FULL PAPER

BOILER EQUIPMENT: TYPICAL ANOMALIES AND THEIR EFFICIENCY CONSEQUENCES

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Abstract

Boiler and power plant efficiency is significantly impacted by equipment anomalies that result from inadequate maintenance. These anomalies can lead to reduced reliability, increased operational costs and even unplanned plant shutdowns. This paper examines common boiler equipment anomalies and their effects on the overall plant efficiency, with an emphasis on case studies that use thermal performance modelling to quantify these impacts.

Typical anomalies include damaged or missing refractory, tramp air ingress from defective ducting and air heater seals, bypassing economiser elements, missing superheater tubes, as well as inadequate insulation in key areas. The case studies demonstrate that such defects result in efficiency losses, increased fuel consumption and higher operational expenses, particularly in dual-fuel plants that utilise both bagasse and coal. For instance, missing refractory and air leaks reduce the combustion efficiency, while defective economisers and air heaters contribute to heat losses. In addition, missing superheater elements and compromised steam line insulation lower the steam temperatures, which negatively affects the turbine performance and power output.

By identifying and quantifying these anomalies, this paper highlights the importance of preventive maintenance strategies. Addressing these issues can enhance boiler efficiency, reduce fuel costs and optimise power production. The findings emphasise the need for proactive maintenance, in order to ensure cost-effective and reliable plant operation.

***Keywords*:** Boiler, power plant, efficiency, turbine, thermal modelling

Introduction

The efficient, reliable and safe operation of the boiler is crucial in the sugar industry, in order to produce sugar at the lowest operational cost and of the highest quality, thereby remaining competitive. Any deficiencies in the boiler performance - whether due to faults in the boiler itself, or its auxiliary equipment - result in direct economic losses. Bagasse-fired boilers rely on a consistent supply of bagasse from the sugar mill, while the mill, in turn, depends on a minimum quantity of steam from the boilers. If the boilers are unable to supply the required steam, this interdependence is disrupted, which necessitates the co-firing of boilers with coal as a supplementary fuel, in order to maintain the steam production. Since coal incurs a direct cost, this leads to additional economic losses.

Co-generation plants are even more severely impacted. These plants supply electricity not only to the sugar factory but also, in some cases, to the national grid under power purchase agreements. The failure to meet these contractual obligations may result in significant penalties, which compels the plant to co-fire bagasse-fired boilers with coal, in order to ensure compliance.

To prevent unplanned shutdowns and optimise boiler performance, sugar mills follow a strict annual maintenance programme. This typically includes comprehensive boiler inspections during the annual off-crop period. It is common practice to involve the boiler's Original

Equipment Manufacturer (OEM) in these inspections. During this process, all boiler components are thoroughly examined, and a formal inspection report is issued. This report identifies equipment anomalies and defects, it provides recommendations for corrective action, and it may also include suggestions for enhancing the boiler performance.

The typical component failures have been categorised in Figure 1, based on the frequency with which they occur across the multiple boilers that were inspected and reported on, over several years. The most common defects are general tube failure and corroded tubes, which account for 20% of all the issues. These are followed by air and gas leaks (15%), refractory and structural damage (15%), combustion and fuel distribution issues (10%), as well as superheater and economiser tube failures (10%). Air heater failures make up 8%, while steam drum issues represent 7% of the total. The remaining 20% includes various other defects, such as problems with the grit collectors and scrubbers, draught fan issues, as well as general wear-and-tear and operational inefficiencies.

