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THESIS NO.: M-402-MSREE-2023-2025

Technical Assessment of Biomass-based Industrial Boilers of Nepal

by

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A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULLFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

APRIL, 2025

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The undersigned certify that read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Technical assessment of biomass based industrial boilers of Nepal" submitted by Nirmal KC (079MSREE012), in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

This study evaluates the operating performance and emission characteristics of biomass-based industrial boilers of Nepal. Major focus has been given to heat loss assessment, boiler efficiency calculation, analysis of energy saving scenarios and emission reduction opportunities. Heat loss assessment reveals that the major factor for heat loss in the boiler is the loss through dry flue gas, which accounts to 82% of the total loss. The key contributor for this loss is the higher level of oxygen in the flue gas, ranging from 17.1% to 19.4%. This has indicated to opt for limit excess air in the combustion chamber of the boiler. Other notable heat losses include loss due to hydrogen in the fuel (6.26%), radiation and convection (5.85%), and moisture in the combustion air (3.13%). Boiler efficiency across sampled industries ranges from 30% to 64%, with fuelwood-based boilers operating more efficiently (60%–64%) compared to rice husk-based boilers (30%–46%). Despite their lower efficiency, rice husk-based boilers demonstrate higher potential for energy savings.

To improve energy performance, three energy-saving scenarios were analyzed: increasing feedwater temperature, reducing excess oxygen in flue gas, and preheating combustion air. The results indicate that rice husk-based boilers offer greater energy savings potential across all scenarios. A 1°C rise in feedwater temperature yields savings of 28.35 MJ to 60.98 MJ for rice husk-based boilers and 7.09 MJ to 31.34 MJ for fuelwood-based boilers. A 20% reduction in oxygen levels results in energy savings of 13.75 GJ to 20.27 GJ for rice husk-based boilers and 0.97 GJ to 5.31 GJ for fuelwood-based boilers. Increasing combustion air temperature to 50°C leads to potential savings of 4.08 GJ to 10.45 GJ for rice husk-based boilers and 0.25 GJ to 1.38 GJ for fuelwood-based boilers. Emission estimates show that the rice husk-based boiler emit lesser pollutants than fuelwood-based boilers. The estimated emission from rice husk-based boilers on daily basis reach up to 45.37 kg of PM, 12,094 kg of CO_2, 491 kg of CO and 24 kg of NO_x. Operational improvements in boilers like increase in feedwater temperature by 5℃, 2% decrease in oxygen level in the flue gas and 10℃ increase in combustion air temperature can reduce emission from 0.27% to 13.25%. These findings highlight the opportunities for enhancing boiler performance and environmental compliance in biomass-based boilers through targeted operational adjustments.

ACKNOWLEDGEMENT

First and foremost, I want to thank my supervisor Assoc. Prof. Dr. Hari Bahadur Darlami for his continuous support and guidance on this research. Your expertise, insightful feedback, and constructive suggestions have been instrumental in shaping this thesis and enhancing the quality of my work.

I would like to express my utmost gratitude to Dr. Maheswor Shrestha, Dr. Kiran Gautam and Sabitri Dhamala for their invaluable support and motivation throughout the research duration. A special thanks to dear brothers Jagdish Chandra Joshi, Akash Paudel, Shisab Pant and Kshitiz Ghimire for their valuable comments and constructive feedback. My heartfelt gratitude goes to the industry's management team, managers and professional for providing their invaluable time for discussion and data collection. Their willingness to share data, technical skills and experiences have played a major role in successfully completing this study.

I am also grateful towards the Master's Program faculty members, Assoc. Prof. Dr. Ajay Kumar Jha, Assoc. Prof. Dr. Shree Raj Shakya and Assoc. Prof. Dr. Nawaraj Bhattarai for continuous guidance regarding various aspects of energy audit and renewable energy engineering. The insights on theoretical aspect and guidance on methodology of the study received from your end have been proved to be cornerstone for this study.

I, furthermore, would like to convey my special thanks to the classmates of MSREE batch 2079 and friends of M.Sc. Hostel (2079-2080 batch) for a thoughtful environment throughout the Masters study. Your presence has made this study journey enjoyable and enlightening. Lastly, I owe my deepest gratitude to my family for their unwavering love, patience, and support. Their understanding and sacrifices have been the foundation of my academic pursuits.

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LIST OF ABBREVIATIONS

AAS	Actual Air Supplied
BC	Black Carbon
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
FBC	Fluidized Bed Combustion
GDP	Gross Domestic Product
IEA	International Energy Agency
IOEGC	Institute of Engineering Graduate Conference
IT	Information Technology
LPG	Liquefied Petroleum Gas
NDC	Nationally Determined Contribution
NH_3	Nitrogen Trihydride
NMVOC	Non-Methane Volatile Organic Compound
NO_x	Nitrous Oxide
OC	Organic Carbon
PM	Particulate Matter
SO_2	Sulphur Dioxide
VFD	Variable Frequency Drive
WECS	Water and Energy Commission Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background and context

Boilers are crucial in energy-intensive industries, supplying the necessary heat and steam for various manufacturing processes. In Nepal, sectors such as cement production, textiles, food processing, and breweries rely heavily on boilers powered by biomass, coal, and fossil fuels to meet their thermal energy requirements. However, the efficiency of these boilers is often compromised due to outdated technology, inadequate maintenance practices, and inefficient operating methods (Ghimire et al., 2023). According to a report by the International Energy Agency (IEA), industrial energy consumption accounts for more than 38% of global energy consumption in 2023, with boilers being a significant contributor to this demand (IEA, 2024).

In Nepal, the industrial sector is a significant consumer of energy, accounting for approximately 20.91% of the nation's total energy consumption (WECS, 2024). This sector relies heavily on boilers for various thermal applications, utilizing fuels such as biomass, coal, and petroleum products. Industries such as cement production, textiles, food processing, and breweries depend on these boilers to meet their heat and steam requirements. However, the efficiency of these boilers is often compromised due to outdated technology and inadequate maintenance practices (Broughton, 2003).

Enhancing the efficiency of industrial boilers is globally acknowledged as a vital approach to decreasing energy consumption, reducing operational expenses, and mitigating greenhouse gas emissions. Significant energy losses in industrial boilers are primarily attributed to heat dissipation through flue gases, suboptimal combustion processes, inadequate insulation, and inefficient operational practices (Rastegarpour et al., 2023). For instance, a study analysing energy, exergy, and economic aspects of industrial boilers found that approximately 10–30% of the heat energy is lost through flue gases, with exhaust temperatures ranging from 150 to 250°C. This underscores the importance of optimizing combustion and enhancing heat recovery systems to improve overall boiler efficiency (Rahman et al., 2010). Addressing these inefficiencies in Nepal’s industries can lead to significant fuel savings, environmental benefits, and enhanced energy security, supporting the country’s goals of sustainable industrial development (Poudyal et al., 2019) .

Improving boiler efficiency is crucial for reducing energy consumption, lowering operational costs, and mitigating environmental impacts. The Government of Nepal, through the Ministry of Industry, Commerce, and Supplies, has been promoting energy efficiency measures and the adoption of cleaner technologies in industries to address these challenges. Implementing such measures aligns with Nepal's broader goals of sustainable industrial development and environmental conservation. According to WECS, targeted energy efficiency interventions in industrial boilers can lead to significant fuel savings and reduced greenhouse gas emissions, supporting the country's commitment to energy sustainability (Water and Energy Commission Secretariat, 2024).

1.2 Problem statement

Despite the critical role of industrial boilers in Nepal's industrial sector, there has been limited research on their energy efficiency and potential for energy savings. Many industries operate at suboptimal efficiency levels due to a lack of systematic energy audits, insufficient technical expertise, and the absence of robust energy conservation practises focused on industrial boiler performance (Bhattarai & Bajracharya, 2016). Studies from other developing economies have demonstrated that implementing energy efficiency measures, such as waste heat recovery systems, and optimized combustion control, can enhance boiler efficiency (Jouhara et al., 2018) (Castro Oliveira et al., 2020) (Suntoro et al., 2022) . However, in Nepal, there is limited number of comprehensive assessments performed for energy-saving opportunities in industrial boilers. This research aims to assess the current boiler performance and analyse the various scenarios of energy savings in the boiler.

