an optical microscope and Scanning Electron Microscopy (SEM).

3.3 Research Stages

The first step carried out was specimen preparation in the form of a waterwall tube boiler that had a leak at a Steam Power Plant in South Sumatra. The specimen will be cut using a wire cut tool so that a sufficient size is produced for testing.

The second stage, the waterwall tube boiler will be tested for the identified chemical content using an Optical Emission Spectrometry (OES) tool at the Center for Materials Processing and Failure Analysis (CMPFA), University of Indonesia. This test uses the 20G class standard at GB 5310 specifications for high pressure boiler steel tubes and pipes as shown in table 1 below.

Table 1. Chemical Composition (%) GB 5310

Steel Grade	C	Si	Mn	P	S	Cr	Mo	V	Fe
20G	0.17-0.23	0.17-0.37	0.70-1.00	≤0.025	≤0.015	-	-	-	Bal

The third stage performs hardness testing with the Rockwell method by pressing the surface of the test object with an indenter. The indenter that is pressed to the object will apply the preliminary load (minor load), then add the main load (major load), then the main load is released while the minor load is still maintained (Obianyo, 2019). Hardness testing can be seen in Figure 4 below.

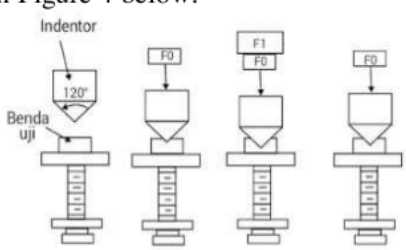

Figure 4. Rockwell Testing Process

In the fourth stage, the specimens were subjected to tensile testing carried out based on the JIS Z 2241 standard and using the 20G class specifications in the GB 5310 specifications for high-pressure boiler steel tubes and pipes. The tensile testing tool can be seen in Figure 5 below.

Figure 5. Tensile Testing Equipment

The fifth stage is conducting metallographic testing using an optical microscope to analyze the phase, shape, and micro size of a material. The mechanical properties of the material such as tensile strength, elongation, properties of heat and also electrical properties are directly related to the microstructure (Fadhilah, 2017). The last stage, the specimen will be tested by Scanning Electron Microscopy (SEM).

RESULTS AND ANALYSIS

3.1 Chemical Composition Analysis on Waterwall Tube Boiler

Below are the results of testing the composition of *waterwall tube boiler*.

Table 2. Chemical Composition of Waterwall Tube Boiler

Sample Code	C	Si	Mn	P	S	Cr	Mo	V	Fe
GB 5310 Grade 20G	0.17-0.23	0.17-0.37	0.70-1.00	≤0.025	≤0.015	-	-	-	Bal
WaterWall Tube	0.20	0.26	0.47	0.012	<0.003	0.043	<0.005	<0.002	Bal

Based on the table above, the chemical composition of waterwall tube boiler is not in accordance with the GB 5310 Grade 20G standard because the element of Manganese (Mn) does not meet the classification of predetermined standards. Based on the test, the Manganese (Mn) element in the boiler tube is only 0.47 out of 0.7 as it should be. The Manganese (Mn) element can only be said to be an alloying element if the level is more than 0.6% (Binudi and Adjiantoro, 2018). Manganese (Mn) functions as a deoxidizer of steel. This element can strengthen sulfur by forming MnS compounds whose melting point is higher than the melting point of steel. Thus it can prevent the formation of FeS whose melting point is lower than the melting point of steel. So that the Mn element can prevent embrittlement at high temperatures (Arief, 2020).

3.2 Thickness Analysis

The data below shows the results of hardness testing on boiler tube waterwall specimens.

Table 3. Results of Waterwall Tube Boiler Hardness Test

Code	1	2	3	4	5	AVG
Thickness (mm)	6.13	6.46	6.30	6.43	5.73	6.23

From the table above, it is found that the average hardness is 6.23 mm on the tube that is not eroded. From the average value, it can be said that it is not in accordance with the standards that have been referred to.

3.3 Tensile Test Analysis

Table 3. Below shows the results of the tensile test on the boiler tube waterwall.

Table 4. Tensile Test Results

Sample	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)
Waterwall Tube	500	285	34.06
GB 5310 Grade 20G	410-550	Min 245	Min 24.00

Based on Table 4, the tensile properties of the waterwall tube are in accordance with the Grade 20G material standards as in the GB 5310 specification for Seamless steel tubes and pipes for high pressure boilers.