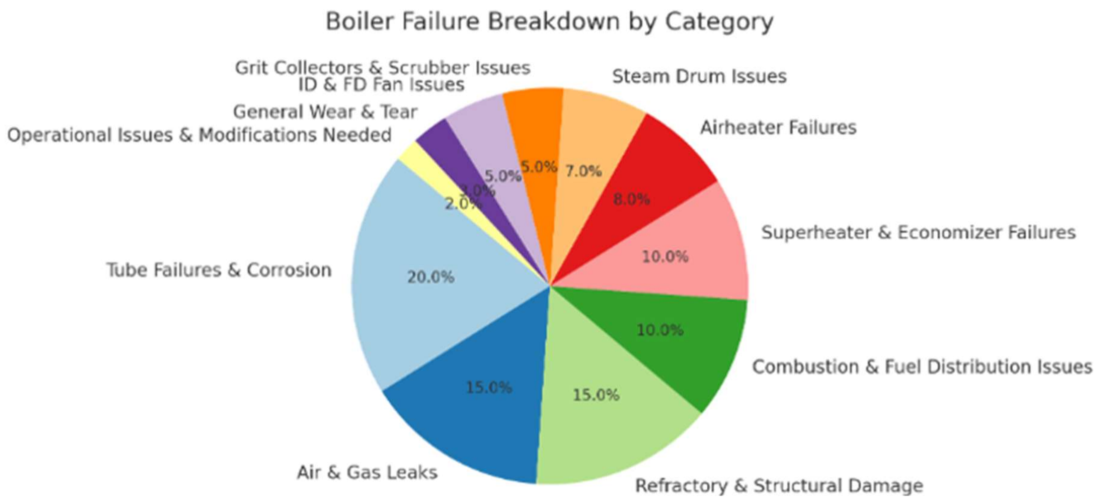

Figure 1. Boiler failures categorised, based on years of OEM inspection reports

This paper focuses on seven common equipment anomalies that are frequently identified during boiler inspections and that fall within the above-mentioned defect categories. These anomalies typically lead to a reduced boiler efficiency. As noted earlier, such reductions often necessitate supplementing the bagasse with coal, in order to maintain the required steam production. The impact of these anomalies on boiler efficiency can be quantified by using a lumped thermal analysis, which allows for the calculation of the additional coal that is required to sustain the steam output to the mill.

The seven identified equipment anomalies are presented, in no particular order, as follows:

1. **Damaged main bank refractory**, which results in elevated boiler gas outlet temperatures.
   (Category: Refractory damage)
2. **Tramp air ingress** at the back-end ducting and air heater, due to corroded tubes and failed rope seals. This increases the final flue gas flow and reduces boiler efficiency.
   (Category: Air heater failures, air & gas leaks)
3. **Blanked-off superheater elements** caused by previous tube failures, which lower the steam temperatures and reduce turbine power generation.
   (Category: Superheater failure)

4. **Partially blanked-off economiser elements** due to prolonged corrosion and erosion, which leads to decreased boiler efficiency.
   (Category: Economiser failure)
5. **Missing casing, lagging and cladding** from the boiler outlet ducting, much of the heat recovery tower ducting and the hot air duct, which contributes directly to heat losses and reduced boiler efficiency.
   (Category: General wear and tear)
6. **Missing lagging and cladding on the main steam line**, resulting from inadequate maintenance. This reduces steam temperature entering the turbine, which leads to decreased power generation.
   (Category: General wear and tear)
7. **Partially-open bypass damper on the air heater**, which lowers under-grate air temperatures and reduces combustion efficiency.
   (Category: Air and gas leaks)

Methodology and Modelling Approach

The basic methodology and thermal modelling approach that is followed here is the same as described by Rawlins *et al*. (2024). Their modelling approach employs simplified mass, energy and momentum balance equations to simulate the boiler and plant performance. Key components - including the furnace (modelled by using the projected method), heat exchangers (via tube bank and LMTD analysis) and balance-of-plant systems - are integrated with system-specific fluid properties and site-calibrated parameters. This enables the evaluation of thermal efficiency, steam utilisation and power generation in industrial applications.

Only natural convection was assumed for the heat-loss calculations in the case studies that involved missing lagging and cladding at the ducting or piping surfaces Cengel *et al*. (2015) give simple empirical correlations for the average Nusselt number for natural convection over various geometries, including flat horizontal, inclined and vertical surfaces, as well as horizontal and vertical pipe surfaces. For natural convection, the Nusselt numbers are typically a function of the Raleigh number, which can be viewed as the ratio of the buoyancy forces and the thermal and momentum diffusivities (Cengel *et al*., (2015)).