1.3 Objectives

The main objective of this study is to perform technical assessment on operational biomass based industrial boilers in Nepal. The specific objectives of this study are as follows:

i. To determine and quantify the heat losses in the boiler.
ii. To assess the current operational efficiency of industrial boilers across six selected Nepalese industries.
iii. To perform technical analysis of the potential energy saving scenarios in the boiler.

iv. To estimate the pollutant emission from the boiler and analyse the reduction in emission from the energy saving scenarios.

1.4 Limitations of the study

This study focuses on selected energy-intensive industries in Nepal that significantly rely on boilers, including textile processing, milk production, wood product, paper processing and breweries. The research involves extensive field surveys, in-depth interviews with plant managers and maintenance personnel, and efficiency measurements using flue gas analysers. Additionally, variations in fuel quality, industry-specific operational constraints, and data availability from industries have posed challenges to the comprehensiveness of the findings. These factors have been carefully considered in the interpretation and analysis of results.

CHAPTER TWO: LITERATURE REVIEW

In Nepalese industries, various types of boilers are used based on the nature of the industry and the availability of fuels. Fire-tube boilers, commonly found in small-scale manufacturing, textile, and food processing industries, typically use diesel, furnace oil, natural gas (rarely), or biomass like wood and briquettes. Water-tube boilers, preferred in large-scale industries such as cement, paper, and breweries, operate on fuels like coal, biomass (e.g., rice husk, bagasse), furnace oil, or diesel. Biomass boilers, designed specifically for burning biomass fuels, are popular in agriculture-based industries, sugar mills, and tea processing factories, utilizing rice husk, bagasse, sawdust, wood chips, and briquettes. Steam boilers are widely used in food processing, pharmaceuticals, and beverage industries and run on coal, diesel, natural gas, or biomass. Package boilers, compact and pre-assembled, cater to smaller industries like hotels, laundries, and small food processing units, relying on LPG, diesel, or furnace oil. Advanced FBC boilers, used in cement factories and large-scale sugar mills, burn coal, bagasse, and other biomass efficiently. Lastly, electric boilers, though limited in usage, are utilized in small-scale industries with access to affordable electricity. Biomass fuels dominate the boiler fuel landscape in Nepal due to their availability and cost-effectiveness, while fossil fuels like diesel, furnace oil, and coal are primarily used in larger industries (Koppejan & Van Loo, 2012).

Industrial energy consumption plays a crucial role in Nepal's economic development, especially as industries contribute significantly to the country's GDP. In Nepal, the manufacturing sector, which includes food processing, cement production, textiles, and agriculture-based industries, consumes a substantial portion of the national energy supply. According to the World Bank (2022), the energy demand from the industrial sector has been increasing in recent years due to the growing need for power-intensive machinery, heating, and cooling systems. Industrial energy consumption in Nepal primarily comes from electricity, fossil fuels (such as diesel, coal, and furnace oil), and biomass fuels (e.g., wood, rice husk, and bagasse). Boilers, which are used for steam and heat generation, are integral to the functioning of these industries, providing essential thermal energy for manufacturing processes.

The demand for industrial boilers in Nepal is vast, with fire-tube boilers commonly used in small-scale industries like textiles and food processing, while larger industries such as cement and paper mills typically employ water-tube boilers. Biomass boilers are particularly prominent in Nepal due to the country's vast agricultural sector, which provides a ready supply of organic waste. For example, in the sugar industry, bagasse (a by-product of sugarcane processing) is widely used as boiler fuel, while rice husks are commonly used in rice mills. As such, boilers are a fundamental component of industrial infrastructure in Nepal, supporting sectors such as food production, pharmaceuticals, and textiles (Bhattarai & Bajracharya, 2016). However, the rising energy demands and the need for sustainable production practices highlight the importance of optimizing energy consumption in industrial boilers.

2.1 The role of boilers in Nepalese Industries

Boilers are essential for generating steam and heat in industrial processes, making them one of the largest energy consumers in industrial facilities. The role of boilers in Nepalese industries cannot be overstated, as they are crucial for various manufacturing processes, including drying, cooking, sterilizing, and power generation. In Nepal, industries like sugar mills, rice mills, breweries, and textile factories heavily rely on boilers for their day-to-day operations. Boilers consume a significant portion of the energy required by these industries, and their efficiency directly impacts the overall energy consumption and operational costs.

In Nepal, boilers are powered by a mix of fuels, including biomass, coal, diesel, and furnace oil, depending on the industry's size, fuel availability, and economic considerations. Biomass boilers, in particular, are favoured in many industrial sectors due to the abundant availability of agricultural residues, which serve as inexpensive, renewable fuel sources. For example, in the sugar industry, bagasse (a by-product of sugarcane processing) is widely used as boiler fuel, while rice husks are commonly used in rice mills. However, the efficiency of these boilers is critical for ensuring optimal energy use, reducing emissions, and lowering operational costs.

2.2 Importance of energy efficiency in industrial boilers

Improving the energy efficiency of industrial boilers is paramount for reducing energy costs, minimizing environmental impact, and ensuring long-term sustainability. Boilers that operate inefficiently consume more fuel to generate the same amount of energy, leading to higher fuel costs, increased emissions, and potential equipment damage. For industries in Nepal, where energy costs can be a significant part of overall operational expenses, energy efficiency in boilers can lead to substantial cost reductions. According to the International Energy Agency , improving boiler efficiency by just 10% can reduce fuel consumption by up to 5-8%, depending on the fuel type used (IEA, 2021).

Moreover, energy-efficient boilers contribute to environmental sustainability by lowering greenhouse gas emissions, which is critical in Nepal's efforts to reduce its carbon footprint. The country has committed to achieving its NDCs under the Paris Agreement, which includes reducing greenhouse gas emissions from industrial sources. By enhancing the thermal efficiency of boilers, industries can play a significant role in helping Nepal meet its climate goals while simultaneously reducing fuel consumption and operational costs.

2.3 Nepal's energy scenario

Nepal's energy sector is characterized by a heavy reliance on biomass, hydroelectricity, and fossil fuels. Hydropower is the largest source of electricity generation, providing over 70% of the country's power needs. However, the country's reliance on biomass for industrial energy use remains high, as it is the most readily available and affordable fuel source in rural areas. Approximately 70% of the energy used for cooking and heating in Nepal comes from biomass, including firewood, agricultural residues, and animal dung (Water and Energy Commission Secretariat, 2024) .

While biomass is a sustainable and renewable resource, its use in industrial boilers presents challenges related to efficiency and emissions. Biomass combustion in poorly optimized boilers can lead to incomplete combustion, resulting in excessive particulate matter and greenhouse gas emissions. This makes improving the efficiency of biomass boilers crucial not only for cost reduction but also for ensuring environmental sustainability (Saidur et al., 2011). Fossil fuels, particularly diesel and furnace oil, are also commonly used in large-scale industries but contribute to higher operational costs and environmental degradation.

2.4 Challenges in energy saving for industrial boilers

Despite the potential for energy savings, industrial boilers in Nepal face significant challenges in achieving high energy efficiency. One of the primary obstacles is the lack of awareness and knowledge about efficient boiler operation and maintenance.

Many industries in Nepal operate older, less efficient boilers that have not been properly maintained or upgraded to meet modern energy standards (Khan et al., 2022). Additionally, the high upfront cost of replacing or retrofitting old boilers with more efficient models discourages many industrial owners from making the necessary investments (Siraj et al., 2023).

Another challenge is the limited availability of skilled labor to maintain and optimize boiler systems. Proper operation and regular maintenance of boilers are essential for ensuring their efficiency, but there is a shortage of trained personnel who can carry out these tasks effectively. Moreover, industries in Nepal often lack access to modern technologies such as advanced flue gas analyzer, which can provide real-time data on boiler performance and fuel efficiency. Without such tools, it is difficult for industries to monitor and optimize their energy consumption effectively.

2.5 Technical data

The ultimate analysis of rice husk is taken as Carbon (C): 36.74%, Hydrogen (H): 5.51%, Oxygen (O): 42.55%, Sulphur (S): 0.55%, Nitrogen (N): 0.28%, and ash : 14.37% (R. D. Yadav et al., 2020). This data is are required for the calculation of theoretical air requirement for the rice husk. Additionally, The ultimate analysis of fuelwood is taken as Carbon (C): 45.60%, Hydrogen (H): 3.96%, Oxygen (O): 37.45%, Sulphur (S): 0.07%, Nitrogen (N): 0.45%, and ash : 3.14% (Oirere et al., 2018). The calorific values for the rice husk and fuelwood are taken as 12,339.60 kJ/kg (Awulu et al., 2018) and 20,420.00 kJ/kg (Bhatt & Tomar, 2002).

