Investigating Soot Blowing Mechanism of Boilers

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Abstract

Soot blowers are often neglected aspects of the boiler operation in a coal power plant whereas they have a significant impact on the financial bottom line as they improve the efficiency of the boiler. Soot deposits are hard to manage if they are left unattended as they form a thick insulating layer, which reduced the efficiency of the boiler. It increases the loss of energy due to high temperature of the exhaust gasses, as well as emissions.

Sasol has a power station at Secunda, South Africa. Sasol uses soot blowers as means of cleaning the boiler during operation which are operated manually. The purpose of this paper is to investigate the soot blowers of the boilers and determine their strengths and limitations as well as the areas that need improving. The paper focuses mostly on the steam soot blowers and comparing it to the acoustic soot blowers.

A literature review was done to highlight the key features of the different types of soot blowers. Tests on the existing concept was done leading to a new model to be introduced to improve efficiency. The final concept was created and modelled via simulations.

Keywords Soot blower; boiler; heat transfer; efficiency; IoT

1. Introduction

A boiler is a vessel in which water is heated into hot water or steam for power production. It is a major component in process industries, and it provides steam at various pressures (Clyde Bergemann, 2019). Combustion of fuel (coal, gas or oil) takes place in the boiler furnace and the hot gases produced come into contact with the water vessel and the heat is transferred into the water resulting in the production of steam which then flows to the turbines. An efficient boiler transfers all the heat from combustion into the water, but it is not possible to achieve that due to heat losses in the boiler which include heat radiated from the outer surface of the boiler, heat carried by dry flue gas as well as incomplete combustion of the fuel (Bergemann, 2019). During combustion, the fuel forms soot or ash as a by-product which is then deposited on the heating surfaces of the boiler and act as a heat insulator (Shandu, 2019; Shandu and Kallon, 2021). If this remains untreated, the soot will affect several units in the boiler which include the super heater, reheater, economizer, etc. This may result in increased exhaust gas temperature, reduced boiler efficiency and increased fuel consumption and therefore the boiler would have to be shut down for cleaning. The soot deposits would also make inspection and maintenance of the boiler difficult (Devi, et. al, 2017).

A soot blower is a device used to prevent the layer of soot from developing. It is used while the boiler is in operation. It is essential as it cleans the boiler, and therefore it extends the boiler availability for production and increases efficiency (Shandu et al, 2021). It also prevents fouling in the boiler units. Steam soot blowers have a tube that transports the cleaning medium that is inserted into the boiler called a lance. Nozzles on the tip of the lance increase the speed of the cleaning medium flow and it is directed under pressure against the heating surface where it removes the soot. The soot is then removed from the walls by the impact (Karthikeyan, 2020). Unlike Steam soot blowers, Acoustic horns soot blowers make use of intense sound pressure to dislodge ash. They are sounded every few minutes to prevent ash from staying on the heat transfer surfaces (Shandu et al, 2019). Other types of soot blowers include air soot blower which uses compressed air as the cleaning medium, water canon soot blowers which directs water jets across the furnace in the boiler. The report will focus mostly on the steam soot blowers and the acoustic soot blowers. (Jameel, et.al. 2017; Nalind, 2017; Shukla, 2013)

2. Materials and Methods

The first step was to understand boilers and how they operate to get an idea on the importance of soot blowers. It was then followed by a literature review for further understanding as well as the background information. More research was done on the existing concepts which include the steam, the air, water cannon and the acoustic soot blowers on how they function and how they differ and the advantages and disadvantages for each. The use of a decision matrix helped in selectin the best type of soot blower that can be used. The steam and the acoustic soot blowers were selected as they met the requirements/performed better than the others. It was also found that the long retractable steam soot blower was the appropriate one for use in high temperature and for sticky soot (Nalind, 2017).