Table 1. Empirical correlations for the average Nusselt number for natural convection over surfaces

Geometry	**Characteristic Length (L_c)**	**Range of Rayleigh number (Ra)**	**Nusselt number (Nu)**
Vertical plate	Plate length (L)	10^4 - 10^9	$Nu = 0.59Ra_L^{1/4}$ **(1)**
Inclined plate	Plate length (L)		Use vertical plate equations for the upper surface of cold plate and the lower surface of a hot plate. Replace g by gcosθ for 0 < θ < 60°. (Note g is the gravitational acceleration constant) **(2)**
Horizontal plate: (a) Upper surface of a hot plate	Plate surface area (A_s) / plate perimeter (p)	$10^7 – 10^{11}$ $10^5 – 10^{11}$	(a) $Nu = 0.1Ra_L^{0.33}$ **(3)** (b) $Nu = 0.27\ Ra_L^{0.25}$

(b) Lower surface of a cold plate			**(4)**
Vertical cylinder	Cylinder length (L)		Treated as a vertical plate
Horizontal cylinder	Diameter (D)	$Ra_D < 10^{12}$	$Nu = \{0.6 + \frac{0.387\ Ra_L^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}}\}$ **(5)**

The Raleigh number (Ra_x) is defined as follows:

$$Ra_x = \frac{g\beta(T_s - T_{amb})L_c^3}{\nu^2}Pr$$

(6)

where β is the coefficient of volume expansion, T_{amb} is the ambient temperature, Pr is the Prandtl number and ν is the kinematic viscosity. Note that all the fluid properties are evaluated at the film temperature ($\frac{1}{2}(T_s + T_{amb})$)).

The Nusselt number (Nu) relates to the heat transfer coefficient (h) as follows:

$$h = \frac{NuL}{k}$$

(7)

where k is the thermal conductivity. Using Equation (7) the convection heat loss to ambient can be calculated as follows:

$$Q = hA_s(T_s - T_{amb})$$

(8)

For radiational heat loss calculated over pipes, the general radiation loss equation is used:

$$Q_{rad} = \varepsilon\sigma\, A_s\, (T_s^4 - T_{amb}^4)$$

(9)

Where ε = 1 (outer surface of the pipe is approximated as a black body), σ = 5.67e-8 W/m^2K^4 and T_s is the average pipe surface temperature.

To compare the anomalies and associated supplementary coal consumption, the same coal specification is used throughout the case studies and is given as follows:

Table 2. Coal specification

Description	**Value**
Coal Type	Peas Gr A
Moisture % (wt/wt)	3.33
Ash % (wt/wt)	12.94
Carbon % (wt/wt)	70.59
Hydrogen % (wt/wt)	3.39
Sulfur % (wt/wt)	0.74
Oxygen % (wt/wt)	7.3
Nitrogen % (wt/wt)	1.7

GCV %	27,670
NCV %	26,849

The cost of coal delivered to the site is measured in Rands per month and it varies, depending on the location of the sugar mill, in relation to the coal source. For example, the average cost of Peas Gr A coal delivered to a mill in the Mpumalanga region is approximately R1 815 per ton, whereas the same coal delivered to a coastal mill can cost around R2 700 per ton. In each of the case studies presented, this range of the coal costs will be considered monthly, using an average month length of 30.4 days, for consistency in the calculations.

Case Study 1 – Damaged mainbank refractory

The boiler specific to this case study is a bi-drum water tube boiler with the following characteristics:

- final steam condition 17.2 Barg, 277°C, 220tph when firing bagasse;
- screened pendant superheater;
- three-pass main generating bank;
- single-pass air heater; and
- single-bank economiser.

The original boiler flue gas outlet temperature is 385°C at the Maximum Continuous Rating (MCR), but due to a local mainbank castable refractory failure in the superheater cavity (refer to Figure 2), the flue gas temperature increased considerably across the boiler outlet duct.