2.6 Efficiencies of biomass based industrial boilers

Study had been conducted to evaluate the performance of a biomass-based boiler working at 25 bar pressure. The fuel used in the operation was bagasse. The indirect method of efficiency calculation was used. Heat loss due to dry flue gas in the boiler was found to be 7.92%, loss due to hydrogen in the fuel was 7.55%, loss due to moisture in the fuel was 13.30%, loss due to moisture in the air was 0.32%, loss due to partial combustion was 13.33% and loss due to radiation and convection was 1.5%. Consequently, the efficiency of the boiler was found out to be 56.08% (Ashfaq & Ghafoor, 2014).

Study concerning rice husk as a fuel in industrial boiler had been performed. In the study, the efficiency of rice husk-based boiler working at 8.5 steam pressure was calculated. The direct method was used to calculate the efficiency, which was found out to be 68% (J. Yadav & Singh, 2011).

Techno-economic sustainability analysis of the biomass based industrial boiler had been performed. The efficiency of the rice husk-based boiler was calculated by direct and in-direct method. The efficiency was found out to be 68.34% by direct method and 69.29% by indirect method (Awan et al., 2019).

2.7 Energy saving options in industrial boilers

In a study, the efficiency of industrial boilers with different fuel types and modes of operation had been investigated, citing that combustion efficiency, heat losses, and operating practices are key determinants of overall boiler performance. Their research was aimed at the impact of fuel selection on efficiency, where biomass-based fuels provide a cleaner alternative to fossil fuels. One of the major areas of boiler efficiency is reducing heat losses, particularly by fuel residues and flue gases that are not burned. As research indicates, application of heat recovery equipment such as air preheaters and economizers can significantly improve efficiency. Improvement of the air-to-fuel ratio to achieve optimal combustion quality and reduce excess air to minimize energy wastage was identified as a suggestion by the author. Industrial boiler fuel consumption and emissions are closely linked, with fossil fuel-based technologies as leading causes of greenhouse gas emissions. Other renewable energy sources like biomass have been proposed as possible alternatives in reducing the carbon footprint of industrial processes. The study also compared emissions from various sources of fuel, showing the environmental benefit of having renewable energy in boiler operations. Besides, energy conservation interventions such as insulation upgrades, maintenance, and real-time monitoring have widely been identified as effective strategies for maximizing boiler efficiency. Not only do these interventions result in energy savings, but they also bring economic benefits through reduced operation costs (Suntoro et al., 2022).

Study have pointed out that the use of an air preheater in industrial boilers dramatically enhances efficiency as a result of recovering waste heat from flue gases. The research shows that air preheaters can increase boiler efficiency by 5% to 10% and up to 15% of fuel consumption decrease. This translates into significant cost savings and lower operating costs. Apart from that, the research shows that air preheater optimization lowers CO_2 emissions by 10% to 20%, and this encourages environmental sustainability. The research compares different air preheaters and indicates that regenerative air preheaters provide more efficiency benefits than recuperative air preheaters. In general, the results affirm that air preheaters provide a low-cost solution for energy saving, reducing fuel costs and emissions while optimizing boiler performance (Suntivarakorn & Treedet, 2016).

Study have also emphasized the importance of feedwater treatment in enhancing boiler efficiency, reducing scale formation, and preventing corrosion failure. The findings validate that effective feedwater treatment enhances boiler efficiency by 5% to 12% and reduces fuel consumption by 10% to 20% accordingly. Furthermore, the research cites that untreated feedwater can result in a 2 mm scale formation, something that will decrease heat transfer efficiency by up to 10% and fuel cost by 8% to 15%. The research also confirms that through the use of advanced treatment technologies such as reverse osmosis and de-aeration, dissolved oxygen can be significantly reduced, thereby decreasing the risk of corrosion by over 50%. Overall, the research underscores that effective feedwater treatment is a good and cost-effective approach to optimizing boiler performance, minimizing maintenance costs, and ensuring energy conservation(Davis F et al., 2022).

CHAPTER THREE: METHODOLOGY

The research methodology follows a systematic approach to assess the operational efficiency and analyze the energy saving scenarios in industrial boilers. It begins with a literature review to understand existing studies and best practices related to boiler efficiency and energy conservation. This is followed by the selection of industries for data collection, ensuring a representative sample of biomass based industrial boilers in Nepal.

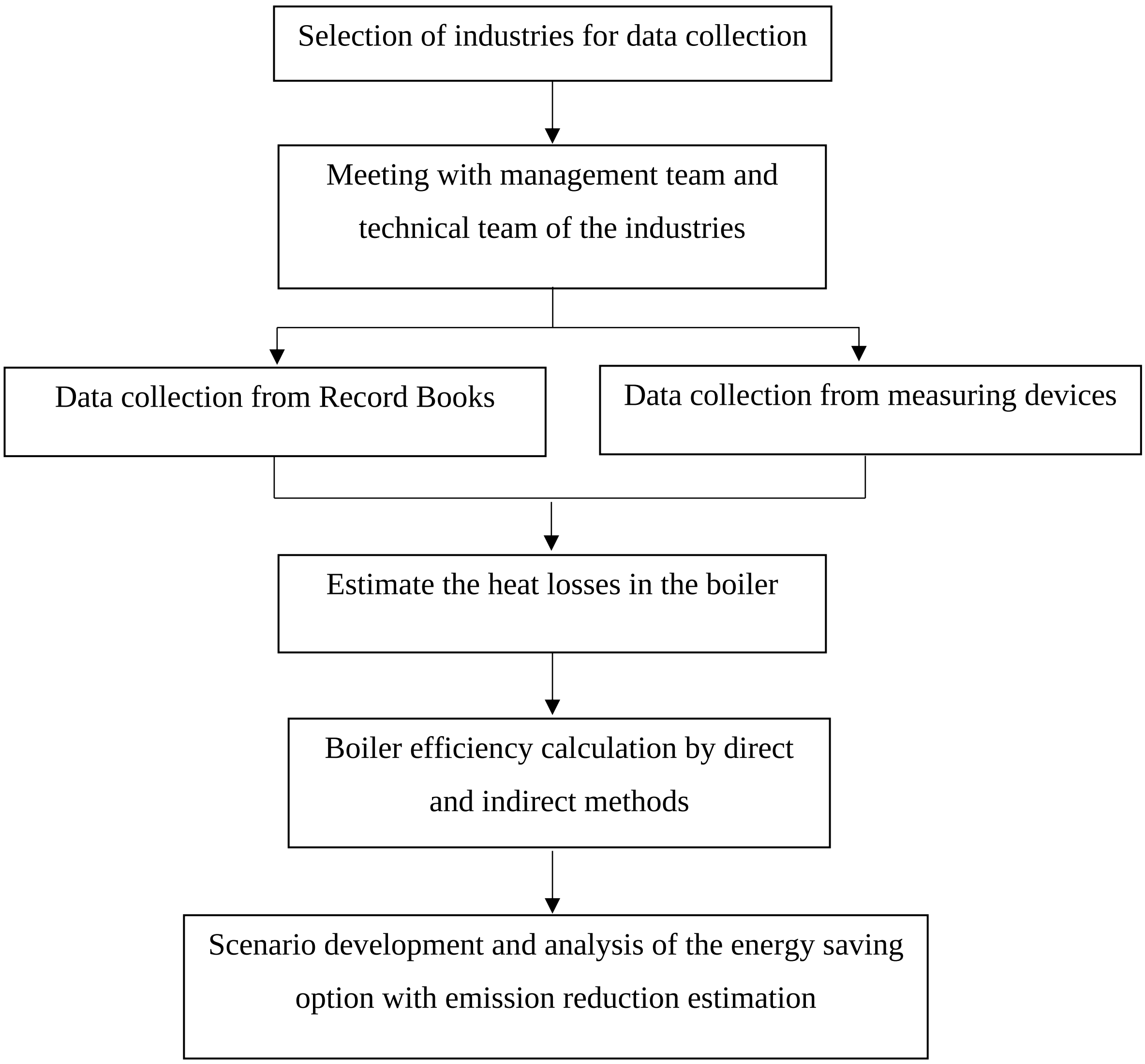

Figure 3.1 Methodological Flowchart

Meetings with management and technical teams of the selected industries are conducted to gather insights on operational practices. Data collection is carried out through record books and measuring devices, ensuring both historical and real-time data on fuel consumption and boiler performance. The collected data is analyzed using direct and indirect methods to determine boiler efficiency. Based on these findings, potential energy-saving measures are explored and assessed for the scenario analysis.