Existing long retractable soot blowers are more vulnerable to bending and corroding as they operate at high temperatures. Stainless steel was chosen as the material that can be used for the lance due to its ability to withstand high temperature while maintaining its structural integrity. Calculations were performed to get the right thickness for the lance that can withstand the steam pressure. To demonstrate the bending effect, Autodesk Inventor was used where a CAD model was produced and the behavior of the lance when it is fully erect was analyzed. The use of new technology was also introduced which includes the IoT which enables the use of mobile devices to control machine as well as an increased level of automation as machine can detect changes on their own and act to correct them. The use of the IoT will also allow for predictive maintenance which will help predict the lifetime of the boiler equipment, reducing unnecessary inspections and check-ups.

2.1 Working principle

The technology will consist of sensors installed in the boiler which will detect temperature changes of the flue gasses. The sensors will then report to the IoT software which will activate the soot blowers. The soot blowers will start operating and the temperature drop will be detected as well, which will stop the operation. The use of the technology will optimize efficiency and operational cost.

3. Model Development

3.1 Calculations

Steam pressure = 21 bar

Thickness = 2,5 mm

Radius = 65 mm

$$\sigma_\theta = \frac{Pb}{t}$$

$$= \frac{(21 \times 10^5)(65)}{2{,}5}$$

$$= 54{,}6\ MPa$$

$$\sigma_r = \frac{P}{2}$$

$$= \frac{21 \times 10^5}{2}$$

$$= 1{,}05\ MPa$$

$$\sigma_z = \frac{Pb}{2t}$$

$$= \frac{(21 \times 10^5)(65)}{2 \times 2{,}5}$$

$$= 27{,}3\ MPa$$

Comparing maximum stresses and deflections of the lance with and without a support structure in the boiler.

Assuming that only gravity is acting on the lance.

3.1.1 Weight of the lance per meter for stainless steel:

$$W = \frac{\pi(D^2 - d^2)}{4} \times 0{,}00788$$

$$= \frac{\pi(70^2 - 65^2)}{4} \times 0{,}00788$$

$$= 5{,}319 \frac{kg}{\text{m}}$$

$$= 5{,}319 \times 9{,}81\ N$$

$$= 52{,}2\ N/m$$

A) Without a support structure:

The length of the lance is 8m

$$\therefore BM_{max} = \frac{WL^2}{2}$$

$$= \frac{(52{,}2)(8)^2}{2}$$

$$= 1{,}67\ kNm$$

$$I = \frac{\pi(D^4 - d^4)}{64}$$

$$= \frac{\pi(70^4 - 65^4)}{64}$$

$$= 302\ 347{,}613\ mm^4$$

$$\sigma = \frac{My}{I}$$

$$= \frac{(1670)(67{,}5)}{(302\ 347{,}613)}$$

$$= 372{,}83\ kPa$$

$$\delta = \frac{WL^4}{8EI}$$

$$= \frac{(52{,}2)(8)^4}{8(200 \times 10^9)(3{,}02 \times 10^{-7})}$$

$$= 0{,}441\ m$$

$$= 441\ mm$$

B) With a support structure:

The length of the lance is 4m from the support

$$\therefore BM_{max} = \frac{WL^2}{2}$$

$$= \frac{(52,2)(4)^2}{2}$$
$$= 417,6\ Nm$$

$$\sigma = \frac{My}{I}$$
$$= \frac{(417,6)(67,5)}{(302\ 347,613)}$$
$$= 0,0923$$
$$= 92,3\ kPa$$

$$\delta = \frac{WL^4}{8EI}$$
$$= \frac{(52,2)(4)^4}{8(200 \times 10^9)(3,02 \times 10^{-7})}$$
$$= 0,02762\ m$$
$$= 27,62\ mm$$

From the calculations, the deflection of the lace without support is bigger than that with deflection. The same can be said for the stresses, proving that including a support will reduce the stress acting on the lance as well as the bending moment.

3.2 Concept Development

The selected concept is the long retractable soot blower as shown in Figure 1 to 3. It consists of a lance tube, poppet valve, carriage and a control system. To reduce unnecessary inspection and unplanned maintenance of the soot blower, a new technology can be introduced to assist in predicting the maintenance of the blower parts. To reduce failure of the lance tube and bending, support structures are introduced inside the boiler.

