A Comparison of compressed air and steam soot blowers in steam boilers.

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Abstract. Ash and soot fouling of boiler tubes impairs heat transfer, elevating fuel consumption and emissions while reducing overall plant performance. Soot-blowers clean boiler tubes on-line. This study presents a comparative analysis of steam and compressed air soot-blowing systems on coal-fired industrial boilers in South Africa. This work quantifies the capital, operational, maintenance, and emission costs. The report addresses the technical performance and practical application such as pressure stability, moisture-related erosion, and cleaning effectiveness. For similar capital costs, the compressed air soot-blowers have a 60% lower operation cost, 80% lower carbon emissions and save eighty-five cubic meters of water annually. This analysis supports soot blower selection to optimise economic, and environmental outcomes.

1. Introduction

Ash accumulation on boiler tubes restricts flue gas flow increasing the pressure drop. Soot and ash deposits form insulating layers on heat-transfer surfaces impeding heat transfer, thus raising stack temperatures. This inefficiency increases fuel consumption and emissions, decreasing overall plant performance. Regular on-line soot-blowing maintains optimal boiler operation.

Advancements in centrifugal compressor technology since the late 1960's have made efficient, reliable high-pressure compressed air a viable option for economic soot-blowing systems [1]. Basu & Debnath [2] indicate that steam and air are both effective for soot-blowing and the selection of the media normally depends upon the availability, reliability, and the cost. Ingersoll-Rand Compressors state that when properly applied either compressed air, saturated steam, or superheated steam will clean the furnace gas side of boiler tubes with equal effectiveness [3] Stevenson [4] provides useful information about the Central Electricity Generating Board (CEGB) successful conversion of steam soot blowers to using compressed air. Pophali et. al. research reviewed the mechanism of steam jet dynamics to remove deposits, and the effectiveness on tube banks. The laboratory tests and theoretical model is compared with results measured on a recovery boiler in Sweden [5]. Waclaw compares the erosion that can be expected due to soot blowing, showing that the erosion rate with compressed air is lower when compared with steam soot blowers using similar pressures [6]. Bilirgen H. describes how the operating parameters of a coal fired power plant and optimizing the soot blowing schedule allowed for the use of low-quality coal [7]. A boiler provider in South Africa used compressed air soot blowers in a project for the first time in 2022 and reported the results were better than their experience with steam soot blowers [8].

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This paper emphasizes the importance of soot blowing providing practical application notes for the two systems and compares the capital costs, operating expenses, maintenance requirements, and the environmental impact of both methods.

2. Problem Statement

Most of the research on soot blowers is related to larger industrial or utility boilers used for power generation, and there is little published work on smaller boilers that would be of broader interest to South African engineers. Steam soot-blowing is more common in South Africa industry than compressed air soot blowers.

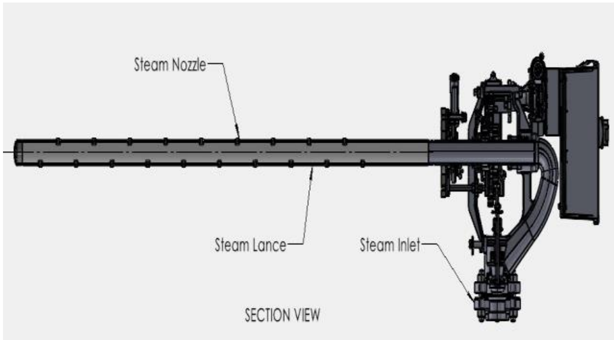

Fig. 1. Rotary soot blower lance detail.

This study addresses the performance of soot blowers of an industrial boiler application. The research was motivated by a lack of experience with compressed air soot blowers among both the design engineers and operators, despite extensive experience with steam systems. The study serves as a monitoring and evaluation exercise to inform future selection, design, and performance assessment of industrial boiler soot blowers.

3. Technical review

3.1 Soot blower information.

Details of two rotary soot blowers in the convection pass of a water-tube boiler are shown in Table 1 below.

Table 1. Soot blower comparison

Media Source	Coal Fired Steam Boiler	Factory Air Compressor
Rated Capacity	25,000 kg/hour	43.2 m³/min
Media supply conditions	2,300 kPa gauge, saturated	700 kPa gauge
Media	Steam	Compressed air
Type of soot blower	Rotary lance	Rotary lance
Lance Outside Diameter, mm	60.3	60.3
Blow duration, seconds	10	10
Cycle (operating time), seconds	33	33
Pressure, bar gauge	20	7
Cycles per day	4	4

The soot blower operating frequency depends on several factors, including the type of fuel, how effective the air-fuel ratio is controlled, and the size distribution, the moisture content, and the amount of ash in the fuel. To maintain the best operation the plant should not soot blow more often than is necessary and should use the soot blowers before the tubes become sufficiently plugged that the blower cannot clean the tubes effectively. If the stack gas temperature or the flue gas pressure-drop becomes excessive the operator must shut down the boiler and the flue gas passes cleaned manually.