Table 3.1 Technical methodological summary

Step	Description
Analyze Flue Gas Data	Evaluate combustion efficiency using flue gas composition (CO_2, O_2, CO).
Identify Energy Losses	Identify energy losses from high flue gas temperature, excess air, and unburnt fuel.
Calculate Boiler Efficiency	Use Direct or Indirect Method to calculate boiler efficiency.
Scenario Development	Identify the possible energy saving scenarios in the boiler
Analysis of the scenarios	Analyze and compare the energy saving scenarios in each boiler. Emission reduction is estimated and compared for each scenario.

3.1 Selection of industries for data collection

The first criterion for the industry selection for the study is the fuel type used for the boiler operation. Boilers using biomass as a fuel are selected for the study. In the next step, the industries shall be selected based on their willingness to provide fuel-related data and allow the installation of measuring equipment for boiler efficiency analysis. The name of the industries shall be kept confidential to ensure the confidentiality.

3.2 Meeting with management and technical team of the industry

Before collecting boiler data, a brief presentation is given to the management and technical teams of each industry to explain the objective and scope of the study. This meeting is crucial in establishing transparency and cooperation, ensuring that industry representatives understood the purpose of data collection and how it could benefit their operations. Discussions during the meeting helped in gaining access to fuel consumption records, combustion-related data, and operational logs. Additionally, industry personnel provided valuable insights into boiler performance, maintenance practices, and potential energy-saving opportunities. The engagement with the management and technical teams facilitated a smooth data collection process while ensuring the reliability and accuracy of the gathered information.

3.3 Data collection

Technical thermodynamic data have been collected from record books maintained by the industries and installing the energy audit equipment in the boiler.

3.3.1 Data collection from record books

To assess boiler performance and energy consumption patterns, fuel consumption data is collected from the record logs maintained by each industry. This includes daily fuel consumption rates for boilers, along with the purchase price of fuels such as rice husk and fuelwood. The data from record books provided historical fuel usage trends, helping to estimate boiler efficiency and operational costs over time. Verifying these records with industry personnel ensured data accuracy and consistency, forming a crucial part of the study’s analysis on energy efficiency and cost-saving potential in industrial boilers.

3.3.2 Data collection from measuring devices

The following measuring equipment were used to record the various parameters:

Table 3.2 Data Collection from Measuring Devices

S.N.	Parameters	Measured Using
1.	Operating pressure	Pressure Guage
2.	Boiler surface temperature	Infrared Thermometer
3.	Steam output	Steam Flow meter
4.	Feedwater temperature	Digital Temperature sensor
5.	Flue gas composition (O_2, CO_2, CO)	Flue Gas Analyzer
6.	Flue gas temperature	Thermocouple Probe

3.4 Boiler efficiency calculation

The efficiency of the boiler is calculated by applying the direct and in-direct method. Direct method relies on measurement of steam flow rate, temperature of steam and feedwater. On the other hand, in-direct method requires composition of flue gas measurement.

3.4.1 Direct method

Direct Method involves the heat obtained by the feedwater in changing its state from water to steam and heat contained in the fuel. (WECS, 2021)

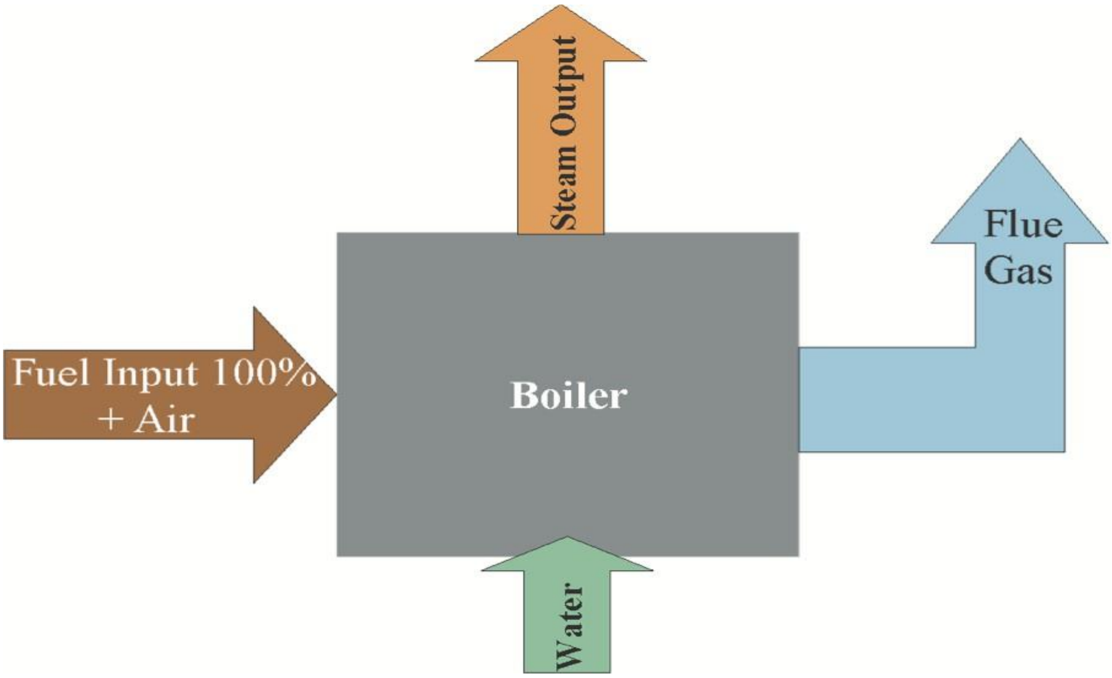

Figure 3.2 Boiler efficiency calculation by direct method

This efficiency is calculated by given formula:

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input} \times 100\% \qquad \dots 3.1$$

$$Boiler\ Efficiency = \frac{Steam\ Flow\ Rate\ \times (Steam\ Enthalpy - Feed\ Water\ Enthalpy)}{Fuel\ Firing\ Rate\ \times Gross\ Calorific\ Value} \times 100\ \% \qquad \dots 3.2$$

3.4.2 Indirect method

Indirect method involves calculating the heat losses in the boiler and deducting the losses from 100 (WECS, 2021).

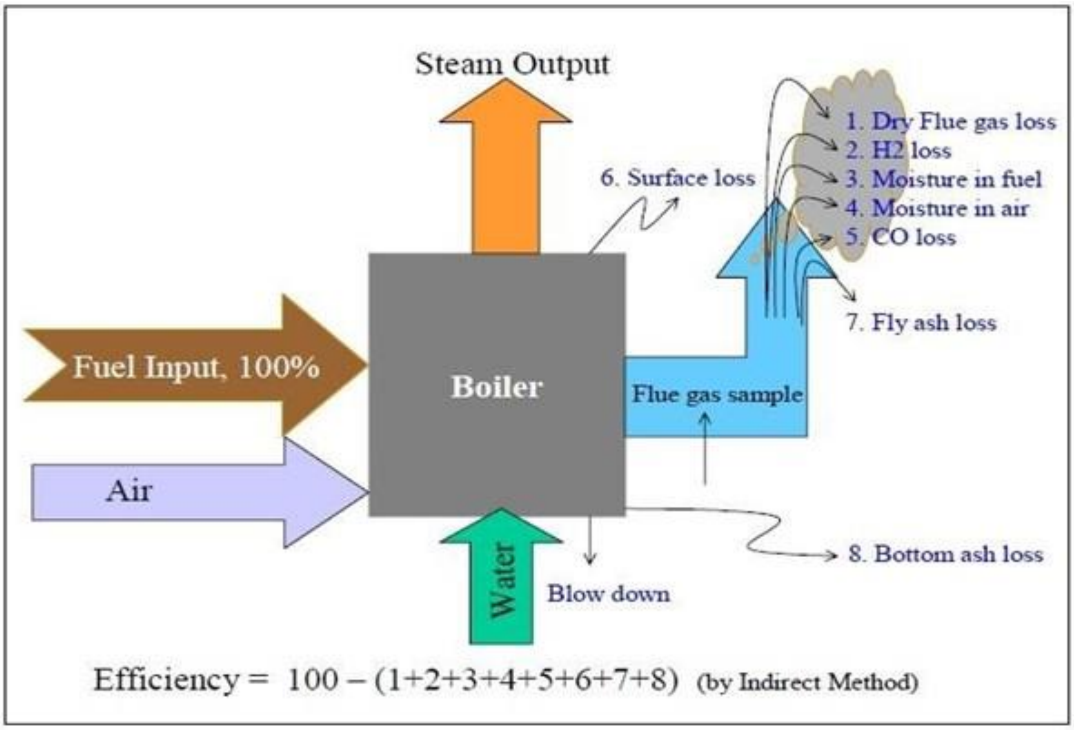

Figure 3.3 Boiler Efficiency Calculation by Indirect Method

Following losses are applicable to liquid, gas and solid fuel fired boiler:

L1- Loss due to dry flue gas (sensible heat)

L2- Loss due to hydrogen in fuel (H_2)

L3- Loss due to moisture in fuel (H_2O)

L4- Loss due to moisture in air (H_2O)

L5- Loss due to incomplete combustion (CO)

L6- Loss due to surface radiation, convection and other unaccounted *

*Losses which are insignificant and are difficult to measure.