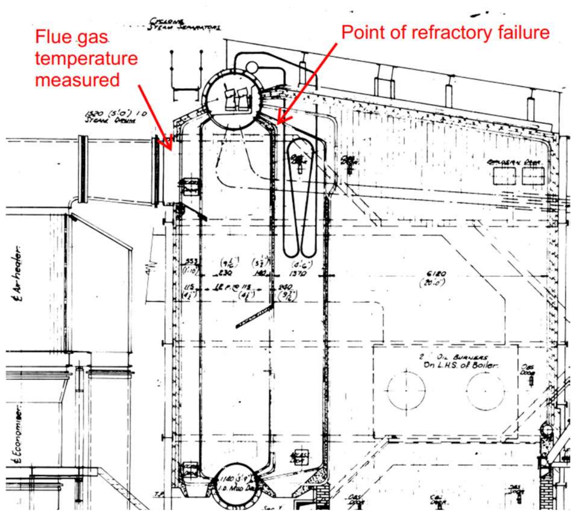

Figure 2. Boiler arrangement showing the location of refractory failure

In Table 3 below, the design case with no defects in the mainbank is compared with the load case where the mainbank refractory has failed:

Table 3. Boiler performance compared with and without refractory failure

	Boiler steam load	Flue gas temperature at boiler outlet	Boiler efficiency (GCV)	Supplementary coal consumption	Cost of coal range
Unit	tph	°C	%	kg/hr	Rand per month
No defect in mainbank refractory	189	380	66.93	None	None
Failed refractory	189	432	65.96	433	R573,704 - R853,444

Case Study 2 – Tramp air ingress

This case study focuses on tramp air ingress that occurs from the boiler back-end through to the economiser, based on the boiler described in the first case study. The tramp air ingress was deduced from visual inspection findings, which included failed expansion joints, worn rope seals, as well as other compromised sealing surfaces across the air heater, with a lesser extent noted across the economiser bank. Figures 3, 4 and 5 illustrate the failure of the air heater casing, the degraded rope seals and the corroded tubes at the bottom of the air heater, which all contribute to the ingress of tramp air.

Tube corrosion in the air heater typically occurs during boiler start-up, due to dew point condensation at the coldest part of the air heater tubes, particularly when the air heater bypass is not engaged. The lowest metal temperatures are found at the cold air inlet side, near the bottom of the air heater, where the flue gas temperatures are also at their lowest. When the tube metal temperature falls below the flue gas dew point, condensation forms on the tubes, which leads to progressive corrosion.

In cases where coal is used as a supplementary fuel, the risk of corrosion increases. The tube metal temperatures at these cold spots can fall below the sulphuric acid dew point, which results in sulphuric corrosion over time. This degrades the tube integrity further and contributes to the reduced boiler efficiency and increased maintenance requirements.

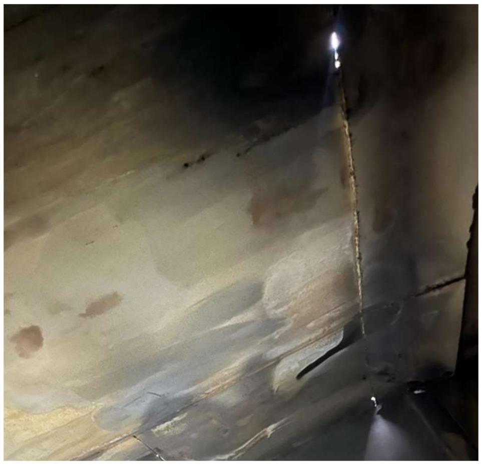

Figure 3. Failed air heater casing

Figure 4. Defective air heater rope seal

Figure 5. Corroded air heater tubes

Table 4 summarises the flue gas parameters that are measured across the air heater and economizer, and it compares them to the original design case with no back-end defects.