In both steam and compressed air systems the soot-blower controls must be integral with the boiler control system. In this study the cost of the soot blower control panel and level of automation are the same for both systems. Details of the soot blowers required for this size of boiler are given in Table 2.

Table 2. Steam lance details

Soot blower	**No. of nozzles**	**Nozzle diameter** [mm]	**Steam flow** [kg / hour]	**Air flow** [standard m^3 / min]
Retract soot blower #1 Screen tubes [note 1]	-	-	-	-
Rotary soot blower #2 Convection tubes	19	11.5	11,400	137
Rotary soot blower #3 Convection tubes	19	8	5,500	66
Rotary blower #4 Economizer [note 2]	1	-	-	-

Note 1: A retractable soot blower is used in high-temperature flue gas near the exit from the furnace. The soot-blower lance remains outside the boiler except during the soot-blowing cycle. This minimizes the exposure of the soot-blower pipes to the flue gas and increases the life of the lance. The retract soot blower is not used in this study as the boiler manufacturer indicated that these soot blowers had a minor impact on the effectiveness in cleaning the boiler. The Owner accepted manual cleaning of the screen tubes as the plant included a standby boiler. This saved the high capital cost of retractable soot blowers.

Note 2: Economizer soot blowers were not considered in this study. A typical economizer of this size requires one or two single nozzle rotary soot blowers.

3.2 Steam soot-blowing

A steam soot blower needs a steady supply of steam from the boiler shell, steam drum, or the steam line. In multi-boiler installations it must be possible to isolate steam to the soot-blowers for maintenance while the other boilers are operating. It is important that the layout of the steam line should drain the condensate to supply dry steam to the soot blowers. Wet steam can cause rapid abrasion of the boiler tubes, causing the tubes to thin, that leads to costly tube replacement and extended unplanned outages.

Boilers with superheaters, should use superheated steam for soot blowing. If saturated steam from the steam drum, upstream of the superheater supplies the soot blowers, the reduction in flow of steam through the superheater while soot-blowing can be enough to cause overheating and premature failure of the superheater tubes.

Steam soot-blowing requires significant amounts of steam. The estimate steam flow rate for the multi-nozzle lance of the No. 2 soot blower, in this example, is 11,400 kg/hr which is over 45% of the rated capacity of the boiler. The typical cycle time of 33 seconds, of which 10 seconds is blowing time. For the two soot blowers this results in the use of 47 kg of steam per soot-blowing cycle. The size of the steam-line to the soot blower must be of sufficient size to supply the required amount of steam for effective soot-blowing. The amount of steam required for one soot-blowing cycle does not account for the sudden step change in the steam flow from the boiler to meet the instantaneous requirement of the soot blower over and above what the factory steam demand is. This is the most challenging type of change for solid fuel fired boilers to respond to, without a loss of steam pressure. To limit the impact on the factory steam pressure it is normal to carry out soot-blowing when the steam demand is low. Only one soot-blower runs at a time, and the steam pressure must recover before operating the next soot blower if it has dropped below acceptable operating needs of the factory.

3.3 Compressed air soot-blowing

A compressed air system requires a source of compressed air, from either a dedicated air compressor at the steam plant or from factory air compressors. In most cases the intermittent use of compressed air in soot blowers is better served using factory compressors. The compressed air pressure and quantity determine the air compressor selection. Like the steam soot blower, the compressed air demand can result in a drop in the air pressure in the system. To allow for the intermittent supply of compressed air to achieve effective removal of soot it usually requires a suitable sized air receiver at the soot blower or in the boiler house. The air receiver meets the sudden short-lived increase in demand, without sacrificing the plant air supply pressure.

4. Capital cost comparison

4.1 Steam soot-blowing

If the steam pressure or temperature exceeds the soot blower's design specification, a pressure-reducing or steam-conditioning valve must be installed to ensure safe and reliable operation. In this example the DN80 steam-line from the steam main isolation does not require a pressure reducing valve. The estimated cost for the soot blower steam line and the capital cost of soot blowers and controls in the convection passes of the boiler is ZAR 435,000 as shown in Table 3.

