

Design of a high temperature erosion apparatus for testing of boiler tubes

Hüseyin ERGÜN, Kadri AYDINOL, Tayfur ÖZTÜRK,* Mustafa DORUK
Department of Metallurgical and Materials Engineering, Middle East Technical University,
Ankara, Turkey

Received: 24.07.2012 • Accepted: 26.12.2012 • Published Online: 04.07.2013 • Printed: 29.07.2013

Abstract: An apparatus was designed that enables the testing of boiler tubes against erosion. The apparatus makes use of a tube sample and simulates conditions similar to those prevailing in boilers in lignite-based power plants. The apparatus is composed of 3 components: a furnace for heating the sample, a loading system that allows the application of tensile stresses while allowing its rotation, and an erosion unit that delivers abrasive particles to the surface of the sample. The unit, as designed, would allow testing of boiler tubes up to a temperature of 650 °C and particle velocities of up to 50 m/s. The apparatus, tested at room temperature for 4 identical samples, yielded very similar erosion values, which were based on measurement of weight loss. At elevated temperature, erosion could be followed by a thickness loss value rather than the weight loss since the oxidation complicates the weight measurements. Two economizer materials (P235GH and 16Mo3) were tested with the current setup at 500 °C with particle velocity of 10 m/s. The testing showed 16Mo3 performed better than P235GH did, the erosion rate of the former being 20% lower than the latter.

Key words: Boiler tubes, erosion, economizer, thermal power plant

1. Introduction

Coal-based thermal power plants have a considerable share in power generation. According to the EIA (2010), this is 42% of the total for the world as a whole. According to the EÜAŞ (2010), the share is lower for Turkey, making up only 28% of the total, the greater portion of the remaining part being made up of power plants based on natural gas. Most coal-based power plants in Turkey make use of lignite with calorific values in the range 1000–2000 kcal/kg. The typical boiler tube failures encountered in thermal power plants are erosion, waterside corrosion, fireside corrosion, long-term overheating, short-term overheating, welding-based failures, and fatigue (EÜAŞ, 2008). In Turkey, data collected by the EÜAŞ over 4 years imply that nearly one-third of the failures originate from erosion due to fly ash. This is followed by short-term overheating usually caused by deposit formation (28%) and long-term overheating (22%).

Fly ash erosion occurs mostly where the boiler tubes are closer together, i.e. the economizer region, and in the regions where the particles have high velocities, i.e. from 15 m/s to 55 m/s (Electric Power Research Institute, 2004). Fly ash is typically made up of SiO₂ (54%), Al₂O₃ (19%), Fe₂O₃ (11%), CaO (5%), and other oxides. Here the values in parentheses refer to the quantity of oxides as measured in Seyitömer thermal power plant (Çelik, 2010). The particles size normally varies between 1 and 200 μm, the median value being 58 μm.

*Correspondence: ozturk@metu.edu.tr

Testing of boiler tubes against erosion has, therefore, been the subject of considerable interest. For instance, Moumakwa and Marcus (2005) developed a basic setup that involved the blowing of erosive particles (SiO_2) onto an angled plate sample. A similar test setup was described by Zhang et al. (2001) where the sample was a tube rather than a plate using fly ash as abrasives. Suckling and Allen (1997) developed a test setup that can also be used at elevated temperatures. In this design, the sample, i.e. a plate, is placed at a constant angle and abrasive particles (SiO_2 , SiC, or fly ash) are fed to the specimen by a LPG flame. A similar test setup was reported by Lindsley et al. (1995) with the added advantage that the inclination of the plate with respect to flow of abrasives (Al_2O_3) could be adjusted to the desired value. Hayashi et al. (2003) used a different approach and tested several samples simultaneously, samples being placed vertically around a rotating cone delivering the abrasive particles.

The current study was undertaken for the purpose of developing a simple setup for testing of boiler tubes in an environment similar to the operating conditions of a boiler in a lignite-coal-based power plant.

2. Setup design

The test apparatus was designed to simulate operating conditions in the boiler of thermal power plants, especially in the economizer zone. The setup consists of 3 components (Figure 1). These are i) a unit for the sample loading system, ii) a unit for blowing the abrasive particles, and iii) a furnace system to control and monitor the temperature of testing.