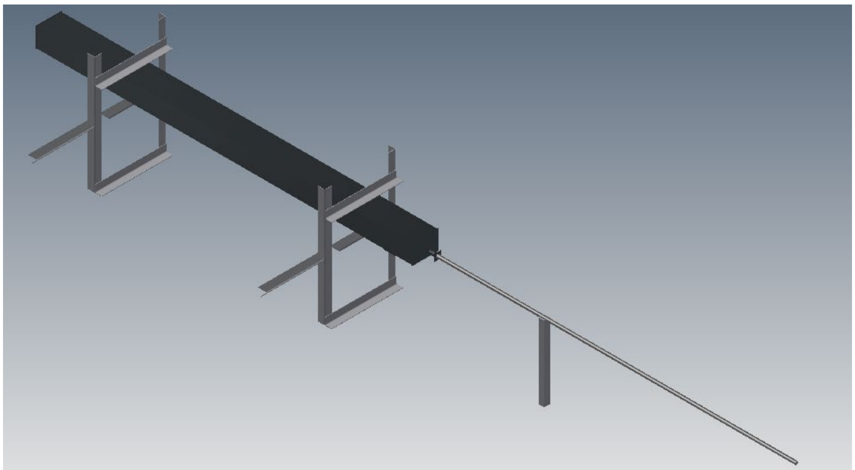

Figure 1: The long retractable soot blower

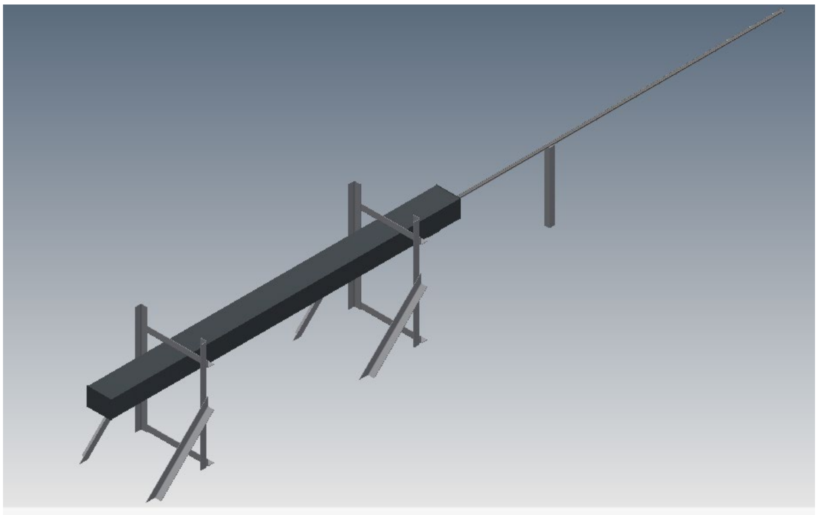

Figure 2: The long retractable soot blower II

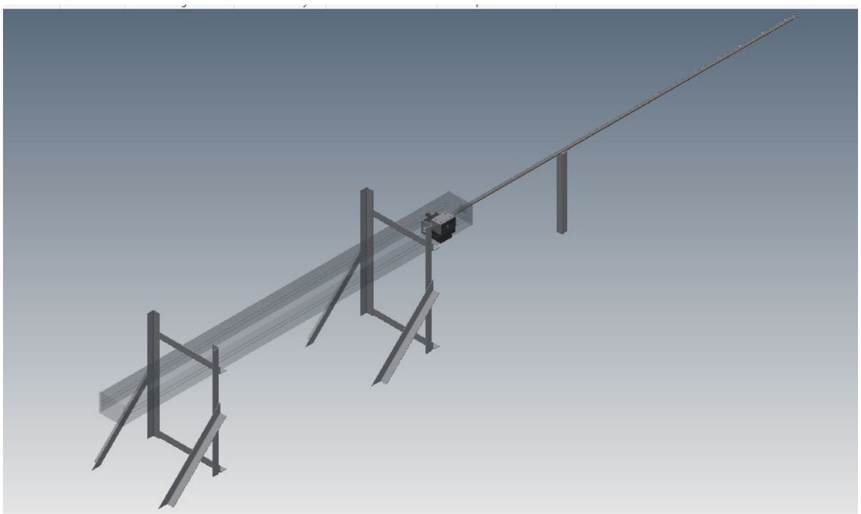

Figure 3: The long retractable soot blower III

3.2.1 Lance tube

Lance tubes are inserted into the boiler and they blast steam onto the soot deposits. They have nozzles at the tip which direct the steam and increases pressure. The lance should be made from stainless steel so that it can withstand the boiler heat without corroding. The lenth of the tube depends on the size of the boiler. Problems with existing soot blowers include the bending of the lance when operating which affects the lance and reduce its usability (Karthikeyan, 2020). This can be solved by introducing support structures within the boiler.