Table 3. Capital cost of steam soot blowers

ITEM	**Cost** (ZAR)
Steam line, DN80 schedule 40 carbon steel, complete with double isolation valves, expansion loop or joint, orifice plate, DN20 steam trap drains, insulation & cladding, supports.	270,000
Steam soot blowers: Two multi-nozzle rotary soot blowers, complete with carbon steel lance, and controls	165,000
TOTAL	**435,000**

4.2 Compressed air soot-blowing

The factory air compressor station supplies compressed air to the factory and the boiler auxiliaries including the soot blowers, Fig 2. The compressed air line, air receiver, and the estimated capital cost of the compressed air soot blowers is ZAR 490,000 as shown in Table 4.

Table 4. Capital cost of compressed air soot blowers

ITEM	**Cost (ZAR)**
Compressed air line, DN80 schedule 40 carbon steel, complete with double isolation valves, and supports.	230,000
Air receiver	95,000
Compressed air soot blowers: Two multi-nozzle rotary soot blowers complete with carbon steel lance, and controls	165,000
TOTAL	**490,000**

The compressed air soot blower airline is less expensive than the steam-line as it does not require insulation, and the pipe route does not need to account for expansion. The cost of the air receiver however makes the capital cost higher than the steam soot blower case.

Fig. 2. Lance of retractable soot blower – inside boiler.

4.3 Comparison of operating and maintenance costs

The following impacts on the boiler efficiency as related to the operation of soot blowers are as follows:

a. The increase in the flue gas temperature that exits from the boiler (or the economizer where used) decreasing the thermal efficiency.

b. The increase in the boiler system flue gas pressure loss, and the resulting increase in the power used by the induced draft fan. In extreme cases the boiler may not be able to produce its rated capacity.

c. The improvement in the heat transfer after soot-blowing, increasing the boiler efficiency, which reduces the fuel consumption.

d. The reduction in emissions resulting from the lower fuel use.

With proper design and the correct soot-blower operating procedures the outcomes of using either steam or compressed air are comparable.

4.4 Thermal and Economic Factors

The electricity costs are from published utility rates [9], Steam properties are from steam tables. Water rates are based on eThekwini tariffs [10].

a. Annual operation: 350 days, 50 weeks, 8,400 hours.

b. Interest rate: 10%,

c. Inflation: 6%,

d. Soot blower life: 40 years

e. Steam lance life: 3 years

f. Air lance life: 5 years

g. Air compressor life: 15 years

h. Gross calorific value of SA grade D coal: 24.0 MJ/kg

i. Boiler electrical operating power: 185 kW (boiler feed pump, ID fan, FD fan, and other miscellaneous electric motors)

4.5 Steam Soot-Blowing

The cost of generating steam from coal is ZAR 353.50 per metric ton of steam is shown in Table 5.

Table 5. Cost of steam

ITEM	Cost (ZAR/MT of steam)
Variable cost	257.75
Fixed cost	95.75
TOTAL	**353.50**

The variable cost above compares with the published 2016 values for Tiger Brands, Mobeni plant of ZAR

255.57 per metric ton, based only on the water and coal costs. [11]

Steam soot-blowing has regular maintenance requirements, which include regular scheduled statutory inspections, cleaning, and repairs of steam pipes, valves, and nozzles are necessary. The cost of energy losses through steam leaks are common and an estimate of the steam-line losses are part of the variable costs.

Table 6 lists the annual operating cost of steam soot blowers as ZAR 41,025.

Table 6. Cost of operating steam soot blowers

ITEM	**Cost** (ZAR/year)
Steam consumed, 85 MT/year	23,225
Water loss (excluding water treatment costs)	4,900
Cost of soot blower replacement	4,200
Soot blower maintenance	8,700
TOTAL	**41,025**

The steam used in the soot blowing operation enters the flue gas and increases the moisture content. This can lead to deposits in the colder parts of economizers and air preheaters where used. The unrecovered soot-blower steam is an additional cost, highlighted as 'Water loss'. The cost of replacement is the annual cost of replacing the soot blowers with new after the end of the life of the soot blower, Fig 3. Maintenance includes the cost of replacing the lance, using high-temperature grease for the soot blower, packing replacement, regular inspection of the steam line, regular inspection of the boiler tubes, regular service of the soot blowers, replacing steam traps, cleaning trap strainers.

Using wet steam when soot-blowing risks damaging the boiler tubes. It is difficult to assess this economically as to frequency and the scope of the damage. Since, with proper precautions, this may not happen, the operating costs do not include an estimate of the cost of boiler tube replacement.