Table 4. Boiler performance with normal and excessive tramp air ingress

	Boiler steam load	**O_2 content increase across backend**	**Boiler GCV efficiency**	**Final flue gas temperature**	**Supplementary coal consumption**	**Cost of coal**
Unit	tph	% (wt/wt)	%	°C	kg/hr	Rand per month
Backend - No defects	189	0.26	66.93	199	None	None
Excessive tramp air ingress across air heater	189	2.56	66.29	193	221	R292 814 – R435,591

Case Study 3 – Missing superheater elements

The boiler and turbine specific to this case study is a bi-drum water tube boiler and condensing turbine with the following characteristics:

- final steam condition 45 Barg, 440°C, 90tph when firing coal;
- screened pendant superheater;
- three-pass main generating bank;
- steam air heater;
- dual-bank economiser; and
- connected to 21.7 MW Thermodyne pass out and condensing TA set.

Upon the examination of the superheater outlet header during the annual boiler inspection, five missing superheater elements were identified (see Figure 6). These elements had been removed and blanked off, due to the previous tube failures that had occurred over several years. Such failures are common in pendant-type superheater tubes and are often attributed to rapid boiler start-ups.

Typically, superheater tube failures occur when steam condenses inside the tubes during start-up and shut-down, and it collects at the elbows near the bottom of the tubes, which is a common phenomenon in non-drainable superheaters. Under normal start-up conditions, this condensed water has sufficient time to evaporate, which allows steam to flow through and cool the tubes, as they are exposed to increasing radiative and convective heat flux from the flue gases. However, during a rapid boiler start-up, the water collected in the elbows may obstruct the steam flow, which prevents proper cooling. As a result, the tube metal is exposed to high flue gas heat flux without adequate internal cooling, which causes the metal temperature to rise above the tube's design limit.

This temperature elevation leads to metal creep - a permanent deformation of the metal under sustained high temperature and stress - which eventually results in tube failure. The repeated occurrence of this failure mechanism necessitates the removal and blanking off of the affected superheater elements.

Figure 6. Missing superheater elements visible at the steam outlet header

The reduction in the superheater tube heating surface has led to lower steam temperatures being delivered to the condensing turbine, which subsequently impacts the power output.

Table 5 compares the original design performance of the boiler and turbine with the current performance, considering the reduced superheater heating surface, at the same steam load.

Table 5. Boiler and turbine performance with and without five superheater elements

	Boiler steam load	**Superheater steam exit temperature**	**Power generated**	**Supplementary coal consumption**	**Cost of coal**
Unit	tph	°C	kW	kg/hr	R per month
No defects in superheater	84	435	15,895	None	None
Missing superheater elements	84	425	15,635	None	None
Missing superheater elements	85.43	425	15,895	84	R111,296 – R165,564

Case Study 4 – Missing economiser elements

The boiler specific to this case study is a bi-drum water tube boiler, which includes:

- final steam condition 32 Barg, 400°C, 150tph when firing bagasse;
- radiant pendant superheater;
- single-pass main generating bank;
- single-pass air heater; and
- single bank H-fin economiser.

During an annual boiler inspection, it was observed that 6 of the 16 economiser elements were heavily corroded and subsequently blanked off by the mill, to prevent further leaks during operation. The corrosion of economiser elements typically occurs at the bottom economiser feedwater inlet (in this case, the economiser was of a counter-flow arrangement) during start-up, when the flue gas temperature is at its lowest. This results in lower tube metal temperatures and, subsequently, dewpoint corrosion on the external surface. Over time, the tube wall thickness fails to meet the minimum design criteria, which leads to premature tube failure. Refer to Figures 7 and 8 for illustrations of the condition of the economiser and tubes. With supplementary coal firing, sulphuric dewpoint corrosion can also result in tube failure, as well as erosion, due to high ash- and sand- loading in the flue gas.