2.1. Sample loading system

A schematic drawing of a sample loading system is given in Figure 2. The system comprises a tubular mill (1) housed in place with the use of 2 bearings (2). Further below, there is an identical mill (3) of short length fixed axially in place and centered in a similar bearing (4). The sample (5) is connected axially to these mills via a pin coupling (6).

The sample is loaded via a spring system. The spring (7), placed around the upper mill with 7 turnings, mean diameter 123 mm, has a spring constant of $k = 346 \text{ N/mm}$. The spring can be compressed with a help of a gear-nut (8) rotated with a gear connected to a motor placed on a horizontal plane (not shown). With the sample in place, when the nut is driven down, it compresses the spring, applying tensile forces to the mill and hence to the sample. The spring system allows the application of tensile forces of up to 30,000 N (85% maximum deflection). The system is designed such that the whole loading system can be rotated with a motor-gear system (9) located at the top; the connection to the tubular mill is made via a central rod with a pin coupling (10).

The loading system as described above allows the use of samples in the form of tubes with a minimum of sample preparation. The sample preparation consists of machining of the central portion of the tube and drilling of 2 holes at both ends of the sample.

2.2. Particle blower

A schematic drawing of the particle blower used in the setup is given in Figure 3. The feeding of particles is based on a Venturi eductor that utilizes the kinetic energy of the high velocity air to create suction. Here air is fed into the system with a compressor (0–8 bar) passing through a conditioning furnace. The system allows the delivery of air with velocity values of up to 50 m/s. The air fed through a thin-walled (1 mm) copper tube (diameter 10 mm) is conditioned by circulating it in a simple tube furnace. The air is fed to the eductor via

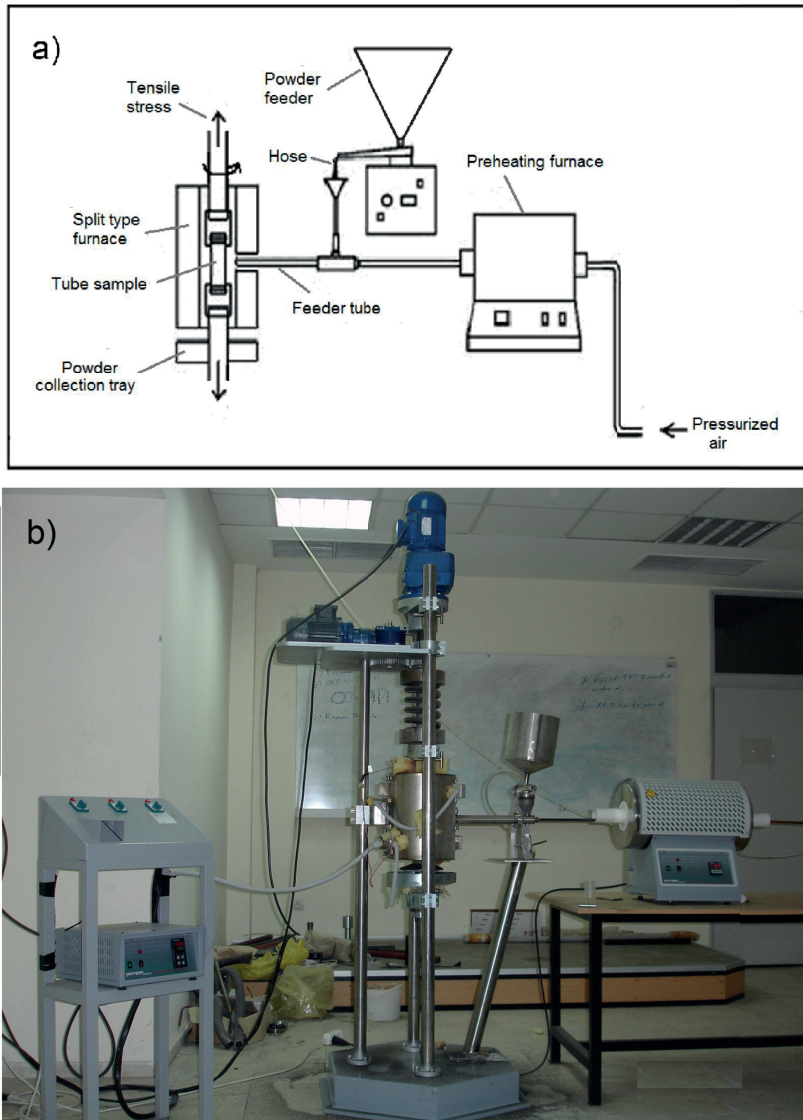


Figure 1. Setup for testing of boiler tubes: a) schematic representation of the test setup; b) photograph of the setup.