3.1.2 Poppet valve

The poppet valve (Figure 4) is used to adjust the blowing pressure. It is replaceable and it is attached by bolts and nuts so that it is easier to install or remove for maintenance. It optimizes the cleaning effect and the consumption of the cleaning media. It should have a locking device to prevent the drifting of pressure during operation.

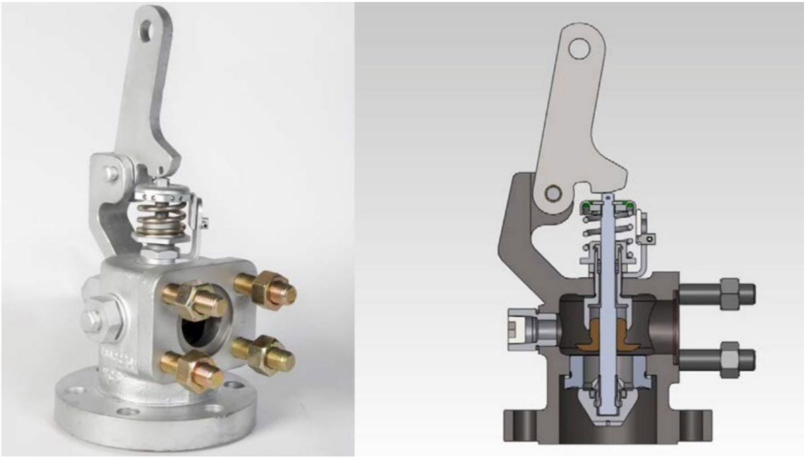

Figure 4: A poppet valve [2].

3.1.3 Carriage

The carriage (Figure 5) consists of the gearbox, motor, chains, etc. that will rotate the lance tube. The lance tube will be attached to the carriage which will be allowing rotational motion. The carriage will move axially along with the lance, this will be giving the lance the back and forth movement.

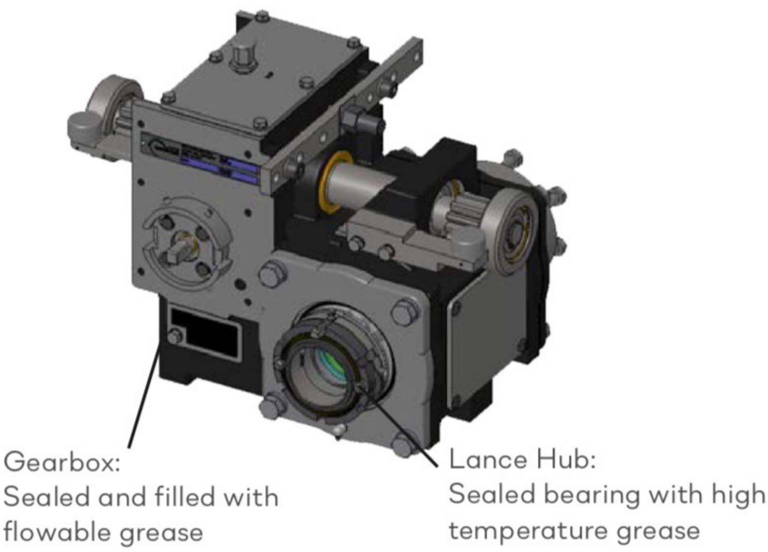

Figure 5 A carriage [2].