The following losses are applicable to solid fuel fired boiler in addition to above;

L7- Loss due to unburnt in fly ash (carbon)

L8- Loss due to unburnt in bottom ash (carbon)

Boiler Efficiency by Indirect Method

$$\text{Boiler Efficiency} = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8) \quad \dots 3.3$$

In the in-direct method of boiler efficiency calculation, first the theoretical (stoichiometric) air fuel ratio and excess air supplied is calculated.

$$Theoretical\ Air\ required\ for\ Combustion$$

$$= (11.6 \times C) + \left\{34.8 \times \left(H_2 - \frac{O_2}{8}\right)\right\} \quad \dots 3.4$$

$$+ (4.35 \times S)]/100\ kg/kg\ of\ the\ fuel$$

Here, C, H_2, O_2 and S are the percentage of carbon, hydrogen, oxygen and sulphur present in the fuel

$$Percentage\ of\ excess\ air\ supplied\ (EA) = \frac{O_2\%}{21 - O_2\%} \times 100 \qquad \ldots 3.5$$

$$Actual\ Air\ supplied = \left(1 + \frac{EA}{100}\right) X\ Theoretical\ air \qquad \ldots 3.6$$

The calculation formulae for the calculation of various types of losses on boiler are given below:

i. Loss due to dry flue gas (sensible heat) (L_1)

$$L_1 = \frac{m \times C_p \times (t_f - t_a)}{GCV} \times 100 \qquad \ldots 3.7$$

where,

m = mass of dry flue gas in kg/kg of fuel

C_p = Specific heat of flue gas in kcal/kg°C or kJ/Kg°C

t_f = Flue gas temperature in °C

t_a = Ambient temperature in °C

GCV = Gross calorific value of the fuel

ii. Loss due to hydrogen in fuel (L_2)

$$L_2 = \frac{9 \times H_2 \times \{584 + C_p \times (t_f - t_a)\}}{GCV} \times 100 \qquad \ldots 3.8$$

Where,

H_2 = hydrogen present in per kg of fuel

C_p = Specific heat of superheated steam in kcal/kg°C or kJ/kg°C

584 = Latent heat corresponding to partial pressure of water vapor

iii. Loss due to moisture in fuel (L_3)

$$L_3 = \frac{\mathrm{M} \times \{584 + C_p \times (t_f - t_a)\}}{GCV} \times 100 \qquad \ldots 3.9$$

Here, M is the mass of moisture present in fuel on per kg basis.

iv. Loss due to moisture in air (L_4)

$$L_4 = \frac{\mathrm{AAS} \times \mathrm{humidity\ factor} \times C_p \times (t_f - t_a)}{GCV} \times 100 \qquad \ldots 3.10$$

Here, AAS is the actual air supplied per kg of fuel and Humidity factor is the mass of water in kg present in 1 kg of dry air

v. Loss due to incomplete combustion (L_5)

$$L_5 = \frac{\%\mathrm{CO} \times \mathrm{C}}{\%\mathrm{CO} + \%CO_2} \times \frac{5744}{GCV} \times 100 \quad \ldots 3.11$$

Here, AAS is the actual air supplied per kg of fuel and Humidity factor is the mass of water in kg present in 1 kg of dry air

Here, CO is the volume of CO in the flue gas and CO_2 is the actual volume of CO_2 in the flue gas.

vi. Loss due to surface radiation, convection and other unaccounted (L_6)

For industrial water tube boiler, this loss is taken from 2% to 3%.

Thus, the efficiency of the boiler is calculated as hundred percent minus all the losses present in the boiler.

3.5 Scenario analysis

Three energy saving scenarios are developed and analyzed, which are mentioned below:

Scenario 1: Increase in feedwater temperature

The increase in feedwater temperature up to enhances the boiler efficiency (Davis F et al., 2022). The temperature of feedwater is recorded. Energy required to convert the feedwater to steam is calculated for observed case. Similarly, the energy required to convert the feedwater at elevated temperature to desired steam temperature is determined. The difference in energy value between the assumed scenario and observed case is evaluated.

Scenario 2: Decrease in oxygen level

Higher oxygen level is the indicator of higher heat loss due to dry flue gas in the boiler. Trimming the oxygen level is the solution to this issue (Kirsanovs et al., n.d.). Thus, it can be achieved through the installation of VFD and oxygen trim sensor. VFD is installed in the blower side. It varies the fan's impeller speed as per the boiler's requirement. Likewise, oxygen sensor is installed in the boiler stack section, which is used to control the VFD. The sensor detects the level of oxygen in the stack. If the oxygen level goes higher than the set value, the sensor signals the VFD to decrease the speed of the blower, consequently decreasing the air flow.

For the analysis of this scenario, the quantity of energy lost due to presence of oxygen level in the flue gas in the observed case is calculated. Similarly, the estimated quantity of energy that could be lost at lower oxygen level is estimated. The difference in energy lost gives the potential energy savings.

Scenario 3: Increase in combustion air temperature

The efficiency of the boiler can be increased by using air preheater. Combustion air at higher temperature helps in better fuel-air mixing and reduces the chances of incomplete combustion (Suntivarakorn & Treedet, 2016). The quantity of energy lost due to dry flue gas in observed condition of air temperature is determined. Scenario is developed to estimate the energy lost at elevated combustion air temperature. The difference in quantity of energy provides the energy savings due to higher temperature combustion air.

By integrating field data and scenario analysis, this methodology provides a comprehensive approach to improving energy efficiency in Nepalese biomass based industrial boilers.

3.6 Emission analysis

Environmental emission due to combustion of biomass (rice husk and fuel wood) is estimated, taking considerations of the standard emission constants (Ram M. Shrestha et al., 2013).

Table 3.3 Emission constant

Pollutants	Emission constant (g/kg of fuel)	
	Rice husk	Fuelwood
PM	6.28	3.82
SO_2	0.18	0.008
CO_2	1,674	1,520
CO	67.98	69.2
NO_x	3.43	1.2
NH_3	4.1	1.29
CH_4	9.6	5.06
NMVOC	7	7.5
BC	0.49	0.85

Pollutants	Emission constant (g/kg of fuel)	
	Rice husk	Fuelwood
OC	2.01	4.75

Table 3.3 shows the emission constants for the combustion of 1 kg of rice husk and fuelwood. The daily emission values are calculated for present operational status of the boiler. As energy is saved by the application of the above scenarios, the emission is also reduced. The magnitude of reduction in emission values are estimated and compared.

CHAPTER FOUR: RESULTS AND DISCUSSION

The study focuses on the collection of thermodynamic data of the operating biomass-based boilers, calculation of heat losses and efficiencies of the boiler and analyzing the energy saving scenarios in the boiler with potential emission reduction benefits.

4.1 Selection of industry

The industries with biomass-based boilers are contacted, and after discussions with their management and technical teams, six industries provided permission to collect data. Table 4.1 shows the type of the industries with specifications of the boilers.

Table 4.1 Boiler specifications

Industry	Boiler capacity (kg/cm^2)	Boiler type	Fuel type
Brewery	8	Water tube	Rice husk
Textiles	8	Water tube	Rice husk
Paper Mills	8	Water tube	Rice husk
Paper Industry	6.5	Water tube	Rice husk
Diary Industry	10.5	Water tube	Fuelwood
Wood Products	6.5	Water tube	Fuelwood

The capacity of the boiler has been taken from 6.5 kg/cm^2 to 10.5 kg/cm^2. The boilers taken for the study are water tube boilers. As biomass is the first criterion for the boiler selection, rice husk-based and fuelwood-based boilers are selected.