a 4-mm (D_i) diameter nozzle. The delivery diameter was 6 mm (D_o). The suction side (D_s) was adjustable from 6 mm to 12 mm by changing the connecting hose. Preliminary experiments using this feeding system (exit velocity: 10 ± 1 m/s, particles: alumina mean diameter of $300 \mu\text{m}$) showed that the unit could deliver particles at a rate of 0.8 g/min. This value achieved with a 6-mm diameter hose could be increased to 7.8 g/min when the diameter (inner) was increased to 12 mm.

2.3. Heating system

Heating of samples was achieved with the use of a split type tube furnace (11) (Figure 2). The furnace heated with resistive elements can reach high temperatures ($1100 \text{ }^\circ\text{C}$), though the testing temperature was never more than $500 \text{ }^\circ\text{C}$ in the present study. The delivery of particles with high velocity air to the sample cools down the chamber atmosphere. Therefore, the use of a more powerful furnace was helpful in maintaining the

targeted temperature. Still, to be able to maintain the temperature in the furnace, air must be preheated in the conditioning unit described above.

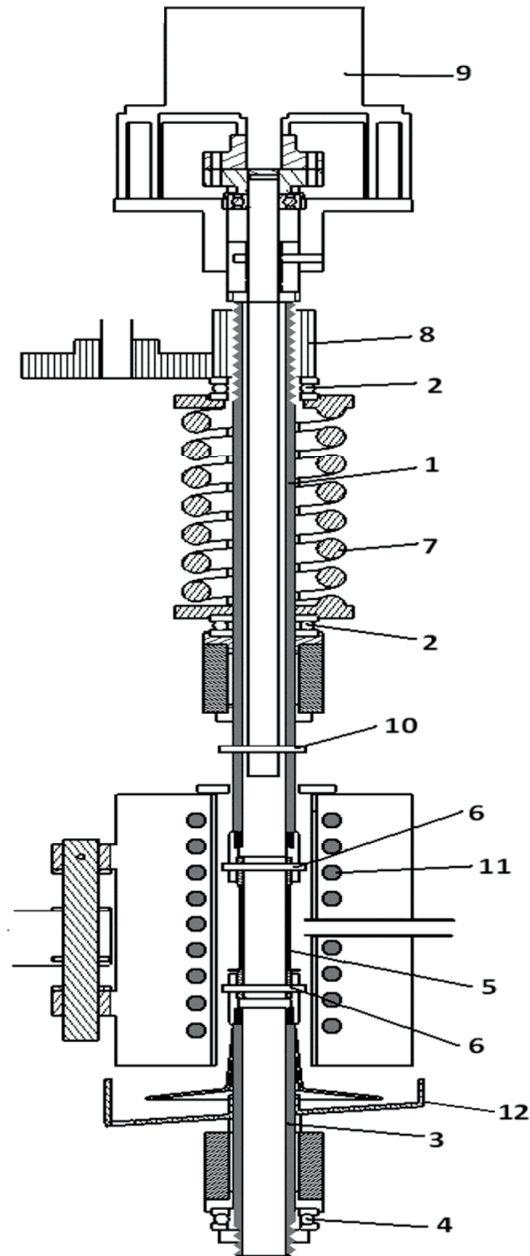


Figure 2. Sample loading system in the setup, see text for details. 1. Tubular upper connector mill, 2. Axial bearings, 3. Tubular lower connector mill, 4. Axial bearing, 5. Sample, 6. Connecting pins (sample), 7. Helical compression spring, 8. Gear, 9. Motor with a reduction gear, 10. Connecting pin (mill), 11. Heating elements, 12. Tray for powder diversion.

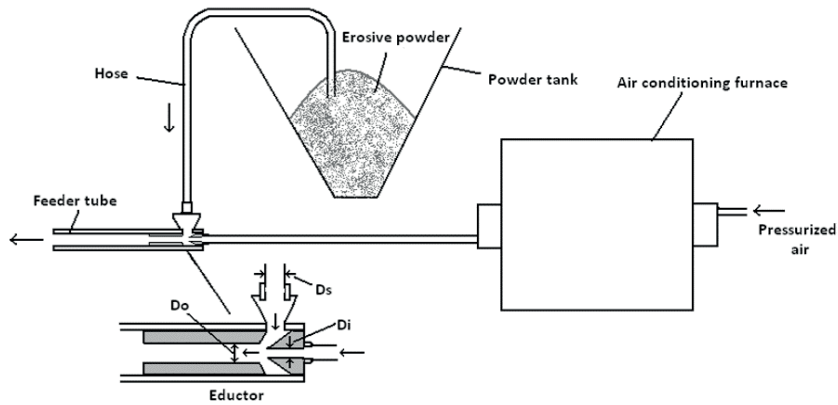


Figure 3. Schematic representation of the particle blower.