3.1.4 Blower Beam

The beam supports the lance tube to prevent bending when in operation. It also houses it when it is at rest, as well as the other components like the carriage (Figure 6).

Figure 6: A carriage [3].

3.1.5 Control system

In order to stay competitive, new technology should be introduced for controlling the operation of the soot blowers, to optimise efficiency and operation time. The introduction of the Internet of Things (IoT) and the use of sensors will help machine communicate with one another. Sensors will be placed in the boiler to sense any changes in temperature or the increase in temperature of the exhaust gas. Computers and software will then analyse the readings from the sensors and automatically initiate operation of the soot blowers without the intervention of humans. The decrease in temperature will also be detected to stop the operation. This will optimise the cleaning effect and also reduce damage on boiler surfaces. This new technology can also store data of the equipment which will allow for predictive maintenance which will reduce the need for manual inspection.

4. Results

The following analysis was performed on Autodesk Inventor. Only gravity was acting on the soot blower.

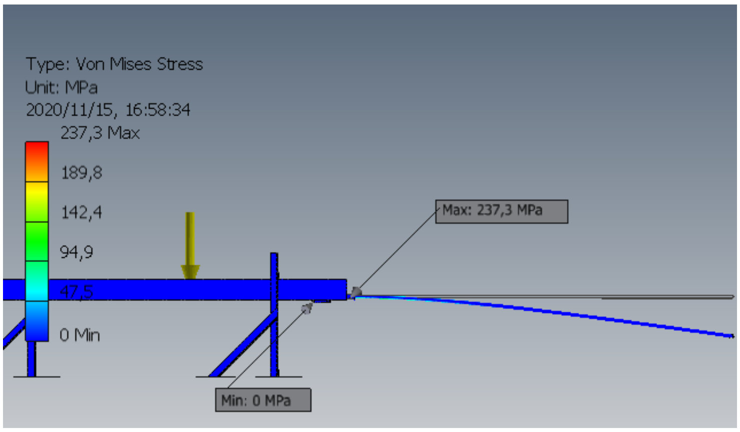

Figure 7: Gravity analysis.

When applying a gravitational force, as shown in Figure 7, the analysis shows that the maximum stress is 237.3 MPa and it is experienced by the lance tube. This proves that the lance is the most vulnerable part of the soot blower. Adding other elements like the thermal stresses will weaken it even further.

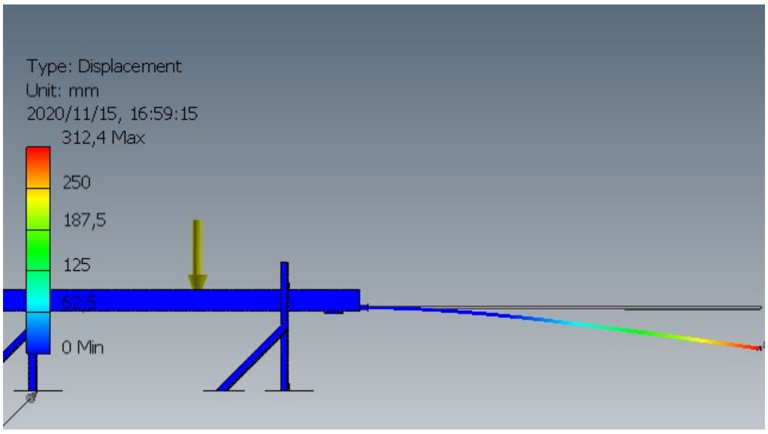

Figure 8: Displacement.

The lance is also experiencing the most bending with a maximum bending displacement of 312,4 mm for an 8m tube (Figure 8). This is one of the reasons the soot blower requires a lot of maintenance.