Figure 7. Economiser with six elements blanked off

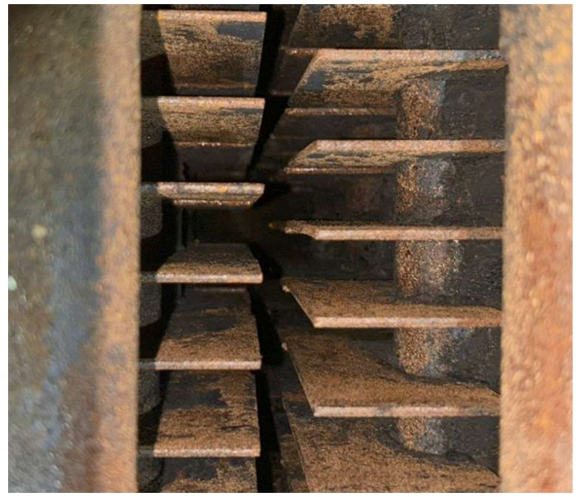
Figure 8. Corroded economiser elements

Table 6 compares the original performance of the boiler with all the installed economiser tubes, to the existing thermal performance of the boiler with the six economiser tubes blanked off.

Table 6. Boiler performance with and without the six elements

	Boiler steam load	**Boiler GCV efficiency**	**Final flue gas temperature**	**Supplementary coal consumption**	**Cost of coal**
Unit	tph	%	°C	kg/hr	R per month
No defects with economiser	150	64.82	247	None	None
Economiser elements blanked off	150	63.26	284	695	R920,841 – R1,369,847

Case Study 5 – Missing hot air and gas ducting lagging and cladding

The boiler specific to this case study is a bi-drum water tube boiler, which includes:

- final steam condition 32 Barg, 400°C, 140tph when firing bagasse;
- radiant pendant superheater;
- single-pass main generating bank;
- two-stage counter flow air heater; and
- dual-bank H-finned economisers.

It is standard practice to replace any missing boiler duct lagging and cladding, especially on hot air ducts from the air heater outlet to the boiler under-grate, or across the back-end, from the boiler flue gas outlet to the last heat recovery equipment. The insulation limits convective heat losses from the hot duct and casing surfaces to the ambient air. Convective heat loss to the ambient air reduces the boiler efficiency, which results in increased supplementary coal firing.

Table 7 illustrates the surfaces identified during an annual inspection that was not insulated.

Table 7. Ducting surfaces not covered with insulation

Location	Type of surface	Surface area (m²)	Surface Number
Boiler gas outlet ducting to air heater inlet	Horizontal surface (Facing Upwards)	57	1
	Vertical surface	38	2
	Inclined surface (45 degrees)	23	3
Air heater air side second pass	Vertical surface	93	4
	Horizontal surfaces (Facing Upwards)	23	5
Air heater air side first pass	Vertical surface	97	6
	Horizontal surface (Facing Downwards)	27	7
Air heater gas outlet to economiser gas outlet	Vertical surface	132	8
	Horizontal surface (Facing Upwards)	4	9
	Horizontal surface (Facing Downwards)	3	10
	Inclined surface (45 degrees)	13	11
Hot air ducting	Vertical surface	198	12
	Horizontal surface (Facing Upwards)	52	13
	Horizontal surface (Facing Downwards)	68	14

Table 8 summarises the heat loss to ambient, as per the surface areas 1 to 14:

Table 8. Heat loss per duct surface as referenced in Table 7

Surface Nr	Ra	Nu	h (W/m²K)	Q (kW)
1	1.55E9	115.8	5.15	88.3
2	1.55E9	117.1	5.21	59.6
3	1.10E9	107.4	4.77	33.1
4.1	2.46E9	60.15	2.15	85.7 (avg)
4.2	1.72E9	120.1	4.97	
5.1	2.46E9	135.0	4.84	21.4 (avg)
5.2	1.72E9	119.8	4.95	
6	2.46E9	131.4	4.71	34.0
7	2.46E9	60.2	2.15	4.3
8.1	2.45E9	131.3	4.80	103.8 (avg)
8.2	2.87E9	136.6	4.58	
9.1	2.45E9	134.8	4.93	3.3
9.2	2.87E9	142.1	4.76	
10.1	2.45E9	60.1	2.20	1.1
10.2	2.87E9	62.5	2.09	
11.1	1.73E9	120.4	4.4	9.4
11.2	2.03E9	125.2	4.2	
12	1.72E9	120.1	4.97	226.0
13	1.72E9	119.8	4.95	51.2
14	1.72E9	119.8	4.95	77.4

Table 9 compares the boiler performance with insulation and without insulation.

