



# Proposal for Predictive Maintenance of Key Components of Biomass Boilers

## *Propuesta de mantenimiento para componentes fundamentales de calderas de biomasa*

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**ABSTRACT:** This study analyzes the contributions and shortcomings of various maintenance approaches applied to fundamental components with biomass boilers in a textile enterprise. It identifies existing deficiencies in the current maintenance practices and evaluates the potential benefits of implementing improved methods. These include the adoption of best practices, time studies, and the integration of new technologies. The proposed tube plugging method for a key component—the flue gas duct—demonstrated a maintenance duration of 9.90 hours and a total cost of \$49,825.00 USD, compared to the current method which required 10.75 hours and cost \$55,625.00 USD. This represents a reduction of 0.75 hours in downtime and a cost saving of \$5,800 USD.

**Keywords:** Maintenance, Boilers, Flue pipe, Tube plugging, Cost Savings.

**RESUMEN:** Se analizaron los aportes y deficiencias de diversos enfoques de mantenimiento aplicados a componentes fundamentales de calderas de biomasa en una empresa textil. Se identificaron las limitaciones del método actual y se evaluaron los beneficios potenciales de implementar mejoras, incluyendo buenas prácticas, estudios de tiempos y nuevas tecnologías. El método propuesto de taponado de tubos en el conducto de gases mostró una duración de 9,90 horas y un costo total de 49 825,00 USD, frente al método actual que requiere 10,75 horas y cuesta 55 625,00 USD. Esto representa una reducción de 0,75 horas en el tiempo de inactividad y un ahorro de 5 800 USD.

**Palabras clave:** mantenimiento, calderas, conducto de humo, taponado de tubos, ahorro.

## INTRODUCTION

A textile company implemented biomass boilers for steam generation, achieving an approximate savings of 10,000 gallons of diesel. However, boiler downtime has resulted in significant economic losses, as documented in the specialized literature (Petrucci et al., 1989; 2002; Jiménez, 1997; Neefus & Lee, 2001; Sevilla, 2004).

Currently, the company has a deficient maintenance system for its biomass boilers, which has led to recurring failures, reduced lifespan, increased production costs, and reliance on corrective maintenance.

The objective of this work is to propose an improved maintenance system for the fundamental components of biomass boilers in textile companies, in order to reduce production costs and improve operational reliability.

## MATERIALS AND METHODS

### Biomass Boilers in Textile Companies

The fire-tube boilers used in textile companies operate with a liquid fluid contained in a vessel traversed by tubes, through which high-temperature gases from the combustion process circulate. The water evaporates due to contact with these exhaust gases (Hanesbrands, 2025).

There are two types of configurations:

- Partially submerged tubes: the water does not completely cover the tubes.
- Fully submerged tubes: the tubes are completely covered by water.

Figure 1 shows a horizontal boiler.

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Figure 1. Horizontal biomass boilers

### Biomass Boiler Maintenance at the Textile Company

Currently, the company performs inspections and maintenance procedures following the guidelines of the ASME International Code, Section I ([American Society of Mechanical Engineers, 1962; 1989](#)).

- **Internal Inspection:** The overall condition of the boiler's interior is evaluated, including tubes, furnace, plates, refractories, burners, economizers, superheaters, steam connections, blowdowns, and valves.
- **Valve Condition:** The boiler must have one or more safety valves, calibrated to release steam at the maximum working pressure without exceeding 6% above that value.
- **Hydrostatic Test:** This is performed to verify the boiler's integrity and leak tightness:
  - After repairs to the boiler shell or pressurized components.
  - Every 13 months.
  - For new boilers, at 1.5 times the maximum design pressure.
  - The minimum duration is 30 minutes, which may be extended at the inspector's discretion.
  - A pressure drop of up to 3% is permitted; if it occurs, the cause must be recorded.

- **Water quality:** The analysis, monitoring, and chemical treatment of the feedwater must be guaranteed, preventing scaling, corrosion, and contamination (oils, chlorides, caustic soda, acids, organic matter, etc.), in accordance with the manufacturer's and service provider's specifications.
- **Boiler deformations:** A specialized supplier must be contacted for deformations due to buckling, bulging, or pockets that weaken plates or tubes, especially if they cause leaks. Service must be suspended until the affected part is properly repaired.