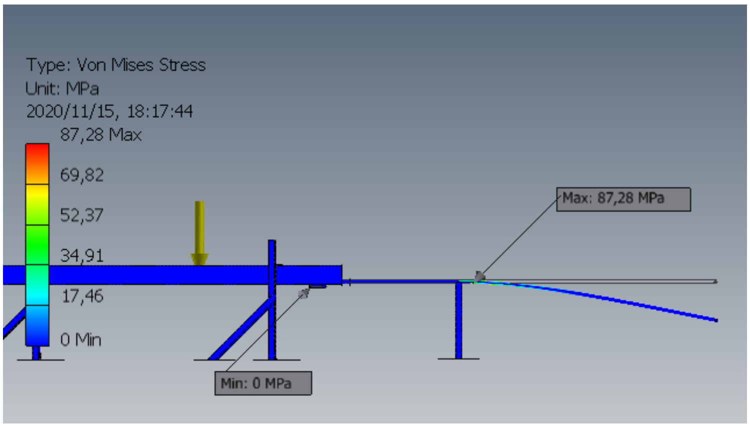

Figure 9: Support structure.

Introduction of a support structure inside the boiler could help reduce the stress experienced by the lance as shown in Figure 9. The new maximum stress under the same conditions is 87,28 MPa which is lower than the initial stress.

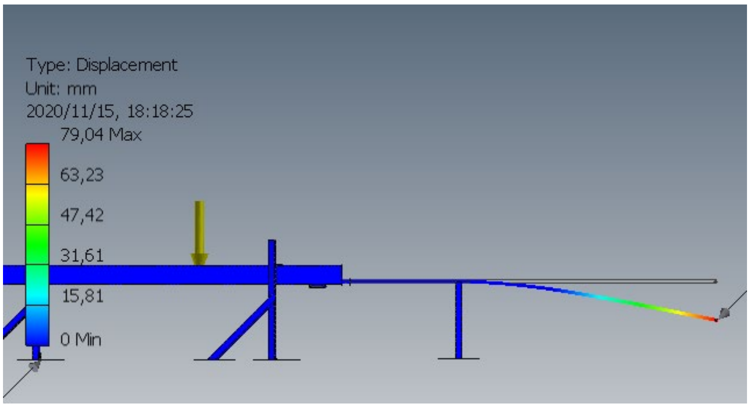

Figure 10: Support structure displacement.

The bending is also reduced as the new maximum displacement is 79.04 mm as shown in Figure 10. Depending on the size of the lance more structure can be added. This also allows for longer lance tubes to cover a large area. The results are summarized in Table 1 and 2.

Table 1. the calculated vs the simulated results (without support)

	Calculated results	**simulation**
Von mises stress	372,8 kPa	237,3 MPa
Displacement	441 mm	312,4 mm

Table 2. the calculated vs the simulated results (with support)

	Calculated results	**simulation**
Von mises stress	92,3 kPa	87,28 MPa
Displacement	27,62 mm	79 mm

4. Discussion

Although steam soot blowers have been around for a while, they are still far from being replaced, this was proven by a decision matrix where acoustic soot blowers were not far behind. The acoustic soot blower on the other and is cost effective and simple in structure but it is not as effective as steam soot blowers when it comes to removing sticky soot which is a huge disadvantage as it means it cannot be used at higher temperature zone. the lance of the steam soot blower is also disadvantaged as it experiences the most stress but introducing a support structure is proven to decrease the stress and deflection by analysis. The introduction of the IoT will benefit Sasol as it will optimize the soot blower operation time by activating them when the heat transfer efficiency decreases.

5. Conclusions

The project was conducted to investigate the soot blowing mechanism of boilers. From research, it was found that the types of soot blowers available were steam, water cannon, air and acoustic soot blowers. Their properties, advantages and limitations were compared to select the most effective one. Steam soot blowers were found to be the most effective on high temperature as and sticky ash and therefore they were selected as the best choice. Acoustic soot blowers were also recommended for lower temperature zones over the steam soot blowers as they have a simple design and they are cost effective as they require less maintenance. Long retractable soot blowers were found to be vulnerable as they have a long lance which experiences higher stress when operating. The introduction of IoT was also covered to show it can optimize efficiency and improve the maintenance of the equipment.

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