Fig 3 Overheat damage in a retract blower.

4.6 Compressed Air Soot-Blowing

Operating costs for compressed air are estimated to be ZAR cent 24.06 per 1,000 standard liter as shown in Table 7.

Table 7. Cost of compressed air

ITEM	**Cost** (ZAR cent/1,000 standard liter)
Power used	19.44
Equipment replacement	1.73
Maintenance	2.89
TOTAL	**24.06**

Maintenance primarily involves maintaining air compressors and associated equipment.

Table 8. Cost of operating compressed air soot blowers

ITEM	**Cost** (ZAR/year)
Air consumed	11,400
Cost of soot blower replacement	1,225
Soot blower maintenance	3,260
TOTAL	**15,885**

A regular leak detection program for compressed air leaks is advisable. Though steam leaks take more time to repair due to the need to cool piping and fittings and remove and replace insulation. The cost of compressed air translated to an annual operating cost of ZAR 15,885 as shown in Table 8 above.

4.7 Greenhouse gas emissions

Table 9 summarizes the greenhouse gas emissions allocated to the soot blower operation in the two cases.

Table 9. Greenhouse gas emissions tCO2e

Emission	**Compressed air blower**	**Steam soot blower**
Boiler- coal	Nil	20.56
Total attributable to the soot blower operation	4.24	21.07
Carbon Tax, Rand/yr.	1,000	4,972

These figures are based on Eskom's Carbon Footprint Report [12] where the overall greenhouse gas intensity is 1.04 tons carbon dioxide equivalent per megawatt-hour (tCO2e/MWh) of electricity supplied. No tax credits are included in the above 'Carbon tax' estimate.

The carbon equivalent is found using the emission factors from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment tariffs. (100-year Global Warming Potential) for a coal-fired boiler plant that supplies process steam.

The carbon tax in South Africa is R236/tCO2e effective Jan 1, 2025.

5. Discussion

This work was undertaken after the recent successful application of compressed air soot blowers in a boiler plant, and the recognition of the gap in knowledge and experience in using compressed air for boiler cleaning in South Africa. A comprehensive comparison between compressed air and steam soot-blowers used in industrial boilers in Southern Africa is shown with a specific case.

The main criteria compared in the example presented shows a compelling case for using compressed air soot blowers.

Economic: Compressed air soot blowers are less expensive to run than steam soot blowers, offering a 60 percent reduction in operating costs.

Environmental impact: Compressed air systems produce 80% lower carbon emissions and eliminate the annual water loss associated with steam soot blowers, making them more environmentally friendly.

Performance: Both systems can deliver comparable cleaning effectiveness.

Compressed air soot blowers avoid moisture related erosion and reduce the risk of boiler tube abrasion, and the potential for corrosion in the boiler gas passes. The operating steam pressure is stable as it is independent of the soot blowing operation.

The compressed air system had a higher capital cost than the steam soot blower system. The added compressed air piping from factory to boiler house, and the inclusion of a dedicated air compressor at the boiler plant may be needed, together with an air receiver.

Future work: This study concentrated on the South African industrial steam boiler market where most soot blowers are used. Further study may look at the viability of compressed air soot blowers for power station boilers. The benefits of compressed air soot blowers in maintaining steam conditions and reducing water treatment for makeup water in boilers supplying steam turbines could be explored. Another area of research interest is the use of high frequency sound to clean boiler tube deposits.

6. Conclusion

While steam soot-blowers are common in Southern Africa, compressed air soot blowers, for equivalent cleaning efficacy, offers many advantages. Table 10 summarizes the results of this work.

Table 10. Summary of the comparison between compressed air and steam soot blowers

Emission	**Compressed air soot blower**	**Steam soot blower**
Capital, Rand	490,000	435,000
Maintenance cost, R/p.a.	15,885	41,025
Annual Emission, tCO2e	4.24	21.07
Annual Carbon Tax, R	1,000	4,972
Annual Water Loss, R	0	4,900

The choice between using steam or compressed air soot blowing depends on several factors some of which are plant specific. A detailed assessment of each specific case is necessary to find the best soot blower to use. Considering the factors outlined in this paper, engineers can make informed decisions about the right soot blowers to optimize boiler performance and reduce operational costs. This study matters because industrial boilers lie at the heart of industry and mining. Heat from boilers is used diverse sectors, products and services such as kiln dried timber, in tea processing, the in the dairy industry, in chemical processing, in pipe hot dip galvanising, in laundry and in general heating. Improvements in soot blowing technology, design and use have heat transfer efficiency implications in a broad range of industries.

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