## RESULTS AND DISCUSSION

### Recurring failures in key components of biomass boilers

Currently, the company's boiler area is experiencing constant failures in the tube bundles, especially due to leaks, poor welding, and wear on the tubes of the two biomass boilers. These problems stem from inadequate maintenance practices, both in plugging and replacing pipes. Several of these failures coincide with the most frequent ones reported in the literature ([ECOPETROL, 1987; Justo, 1994](#)). [Figure 2](#) shows a poor weld on a biomass boiler.

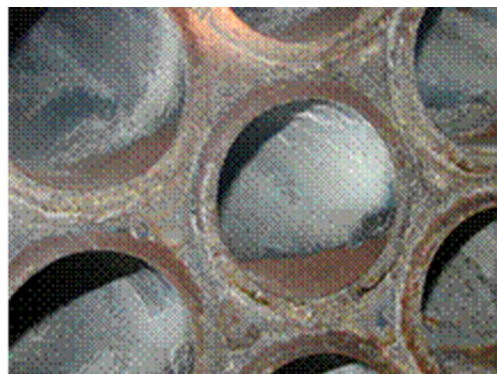


Figure 2. Poor welding on the biomass boiler

[Figure 3](#) shows poorly sealed tubes and tube deformation. [Figure 4](#) shows sediment fouling in the tube bundle.



Figure 3. Poorly sealed tubes, biomass boiler, and deformation thereof



**Figure 4.** Sediment buildup in a biomass boiler

The accumulation of ash in the tubes reduces heat transfer, accelerates corrosion, and causes ruptures in the tube walls.

#### Failure analysis by component

Table 1 shows that 94.7% of the failures are concentrated in the flue pipes (71 out of 75 failures), justifying focusing maintenance on this critical component.

**Table 1.** Recurring failures of key components in biomass boilers from May 2023 to February 2024

Key components of the boiler		
Article	Description	Number of failures
1	Hearth or stove	0
2	Hearth door	3
3	Grates	0
4	Ash pan	0
5	Ash pan door	0
6	Altar	0
7	Masonry	0
8	Flue pipes	71
9	Smoke box	0
10	Chimney	0
11	Draft regulator	0
12	Inspection cover	0
13	Blast door	0
14	Water chamber	0
15	Steam chamber	0
16	Water feed chamber	0
17	Pressure relief valve	1
<b>Total number of failures</b>		<b>75</b>

**Table 2.** Summary of smoke duct maintenance costs

Key components of the boiler				
Article	Descripción	Number of failures	Repair cost (USD)	Cost/Downtime \$USD
1	Pipe blockage	24	14,375.00	157,650.00
2	Pipe replacement	47	48,600.00	367,850.00
Subtotal			62,975.00	525,500.00
<b>Grand Total</b>			<b>588,475.00</b>	

#### Current Maintenance Costs

Table 2 presents the costs associated with current maintenance methods:

- Pipe plugging: 24 failures, repair cost \$14,375 USD, total cost \$157,650 USD
- Pipe replacement: 47 failures, repair cost \$48,600 USD, total cost \$367,850 USD
- Total cumulative cost: \$588,475 USD

#### Major Maintenance in December 2023

A major intervention was performed on both boilers, with complete tube installation by contractors:

- Table 3: 600 tubes plugged, repair cost \$169,718 USD, downtime cost \$2,364,750 USD
- Total cost: \$4,063,468 USD

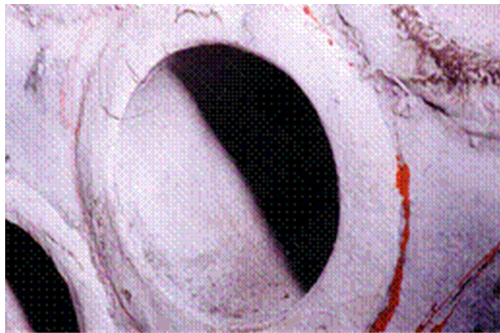
In addition, an extra expense of \$2,362,500 USD was incurred for the consumption of 450,000 gallons of diesel during the shutdown, due to the activation of the fossil fuel boiler.