Table 9. Boiler performance with and without gas- and air-duct insulation

	Boiler steam load	**Boiler GCV efficiency**	**Final flue gas temperature**	**Supplementary coal consumption**	**Cost of coal**
Unit	tph	%	°C	kg/hr	R per month
Boiler with insulation	140	64.30	166	None	None
Missing insulation	140	63.86	165	156	R206,692 – R307,476

Case Study 6 – Missing main steam lagging and cladding

The boiler specific to this case study is a bi-drum water tube boiler with the following characteristics:

- final steam condition 45 Barg, 440°C, 80tph when firing coal;
- radiant pendant superheater;
- single-pass main generating bank;
- single-bank H-fin economisers;
- two-stage counter-flow air heater; and
- connected to 18.8 MW ABB pass out and condensing TA set.

This case study examines the impact of missing main steam lagging and cladding on the steam temperature entering the turbine and the subsequent underperformance of the turbine, in terms of power generation. During a boiler inspection, it was found that missing insulation on the main steam line accounted for 30% of the entire pipe length, from the boiler outlet to the turbine inlet. The main steam line under investigation is a 300NB Schedule 40 pipe, 74.7m long, with 19.5 m vertical sections and 8 elbows. The uninsulated vertical pipe sections comprised 10% of the total vertical pipe length, while the uninsulated horizontal pipe sections comprised 20% of the total horizontal pipe length.

The convective heat loss for the main steam line is calculated in Table 10, based on the equations described in Table 1. The reduction in steam temperature across the main steam line is less than 5°C, and the assumption of a constant pipe wall temperature across the entire length of the pipe is considered to be valid.

Table 10. Main steam pipe losses (convective and radiant heat)

Main steam surface	**Pr**	**Ra**	**Nu**	**h (W/m²K)**	**Q (kW)**
Horizontal pipe section – Convection	0.6954	2.21E7	35.8	4.34	3.5
Vertical pipe section - Convection	N/A	2.21E7	40.4	0.81	0.7
Horizontal pipe section - Radiation	N/A	N/A	N/A	N/A	207.0
Vertical pipe section - Radiation	N/A	N/A	N/A	N/A	27.7

Table 11 compares the turbine performance and the power that is produced, with the main steam line insulated and uninsulated:

Table 11. Boiler and turbine performance with and without main steam heat loss

	Boiler steam load	**Steam temp. at boiler outlet**	**Steam temp. at turbine inlet**	**Power produced**	**Supplementary coal consumption**	**Coal cost**
Unit	tph	°C	°C	kW	kg/hr	R per month
Fully insulated main steam pipe	72	440	440	16,452	None	None
Partially uninsulated main steam pipe	72	440	435	16,321	None	None
Partially uninsulated main steam pipe	72.54	440	435	16,452	68	R90,097 – R134,028

Case Study 7 – Partially by-passed air heater

This case study focuses on the same boiler, as specified in Case Study 6. A partially-open bypass damper (10% open) was noted during the boiler inspection, which will result in an uncontrolled amount of air by-passing the air heater at a lower under-grate air temperature. The type of damper fitted on this boiler is a twin-bladed parallel flow damper. The inherent flow characteristics of a parallel blade damper is given in Figure 9 (Johnson Controls (1991)).