4.2 Measured parameters and values

The pressure of steam generated is recorded using the pressure gauge. It is verified from the log book maintained by the industry. Table 4.2 shows the measured values of various parameters of steam generated from the boiler and feedwater sent to the boiler. The boilers are observed operating up to 43% below steam pressure with respect to the rated pressure, implying over-sizing of the boiler than required. As per the industries, the over-sizing has been done to increase the production size in the future. The steam flow rate is measured using flow meter at the boiler output. The temperatures of steam generated and feedwater are taken using the digital thermometer.

Table 4.2 Measured Values for steam and feedwater

Industry	Working Pressure (kg/cm^2)	Steam Flow Rate (kg/hr)	Steam Temp (ºC)	Temp of Feedwater (ºC)
Brewery	7	521	182	78.2
Textiles	6.5	1,214	260	64.0
Paper Mill	4.58	1,126	190	65.0
Paper Industry	3.87	682	178	75.0
Dairy industry	9.5	212	163	55.0
Wood Products	4.58	624	183	61.0

The flue gas parameters are measured by installing the flue gas analyzer at the chimney of the boiler. Table 4.3 shows the measured values of various parameters of the flue gas. The observed values show that the composition of oxygen in flue gas exceeds by more than 16%, signifying the appreciable amount of heat loss due to dry flue gas. The CO level in the flue gas lies in the range of 200-1000 parts per million (ppm), indicating incomplete combustion.

Table 4.3 Measured values for flue gas

Industry	Temperature of flue gas (ºC)	Oxygen level	CO level (ppm)	CO_2 level
Brewery	132.0	19.40%	947	0.60%
Textiles	175.0	18.50%	660	2.20%
Paper Mill	215.8	17.40%	240	2.70%
Paper Industry	223.6	17.10%	212	1.60%
Dairy industry	218.7	17.20%	231	2.30%
Wood Product	207.7	17.80%	302	2.65%

4.3 Technical assessment of boilers

Four rice husk-based and two fuelwood-based water tube boilers are taken for study. The technical assessment of these boilers comprises of the calculation of boiler efficiencies by direct and in-direct method, heat losses by various means in the boiler, emission estimation from the boiler and potential energy savings in the boiler.

4.3.1 Rice husk-based boilers

Rice husk is used as a primary fuel for operating the boiler. The efficiency of the boiler is calculated by using both direct method and indirect method. Table 4.4 shows the calculation of efficiency of the boiler by direct method. Heat input is calculated using the mass flow rate of steam and the enthalpy differences of steam and supplied water. Enthalpy is taken from the standard steam table with the help of temperature and pressure of feedwater and steam. Heat output is calculated by multiplying the calorific value of the fuel and mass of fuel supplied. Thus, the boiler efficiency is calculated from the direct method by dividing the heat output from the boiler to heat input to the boiler. The efficiencies of the rice husk-based boilers are calculated to be 31.46%, 37.35%, 45.50% and 46.47% using the direct method.

Table 4.4 Efficiency calculation of rice husk-based boilers using direct method

Parameters	Brewery	Textiles	Paper Mill	Paper Industry
Steam working pressure (bar)	7.00	6.50	4.58	3.87
Steam temperature (ºC)	182.20	260.00	190.00	178.00
Daily Fuel consumption (tonne)	4.20	8.50	6.00	5.10
Working hours in a day (hrs)	13.00	12.00	12.00	18.00
Steam flow rate (kg/hr)	521.00	1,214.00	1,126.00	682.00
Feedwater temperature (ºC)	78.20	64.00	65.00	75.00
Calorific value of fuel (kJ/kg)	12,339.60	12,339.60	12,339.60	12,339.60
Enthalpy of steam (kJ/kg)	2,734.00	2,957.00	2,765.00	2,696.00
Enthalpy of feedwater (kJ/kg)	326.95	267.90	272.09	313.52
Heat Output (GJ/hr)	1.25	3.26	2.81	1.62
Heat Input (GJ/hr)	3.99	8.74	6.17	3.50
Efficiency of Boiler (%)	31	37	45	46

It is observed that the rice husk-based boilers are operated under 46% efficiency as demonstrated by the direct method of calculation. This implies that the boiler can be operated with higher efficiency by the application of energy saving techniques in the boiler.

Table 4.5 illustrates the calculation of the boiler's efficiency by in-direct method. Evaluation of boiler efficiency by in-direct method commences with the estimation of theoretical air requirement for the combustion of the fuel. For rice husk, the theoretical air requirement has been taken as 4.82 kg/kg of the fuel from the literature. Level of oxygen in the flue gas has been recorded using flue gas analyzer. In rice husk-based boiler, the higher quantity of oxygen in the flue gas has been observed (17.10% to 19.40 %). Consequently, the heat loss due to dry flue gas in the boiler has been estimated to 46.78% to 57.04%. Heat loss due to hydrogen present in the fuel has been found u pto 4%. Similarly, the heat loss due to other factors like moisture present in the fuel and air, incomplete combustion, radiation and convection has been found to be under 3%. Thus, the efficiencies of the rice husk-based boilers are calculated to be 30.98%, 34.57%, 42.78% and 43.32% by in-direct method.

Table 4.5 Efficiency calculation of rice husk based boilers using in-direct method

Parameter	Brewery	Textiles	Paper Mill	Paper Industry
Theoretical air for combustion				
Carbon percentage (%)	36.40	36.40	36.40	36.40
Hydrogen percentage (%)	4.84	4.84	4.84	4.84
Oxygen percentage (%)	25.11	25.11	25.11	25.11
Sulphur percentage (%)	0.17	0.17	0.17	0.17
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Excess air supplied				
Oxygen percentage (%)	19.40	18.50	17.40	17.10
Excess air supplied (%)	1,212.50	740.00	483.33	438.46
Actual mass of air supplied (kg/kg)	63.29	40.50	28.13	25.96
Heat loss due to dry flue gas				
Temperature of flue gas (°C)	132.00	175.00	215.80	223.60
Ambient air temperature (°C)	30.90	22.40	28.00	21.50
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Gross calorific value (kJ/kg)	12,339.60	12,339.60	12,339.60	12,339.60
Heat loss due to dry flue gas (%)	57.04	55.10	47.09	46.78
Heat loss due to hydrogen in fuel				

Parameter	Brewery	Textiles	Paper Mill	Paper Industry
kg of hydrogen on 1kg basis (kg/kg)	0.06	0.06	0.06	0.05
Specific heat capacity of superheated steam (kJ/kg·°C)	2.10	2.10	2.10	2.10
Latent heat (kJ/kg)	584.00	584.00	584.00	584.00
Heat loss due to hydrogen in fuel (%)	3.48	3.63	4.00	3.68
Heat loss due moisture present in fuel				
kg of moisture in fuel on 1 kg basis (kg/kg)	0.15	0.15	0.15	0.15
Heat loss due to moisture present in fuel (%)	0.97	1.10	1.19	1.23
Heat loss due to moisture present in air				
Humidity factor (kg/kg)	0.02	0.02	0.02	0.02
Heat loss due to moisture present in air (%)	2.18	2.10	1.80	1.79
Heat loss due to incomplete combustion				
Volume of CO in flue gas (ppm)	947.00	660.00	240.00	212.00
Volume of CO_2 percent in flue gas (%)	0.60	2.20	2.70	1.60
Carbon content per kg of fuel (kg/kg)	0.37	0.37	0.37	0.36
Heat loss due to partial combustion (kJ/kg)	5,744.00	5,744.00	5,744.00	5,744.00
Heat loss due to incomplete combustion (%)	2.35	0.50	0.15	0.22
Unaccounted losses				
Radiation, convection and Miscellaneous (%)	3.00	3.00	3.00	3.00
Efficiency (%)	30.98	34.57	42.78	43.32

Emission Estimation

Various types of pollutants are emitted to the atmosphere due to the combustion of the biomass. The quantity of emission has been estimated by multiplying the mass of fuel consumption to the standard emission constant (refer to Table 3.3). The pollutants emitted from the boiler on daily basis is presented in Table 4.6.