3.4 Macroscopic Observations

Figure 6 below is a part of the boiler tube waterwall that has failed and which will be carried out a microstructure analysis

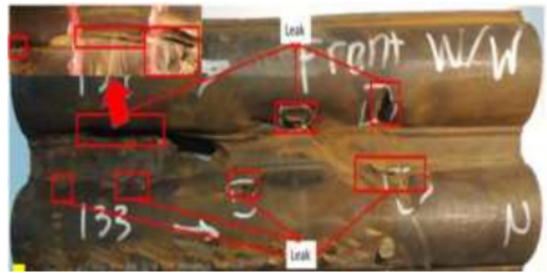

Figure 6. Indication of leakage of boiler tube waterwall

Figure 7. Visual Inspection of Waterwall Tube Boiler Failure.

Based on Figure 6, the leak is clearly indicated on the boiler tube. Most of the waterwall tube leakage comes from the welded joints between the plate and tube / tube. Leakage can also be observed from the outer diameter and the inner diameter of the tube as shown in Figure 7b and Figure 7c. Whereas in Figure 7a, you can see the erosion path in the waterwall tube that is leaking and the direction of the erosion comes from the position of the waterwall tube boiler which is leaking.

Based on figures 6 and 7 above, it can be observed that the inner surface of the boiler tube waterwall has no crust and no signs of erosion. However, other leaks are caused by thinning walls due to erosion. This thinning of the tube walls is caused by cracks that open causing the discharge of high velocity fluids to hit the surrounding surface creating erosion failure.

3.5 Microstructural Analysis

Waterwall tube boiler specimens were prepared for metallographic testing. Preparation for metallographic testing begins with mounting, grinding, polishing, etching, and observation. Etching is carried out using a nital solution to reveal the microstructure of the material. Metallographic testing is carried out on the welded waterwall tube joint because it is the origin of the leak.

ISSN No. 1978-3787 (Cetak)
ISSN 2615-3505 (Online)

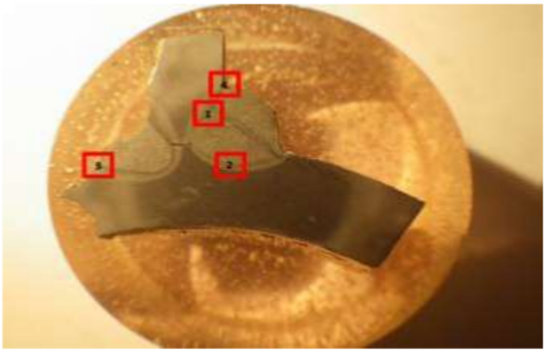

Figure 8.Waterwall Tube Metallographic Test Specimen 1

Figure 9. Micro Structure of Water Wall Tub at location 1 - Welding metal with 500X magnification

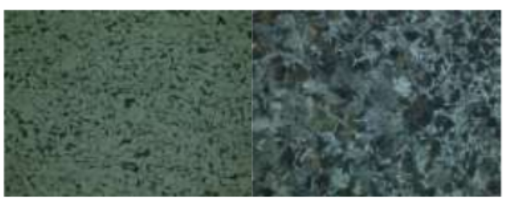

Figure 10. Micro Structure of Water Wall Tube 1 at location 1 - Base and HAZ with magnification 500X

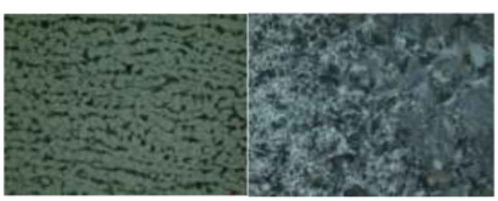

Figure 11. Micro Structure of Water Wall Tube 1 at location 2 - Base and HAZ with magnification of 500X

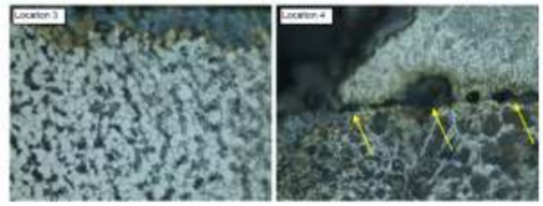

Figure 12. Micro Structure of Water Wall Tube 1 at locations 3 and 4 with a magnification of 500X.