3. Testing of boiler tubes

Initial experiments with the setup involved room temperature testing. These were carried out with the purpose of checking the reproducibility of the test results, i.e. erosion taking place in the samples. Four samples were manufactured from 10CrMo9-10 tubes (EN 10216-2) (Institute of Turkish Standards, 2010), the outside diameter of which, after machining, was 37 mm with a wall thickness of 5 mm.

Erosive particles used in the experiments were a mixture of oxides, the greater portion of which was alumina. The other oxides present were SiO_2 , CaO , TiO_2 , and Fe_2O_3 , the sum of which was not more than 10%. The particles had a distribution of sizes between 80 and 420 μm (99%), the average occurring at 300 μm . Particles were blown onto the sample at a velocity of 10 ± 1 m/s at a rate of 4.5 g/min.

Duration of the experiments was 20 h for each specimen. Erosion occurred over a distance of 25 mm, as seen in Figure 4. The erosion was measured by weighing the sample before and after the experiment, i.e. in terms of material loss. The measured values for 4 samples were 0.05, 0.06, 0.04, and 0.05 g. The values are quite close to each other, indicating that the test results are quite reproducible. The average loss in the samples was 0.05 ± 0.007 g.

Having checked that the setup produces a reliable result at room temperature, experiments were carried out at an elevated temperature. Two samples were tested. Duration was 50 h and the temperature was 500 °C (± 20 °C). For this purpose, having connected the sample, the furnace was set at 700 °C and operated for 1 h. The air conditioning furnace was operated simultaneously, the temperature of which was selected based on the results of the preliminary experiments. Having stabilized the temperatures, the experiment was started by switching on the air supply and activating the control for the rotation of the test piece.

For elevated temperature testing, the measurement of erosion using the weighing method did not yield a reliable result. This was due to oxidation of the sample, which led to weight gain, resulting in a material loss value that was less than that realized by erosion. Thus, for elevated temperatures, measurement of erosion by weight loss was not suitable.

Figure 5 shows the variation in the wall thickness of the sample in the eroded region. Initially uniform wall thickness decreases as one moves into the eroded region, reaching a maximum thickness loss value of 0.080 mm at the very center of the region. The variation in wall thickness is such that the thinnest portion of the sample can be located quite easily. This shows that the maximum value of thickness loss can be determined with ease.



Figure 4. A sample after testing for 20 h at room temperature. Note that particles blown onto the sample cover a distance of approximately 25 mm. A collar close to the lower end of the sample is firmly fitted to the sample, diverting the abrasive particles away from the pin coupling.

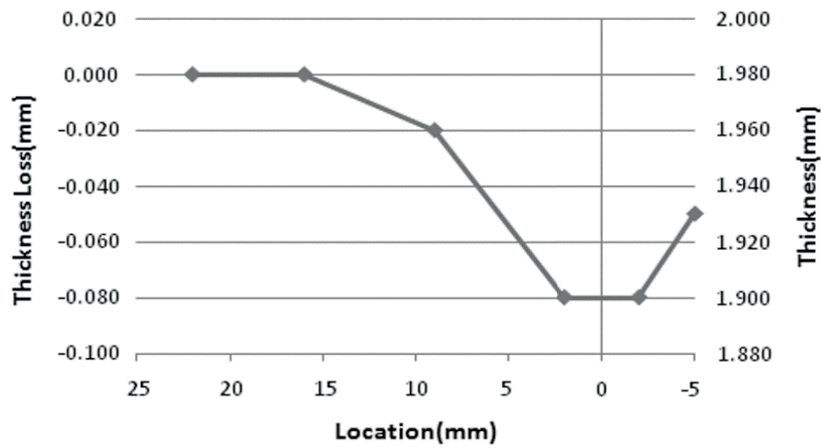


Figure 5. Variation in thickness loss as a function of location in the eroded zone. Note that thickness loss increases as one move to the center of the eroded zone. The sample is 10CrMo9-10 steel. Note that the tube has a maximum thickness loss value of 0.080 mm.