**Table 3.** Related Expenses

Article	Description	Key components of the boiler		
		Retubed pipes	Repair cost \$ USD	Cost of downtime USD
1	Boiler Retubing I	300	83,609.00	2,364,750.00
2	Boiler Retubing II	300	86,109.00	
Sub - total			1,698,718.00	2,364,750.00
<b>Grand total</b>			<b>4,063,468.00</b>	

**Technical problems during rework**

Following the rework, leaks were detected due to over- and under-drilling of the pipes, which caused plate deformations and leaks in the sealing system. Non-destructive testing revealed cracks in the welds (Figure 5).



**Figure 5.** Non-destructive testing reveals cracks

**Methodological Proposal for Improved Maintenance**

*Pipe Plugging*

The use of prefabricated monoblock plugs (Figure 6) and single-revolution cutters (Figure 7) is proposed for perforating and venting the pipe before plugging.



**Figure 6.** Boiler tube plug. Source: [TECNOLOGIES \(2007\)](#)



**Figure 7.** One-revolution tube cutter. Source: [TECNOLOGIES \(2007\)](#)

Advantages:

- Reduced working time and labor costs
- Chemical compatibility with the pipe material
- Ease of welding
- Prevent reactivation due to internal pressure

*Economic Comparison of the Proposed Method*

Table 4 presents a comparison of the current method against the proposed method to quantify the savings between the two.

Total savings: \$5,809.60 USD and a reduction of 0.95 hours

**Table 4.** Savings of current method versus proposed method of tube plugging

Method	Saving	
	Time (h)	Cost \$ USD
Current method	10.75	55,616.18
Proposed method	9.8	49,806.58
Difference	0.95	5,809.60

*Pipe replacement with advanced technology*

It is proposed to hire specialists with modern equipment: Cutting and grinding: power tools (Figures 8 and 9).



**Figure 8.** Tube cutter and beveler. Source: [TECNOLOGIES \(2007\)](#)



**Figure 9.** Electric motor for pipe cutting. Source: [TECNOLOGIES \(2007\)](#)

Extraction: hydraulic extractor (Figure 10)



**Figure 10.** Tube extractor. Source: [TECNOLOGIES \(2007\)](#)

Expansion and machining: motor with digital torque (Figure 11) and tube expander (Figure 12)



Figure 11. Digital torque meter. Source: TECNOLOGIES (2007)



Figure 12. Boiler tube expander-flar. Source: TECNOLOGIES (2007)

*Economic Analysis*

Practical validation: In March 2024, the proposed method was applied to 19 pipes, with no failures in testing or operation.

Similarly, as in the previous case, a flowchart was established for the operations to be preformes.

Table 5 shows the savings of the proposed pipe replacement method compared to the current method.

The proposed method resulted in savings of USD 5809.60 and a reduction of 0.95 hours.

Table 5. Savings of the proposed pipe replacement method versus the current method

Method	Time (h)	Cost \$ USD
Current method	11.52	2,392,053.40
Proposed method	10.24	2,080,596.86
Difference	1.28	311,456.54

**CONCLUSIONS**

The following advantages were concluded from the technical and economic analysis:

- A reduction in the total maintenance cost of tube plugging of \$5,809.00 USD, a 12% reduction compared to the current cost.

- A reduction in the total maintenance cost of tube replacement equivalent to \$7,786.41 USD, a 15% reduction compared to the current method.
- Reduced labor costs for both maintenance methods.
- Longer lifespan of the plates supporting the flue pipes because this method is non-invasive.
- Greater precision during tube boring.
- Reduced risk of workplace accidents that could harm the health and safety of workers.
- Reduced risk of accidents that could compromise the boiler's lifespan, as the critical components of the boiler are not compromised, thus avoiding weakening the properties and composition of its materials.
- Reduced CO2 emissions due to shorter commissioning times for biomass boilers.
- Extended lifespan of the flue and flue pipes, key components of the boiler.

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