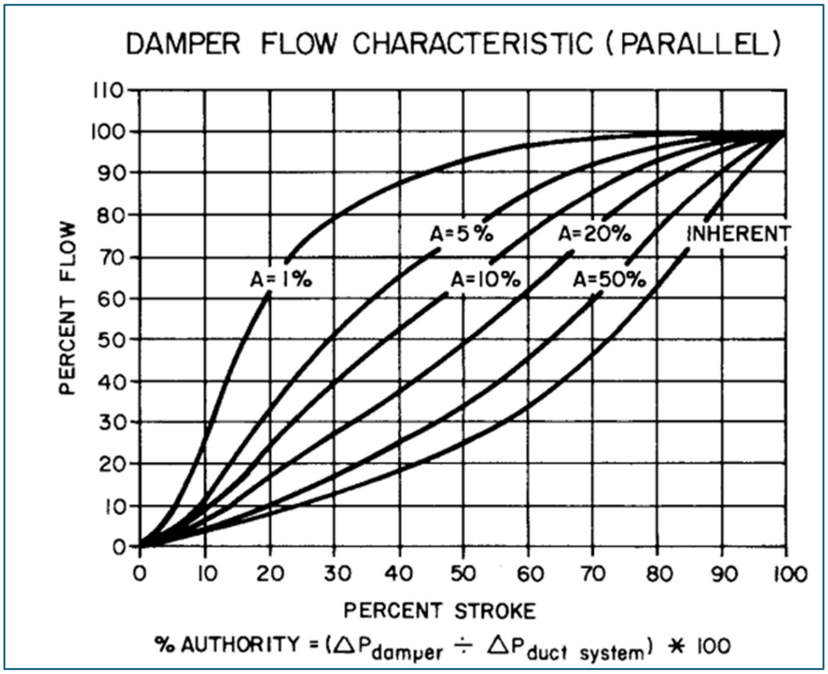

Figure 9. Damper flow characteristics for a parallel flow damper

The damper authority is determined as a percentage of the pressure drop across a wide-open damper, relative to the total pressure drop across the entire duct system, from the forced draught fan to the boiler under-grate inlet.

% Authority = (ΔPdamper / Δ*P*system)

(10)

In this case, the pressure-drop across the air side dampers is less than 152 Pa, as per the original design, compared to the overall air duct losses of 1286 Pa, which results in a damper authority of less than 12%. Based on Figure 9, the percentage flow through the bypass damper is approximately 10%. Table 12 compares the boiler performance when the damper is fully closed to when it is 10% open, which allows 10% of the total under-grate air to bypass the air heater. The results emanate from the thermal model of the case study boiler system.

Table 12. Boiler performance with the air heater damper fully-closed and partially-open

	Boiler steam load	**Total under-grate air flow**	**Bypassed air flow**	**Under-grate air temp.**	**Supplementary coal consumption**	**Coal cost**
Unit	tph	kg/hr	kg/hr	°C	kg/hr	R per month
Damper fully closed	72	79,087	None	134	None	None
Damper 10% open	72	79,249	7,925	129	18	R23,849 – R35,478

Conclusion

This research has thoroughly investigated the impact of common boiler equipment anomalies on the efficiency of co-generation power plants, with a particular focus on operations within the sugar industry. By applying thermal modelling techniques and cost evaluations, this paper has quantified the performance deficits that are associated with seven key anomalies that range from refractory and insulation failures to air heater bypass and economiser degradation.

Each anomaly, while varying in its direct effect on the thermal efficiency, invariably contributes to an increased supplementary coal consumption and, therefore, higher operational costs. The findings demonstrate a consistent correlation between the presence of equipment anomalies and the need for coal co-firing, even under optimal bagasse combustion conditions. For instance, a damaged refractory was shown to increase the flue gas outlet temperature and reduce the boiler efficiency, which led to a coal cost of up to R853,444 per month. Similar efficiency penalties were observed across all the other studied cases, which underscores the cumulative financial and operational impact of neglecting boiler maintenance.

The case studies reinforce the critical importance of comprehensive and proactive maintenance regimes, particularly those involving OEM-guided annual inspections. Preventative maintenance not only mitigates the risk of unplanned down-times, but it also safeguards against the erosion of operational efficiency and contractual penalties in the power purchase agreements.

In conclusion, this paper emphasises that it is essential to pay meticulous attention to boiler integrity and component performance, in order to optimise the thermal efficiency, to reduce the fuel costs and to ensure reliable power generation. Investing in routine inspections and prompt anomaly resolution is not merely a maintenance strategy, but it is also a fundamental requirement for sustainable and profitable plant operation.

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