Figure 13.Waterwall Tube Metallographic Test Specimen 2

Figure 14. Waterwall tube microstructure with magnification of 100X and 500X

Microstructure analysis of boiler tube waterwall using metallographic testing was carried out in the area of the weld joint between the plate and tube because this area was the most leaking area. The analysis was carried out on the base metal, weld metal, and the heat affected zone (HAZ). The analysis showed that the metallographic structure of the weld joint was ferrite-pearlite, normal structure of 20G. This shows that the boiler tube waterwall is not induced by excess heat (Du et al., 2014).

Figure 12 shows the microstructure of the weld joint. The lack of fusion in the side wall of the boiler tube waterwall weld connection has the potential to be the cause of the initial crack or the beginning of the crack. Under the influence of cyclic loads such as cyclic thermal, this fusion deficiency can propagate if the waterwall tube boiler is exhausted.

3.6 Scanning Electron Microscopy (SEM) Observation Analysis

Scanning Electron Microscopy (SEM) observations were taken on the surface area of the waterwall tube boiler leak fracture as shown in Figure 15.

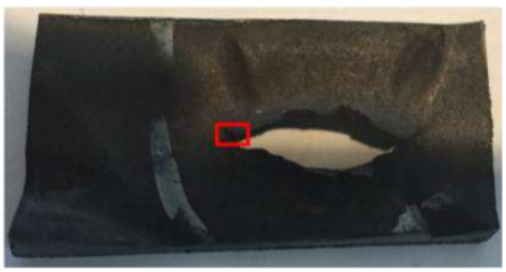

Figure 15. SEM test specimens for boiler tube waterwall

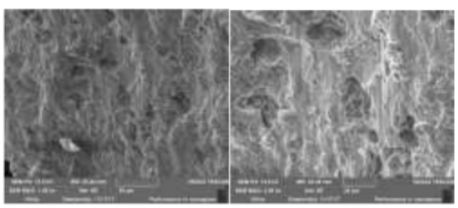

Figure 16. SEM observations of waterwall tube with 1000X and 2000X magnification

The surface in Figure 16 is covered by oxides due to corrosion. A little indication of dimple was found under observation with 2000X magnification. Dimple in tube failure usually associated by thinning rupture occurred on the tube. EDS analysis was not performed due to lack of corrosion product found on the surface of area of failure.

CONCLUSIONS

The composition of the waterwall tube is not up to standard. There are some elements which are lower than specification. However, the mechanical properties are still up to standard. The damage mechanism analysis was carried out on the waterwall pipe as this sample had several visible leaks. The damage analysis found that the waterwall pipe has a damage model, namely leakage caused by cracks. The crack is thought to have occurred due to a weld defect on the outer surface which acts as a stress concentration. Under cyclic loads such as cyclic thermal loads, cracks propagate and cause fatigue so that the damage then begins with 'thermal fatigue' which creates cracks in a particular weld seam. These open cracks produce leaks which cause the discharge of high velocity fluids which hit adjacent surfaces creating an 'erosion' failure which then results in thinning of the walls of the tube. Wall thinning starts at the outer diameter and takes up thickness until the wall is thin enough and unable to withstand internal stresses and fails due to excessive tearing. The thinning of the walls then causes another leak. Therefore, a series of erosions occurred which resulted in several leaks. The fact is that the failure is preferably located in the area of the weld seam which makes it the root cause of the failure.

REFERENCES

[1] Adrian, J., Latif, N., Noerochim, L., Kurniawan, B.A., 2016. Analisa Kerusakan Superheater Tube Boiler Tipe ASTM A213 Grade T11 pada Pembangkit Listrik Tenaga Uap. J. Tek. ITS 5. https://doi.org/10.12962/j23373539.v5i2.18561

[2] Ahmad, R., Rahmatullah, R., 2018. Analisa Pengujian Lelah Material Bronze Dengan Menggunakan Rotary Bending Fatigue Machine. J. Rekayasa Mater. Manufaktur dan Energi 1, 1–11. https://doi.org/10.30596/rmme.v1i1.2430

[3] Arief, S., 2020. Analisis Welding Joint Performance Material ASTM SA 178 D Pada Waterwall Tube Boiler PLTU Paion Unit 1-400.