This thickness loss value may be used as a measure of material erosion. In fact, the experiment reported above was repeated with a second sample, yielding a thickness loss value of 0.075 mm. The values are quite

close to each other, indicating that thickness loss is nearly as reliable as the weight loss method used at room temperature.

4. Concluding remarks

As described above, the setup developed enables the testing of boiler tubes simulating conditions similar to those present in lignite-coal-based boilers. The main feature under study was erosion caused by fly ash for which particle speeds of up to 50 m/s can be tested. The temperatures can be as high as 650 °C. Although in the current study no stress was imposed on the samples, the setup is capable of applying tensile forces of up to 30,000 N. Testing of this setup showed that the erosion of tubes can be evaluated quite reliably using a thickness loss parameter.

Finally we have used this setup to evaluate 2 economizer materials. These were P235GH and 16 Mo3 (EN 10216-2) tubes of 37 mm diameter (wall thickness: approx. 2 mm). Testing carried out for 50 h yielded thickness loss values of 0.12 and 0.10 mm for P235GH and 16 Mo3 tubes, respectively. This implies that in terms of erosion behavior 16 Mo3 tubes are superior to P235GH ones.

5. Conclusion

In this study an apparatus was designed that enables the testing of boiler tubes in conditions simulating those prevailing in lignite-coal-based boilers, especially in the economizer zone. The apparatus as tested at room temperatures with particle velocity of 10 m/s displayed erosion characteristics very similar to those measured by a weight loss value. At elevated temperature, it was shown that erosion could be measured by a thickness loss value, which was also reproducible. Finally, the setup was used for testing of 2 economizer materials: P235GH and 16Mo3. This showed that 16Mo3 performed better than P235GH did against erosion, with the rate of erosion differing by 20%.

Acknowledgment

The work reported in this paper was supported by DPT (BAP-03-08-DPT-2007K120220), which the authors gratefully acknowledge.

References

- Çelik, Ö., “The effects of fly ash, silica fume and sludge additives on the strength of cement”, <http://www.dogateknik.com.tr/Teknik-Belgeler/Ucucu-kul-silis-dumani-ve-atik-camur-katkilarinin-cimento-dayanimlarina-etkileri.pdf>, in Turkish, 2010.
- EIA, International Energy Outlook, U.S. Energy Information Administration, [http://www.eia.doe.gov/oiaf/ieo/pdf/0484\(2010\).pdf](http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2010).pdf), 2010.
- Electric Power Research Institute, “Field Guide: Boiler Tubes Failure Report”, Section 3-4-5, 2004.
- EÜAŞ (Elektrik Üretim AŞ), “Elektrik Üretim Sektör Raporu”, www.enerji.gov.tr/yayinlar_raporlar/Sektor_Raporu_EUAS_2009.pdf, in Turkish, 2010.
- EÜAŞ (Elektrik Üretim AŞ), Gölbaşı Laboratory, Report on Failure Analysis: 2004–2008 (unpublished study), 2008.
- Hayashi, N., Kagimoto, Y., Notomi A., Takeda Y. and Katoba K., “Development of New Testing Method by Centrifugal Erosion Tester at elevated temperature”, *Wear* 258, 2003, 443–457.
- Institute of Turkish Standards, “TS EN 10216-2. Seamless steel tubes for pressure purposes- Technical delivery conditions – Part: 2 Non-alloy steel tubes with specified elevated temperature properties”, in Turkish, Ankara 2010.

Lindsley B., Stein K. and Marder A.R., “The Design of a High-Temperature Erosion Apparatus for Studying Solid Particle Impact”, *Meas. Sci. Technol.* 6, 1169–1174, 1995.

Moumakwa, D.O. and Marcus K., “Tribology in Coal-Fired Power Plants”, *Tribology International* 38, 805–811, 2005.

Suckling, M. and Allen, C., “Critical Variables in High Temperature Erosive Wear”, *Wear* 203-204, 528–536, 1997.

Zhang, L., Sazonov, V., Kent, J., Dixon, T. and Novozhilov, V., “Analysis of Boiler-Tube Erosion by the Technique of Acoustic Emission Part I, Mechanical Erosion”, *Wear* 250, 762–769, 2001.