Table 4.6 Daily emission estimation for boiler of brewery industry

Pollutants	Brewery	Textiles	Paper Mill	Paper Industry
PM	22.42	45.37	32.03	27.22
SO2	0.64	1.30	0.92	0.78
CO2	5,976.18	12,094.65	8,537.40	7,256.79
CO	242.69	491.16	346.70	294.69
Nox	12.25	24.78	17.49	14.87
NH3	14.64	29.62	20.91	17.77
CH4	34.27	69.36	48.96	41.62
NMVOC	24.99	50.58	35.70	30.35
BC	1.75	3.54	2.50	2.12
OC	7.18	14.52	10.25	8.71

Scenario development for energy efficiency opportunities in rice husk-based boilers:

Scenario 1: Increasing the feedwater temperature

The feedwater is supplied at a temperature of 78.20℃, 64℃, 65℃, 75℃ to the boiler. The feedwater can be pre-heated using the excess heat of the flue gas before supplying to the boiler, which shall save energy of the boiler. Figure 4.1 illustrates the quantity of energy savings which can be saved by increasing the feedwater temperature. The detail procedure for the calculation of energy savings by increasing feedwater temperature is demonstrated in Annex 1, Annex 4, Annex 7 and Annex 10.

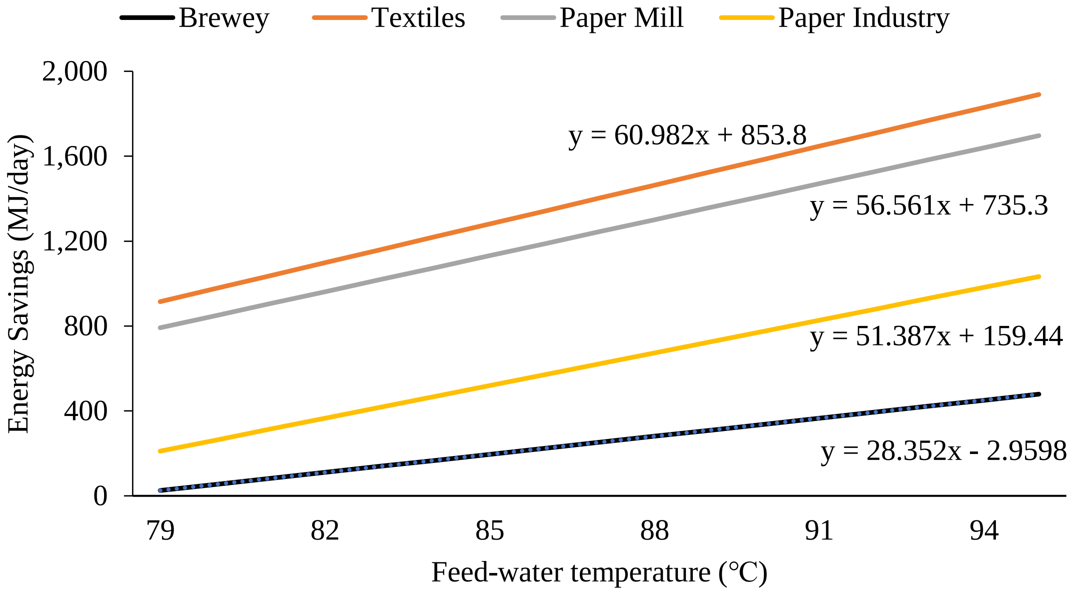

Figure 4.1 Energy savings by increasing feedwater temperature in rice husk-based boiler

The quantity of energy savings in a day grows linearly with the increase in feedwater temperature. With the increment of 1°C of temperature of feedwater, the energy savings increases by 60.98 MJ in the boiler of textile industry. Similarly, the energy savings per °C increment in feedwater temperature in the boiler of paper mill, paper industry and brewery industry has been estimated to be 56.56 MJ, 51.38 MJ and 28.35 MJ per day.

This can be illustrated in the form of annual rice husk saving and cost savings. For 10°C rise in feedwater temperature, the energy savings per day shall be 283.50 MJ, 609.80 MJ, 565.60 MJ and 513.80 MJ in the studied rice husk-based boilers. Annual energy savings have been estimated assuming 300 working days in a year. The cost of the biomass has been taken from the respective industries. The annual rice husk saving for the studied boilers have been estimated from 6.89 tonne to 14.83 tonne, which corresponds to NPR 55,139.55 to 130,463.87 of fuel cost savings.

Table 4.7 Annual fuel mass and cost savings by 10°C rise in feedwater temperature

Parameters	Brewery	Textile	Paper Mill	Paper Industry
Energy saving per day (MJ)	283.50	609.80	565.60	513.80
Annual energy saving (MJ)	85,050.00	182,940.00	169,680.00	154,140.00

Parameters	Brewery	Textile	Paper Mill	Paper Industry
Calorific value	12,339.60	12,339.60	12,339.60	12,339.60
Biomass saving (kg)	6,892.44	14,825.44	13,750.85	12,491.49
Biomass saving (tonne)	6.89	14.83	13.75	12.49
Rate per tonne (NPR)	8,000.00	8,800.00	8,500.00	8,200.00
Annual fuel cost saving (NPR)	55,139.55	130,463.87	116,882.23	102,430.22

Scenario 2: Decrease in oxygen level in the flue gas

The high concentration of oxygen in the flue gas suggests the higher quantity of heat loss due to flue gas. Figure 4.2 shows the quantity of energy savings that can be achieved at various oxygen level in the flue gas. The detail procedure for the calculation of energy savings by decreasing the oxygen level in the flue gas is demonstrated in Annex 2, Annex 5, Annex 8, and Annex 11.

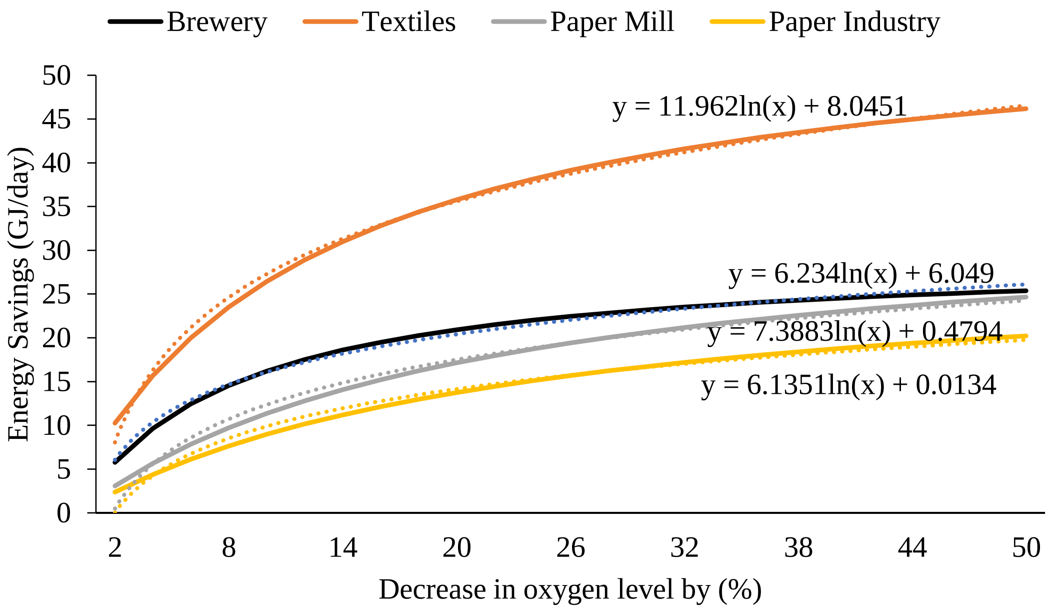

Figure 4.2 Energy savings by decreasing the oxygen level in flue gas in rice husk-based boilers

The quantity of energy savings per day grows logarithmically with the decrease in oxygen level in the flue gas. For the studied boiler of textile industry, 35.79 GJ of energy can be saved in a day with the application of oxygen trimming technology, which reduces the oxygen level by 20%. Similarly, the energy savings for the boilers of studied brewery, paper mill and paper industry are estimated to be 20.93 GJ, 17.14 GJ and 13.75 GJ per day. Thus, it is recommended to install the oxygen trimming technology in the studied brewery industry.

Table 4.8 shows the annual fuel mass and cost savings by 20% decrease in oxygen level in the flue gas. This can be achieved by installing the oxygen trim technology in the boiler. The annual rice husk savings has been estimated to be around 33 tonne to 87 tonne, which corresponds to 0.27 million NPR to 0.76 million NPR.