[4] Cai, R., Zhang, H., Zhang, M., Yang, H., Lyu, J., Yue, G., 2018. Development and application of the design principle of fluidization state specification in CFB coal

ISSN No. 1978-3787 (Cetak)
ISSN 2615-3505 (Online)

combustion. Fuel Process. Technol. 174, 41–52. https://doi.org/10.1016/j.fuproc.2018.02.009

[5] Chudhoifah, M.N., Suastiyanti, D., Rupajati, P., 2020. Analisa Kerusakan Pipa Boiler Super Kritikal. J. Tek. Mesin ITI 4, 24. https://doi.org/10.31543/jtm.v4i1.334

[6] Ding, Q., Tang, X.F., Yang, Z.G., 2017. Failure analysis on abnormal corrosion of economizer tubes in a waste heat boiler. Eng. Fail. Anal. 73, 129–138. https://doi.org/10.1016/j.engfailanal.2016.12.011

[7] Drastiawati, N.S., Soekrisno, R., 2020. Failure Analysis on Reheater Tube Boiler Furnace Base on Tensile and Impact Test 196, 355–360. https://doi.org/10.2991/aer.k.201124.064

[8] Duarte, C.A., Espejo, E., Martinez, J.C., 2017. Failure analysis of the wall tubes of a water-tube boiler. Eng. Fail. Anal. 79, 704–713. https://doi.org/10.1016/j.engfailanal.2017.05.032

[9] Du, H.Y., Sun, X.H., Li, Y.M., Ren, Z.A., 2014. Analysis on waterfall tube corrosion and strength calculation for boilers exceeding service life. Adv. Mater. Res. 900, 695–698. https://doi.org/10.4028/www.scientific.net/AMR.900.695

[10] Fadhilah, I., 2017. Analisis Struktur Mikro Metalografi).

[11] Gao, M., Hong, F., Liu, J., 2017. Investigation on energy storage and quick load change control of subcritical circulating fluidized bed boiler units. Appl. Energy 185, 463–471. https://doi.org/10.1016/j.apenergy.2016.10.140

[12] Hill, T., 2000. ERA Technology Reports. Ind. Manag. Data Syst. 100, 46–48. https://doi.org/10.1108/imds.2000.100.1.46.6

[13] Kurniawan, R.T., Wibisono, A.T., Noerochim, L., 2017. Analisis Kegagalan Komponen Spring Rod dalam Spring Suspension Assembly pada Coal Mill Tuban I PT. Semen Indonesia Tbk. J. Tek. ITS 6. https://doi.org/10.12962/j23373539.v6i2.24476

[14] Obianyo, I., 2019. Laboratory manual for hardness test.

[15] Rumendi, U., 2018. ANALISA UJI KEAUSAN MATERIAL St 37 HASIL CARBURIZING DAN HARDENING DENGAN 0–5.

[16] Sahlan, 2013. Analisis Fraktografi Dan Kerusakan Abrasif Water Wall Tube Boiler Pltu Tarahan 23–24.

[17] Syofyan, A., Adnyana, D.., 2018. Analisa Kegagalan Swing Drive Wheel Exavator M 322 C 1, 1–8.

[18] Xiong, X., Liu, X., Tan, H., Deng, S., 2020. Investigation on high temperature corrosion of water-cooled wall tubes at a 300 MW boiler. J. Energy Inst. 93, 377–386. https://doi.org/10.1016/j.joei.2019.02.003

[19] Yudha Kurniawan Afandi, Irfan Syarif Arief, A., 2015. Analisa Laju Korosi pada Pelat Baja Karbon dengan Variasi Ketebalan Coating. J. Tek. Its 4. 1-5.

WATERWALL TUBE BOILER DAMAGE ANALYSIS IN A 150 MW STEAM POWER PLANT

ORIGINALITY REPORT

8%
SIMILARITY INDEX

PRIMARY SOURCES

1	core.ac.uk Internet	155 words — 4%
2	A.K. Sethi, Om Vikash. "Failure analysis of the water-wall tube in once through Benson boiler", Materials Today: Proceedings, 2022 Crossref	80 words — 2%
3	Hongfu Zhang, Mingming Gao, Chun Liu, Jizhen Liu, Guangxi Yue, Jiahui Zhang. "Dynamic prediction of in-situ SO2 emission and operation optimization of combined desulfurization system of 300MW CFB boiler", Fuel, 2022 Crossref	67 words — 2%

EXCLUDE QUOTES	OFF	EXCLUDE SOURCES	< 2%
EXCLUDE BIBLIOGRAPHY	OFF	EXCLUDE MATCHES	OFF