Table 4.8 Annual fuel mass and cost savings by 20% decrease in oxygen level in flue gas

Parameters	Brewery	Textile	Paper Mill	Paper Industry
Energy saving per day (GJ)	20.93	35.79	17.14	13.75
Annual energy saving (GJ)	6,279.00	10,735.78	5,140.86	4,126.03
Calorific value	12,339.60	12,339.60	12,339.60	12,339.60
Biomass saving (kg)	50,884.96	87,002.66	41,661.45	33,437.28
Biomass saving (tonne)	50.88	87.00	41.66	33.44
Rate per tonne (NPR)	8,000.00	8,800.00	8,500.00	8,200.00
Annual fuel cost saving (NPR)	407,079	765,623	354,122	274,185

Scenario 3: Increase the combustion air temperature by preheater

The combustion air can be preheated by the use of heat lost in flue gas, which consequently assists in enhancing the energy efficiency of the boiler. Figure 4.3 shows the quantity of energy savings that can be achieved at various elevated combustion air temperature. The detail procedure for the calculation of energy savings by increasing the combustion air temperature is demonstrated in Annex 3, Annex 6, Annex 9 and Annex 12.

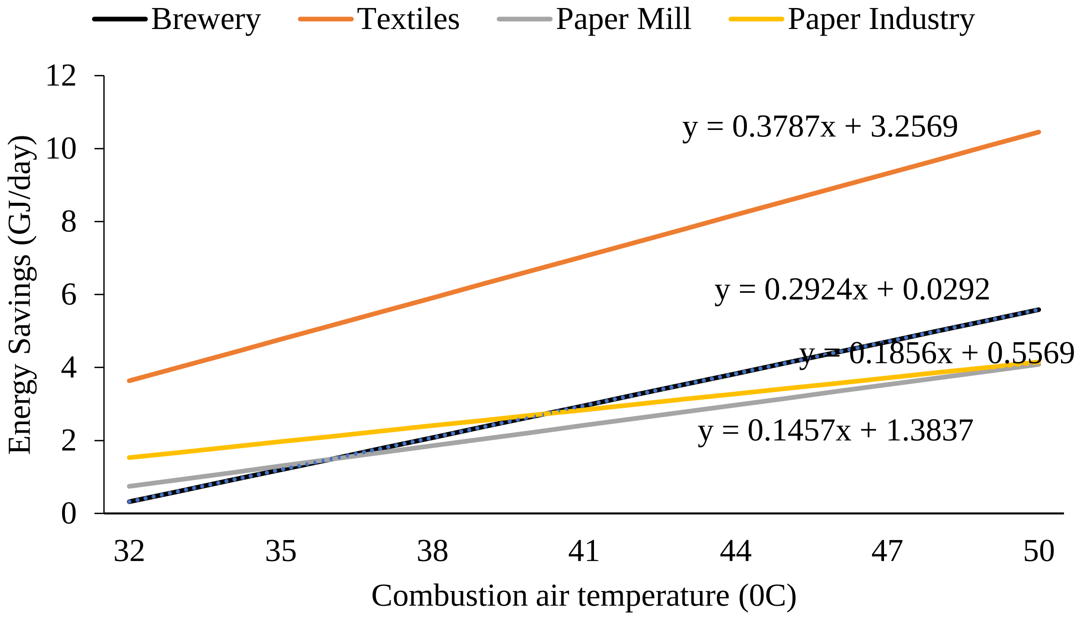

Figure 4.3 Energy savings by increasing combustion air temperature in rice husk-based boilers

The quantity of energy savings in a day grows linearly with the increase in combustion air temperature. With the increment of 1℃ of temperature of combustion air, the energy savings is estimated to be 378.7 MJ per day for the studied boiler of textile industry. Additionally, the energy savings for the studied boilers of brewery, paper mill and paper industry is estimated to be 292.4 MJ, 185.6 MJ and 145.7 MJ per day for 1℃ temperature increment of combustion air.

Table 4.9 shows the fuel mass and cost savings in a year for 10℃ increases in combustion air temperature. This can be achieved by installing air preheater in the boiler. It is estimated that the 3.54 tonne to 9.21 tonne of rice husk can be saved by opting to increase the combustion temperature by 10℃. Consequently, 0.37 million NPR to 0.81 million NPR can be saved.

Table 4.9 Annual fuel mass and cost savings by 10℃ increase in combustion air temperature

Parameters	Brewery	Textile	Paper Mill	Paper Industry
Energy saving per day (GJ)	2.92	3.79	1.46	1.86
Annual energy saving (GJ)	877.20	1,136.10	437.10	556.80
Calorific value	12,339.60	12,339.60	12,339.60	12,339.60

Parameters	Brewery	Textile	Paper Mill	Paper Industry
Biomass saving (kg)	7,108.82	9,206.94	3,542.25	4,512.30
Biomass saving (tonne)	7.11	9.21	3.54	4.51
Rate per tonne (NPR)	8,000.00	8,800.00	8,500.00	8,200.00
Annual fuel cost saving (NPR)	56,870.56	81,021.10	30,109.16	37,000.88

4.3.2 Fuelwood-based boiler

Fuelwood is used as a primary fuel for operating the boiler. The efficiency of the boiler is calculated by using both direct method and indirect method. Table 4.10 shows the calculation of efficiency of the boiler by direct method. The boiler's performance analysis using direct method is done by considering heat input and heat output resulting an efficiency of 64.48% and 60.51%.

Table 4.10 Efficiency Calculation of the uelwood-based boiler using direct method

Parameters	Dairy	Wood Product
Steam working pressure (bar)	9.50	4.58
Steam temperature (ºC)	163.00	183.00
Daily Fuel consumption (tonne)	0.33	1.45
Average working hours in a day (hrs)	8.00	12.00
Steam flow rate (kg/hr)	212.00	624.00
Feedwater temperature (ºC)	55.00	61.00
Calorific value of the fuel (kJ/kg)	20,420.00	20,420.00
Enthalpy of steam (kJ/kg)	2,792.27	2,648.00
Enthalpy of feedwater (kJ/kg)	230.23	255.35
Heat Output (GJ/hr)	0.54	1.49
Heat Input (GJ/hr)	0.84	2.47
Efficiency of Boiler (%)	64.48	60.51

Table 4.11 illustrates the calculation of the boiler’s efficiency by in-direct method. The inefficiency of the boiler is caused due to heat losses in flue gases (29.03% and 32.76%) by high exhaust temperatures and excessive air (452.63% and 556.25%), which carry away significant heat. Combustion of hydrogen and moisture in fuel causes additional latent heat losses (up to 3% and 1% respectively), while incomplete combustion (up to 0.14%) leads to unburnt carbon, reducing energy output. Radiation

and convection losses (3%) occur through the boiler's surface. Thus, the efficiency of the fuelwood- based boilers of dairy and wood product industry have been calculated as 63.39% and 59.57% respectively using in-direct method.

Table 4.11 Efficiency Calculation of the fuelwood-based boiler using in-direct method

Parameter	Dairy	Wood Product
Theoretical air for combustion		
Carbon percentage (%)	45.60	45.60
Hydrogen percentage (%)	3.96	3.96
Oxygen percentage (%)	37.45	37.45
Sulphur percentage (%)	0.07	0.07
Theoretical air required (kg/kg)	5.04	5.04
Excess air supplied		
Oxygen percentage (%)	17.20	17.80
Excess air supplied (%)	452.63	556.25
Actual mass of air supplied (kg/kg)	27.86	33.09
Heat loss due to dry flue gas		
Temperature of flue gas (℃)	218.70	207.70
Ambient air temperature (℃)	25.30	23.90
Specific heat capacity of flue gas (kJ/kg·℃)	1.10	1.10
Gross calorific value (kJ/kg)	20,420.00	20,420.00
Heat loss due to dry flue gas (%)	29.03	32.76
Heat loss due to hydrogen in fuel		
kg of hydrogen on 1kg basis (kg/kg)	0.06	0.06
Specific heat capacity of superheated steam (kJ/kg·℃)	2.10	2.10
Latent heat (kJ/kg)	584.00	584.00
Heat loss due to hydrogen in fuel (%)	2.62	2.57
Heat loss due moisture present in fuel		
kg of moisture in fuel on 1 kg basis (kg/kg)	0.15	0.15
Heat loss due to moisture present in fuel (%)	0.73	0.71

Parameter	Dairy	Wood Product
Heat loss due to moisture present in air		
Humidity factor (kg/kg)	0.02	0.02
Heat loss due to moisture present in air (%)	1.11	1.25
Heat loss due to incomplete combustion		
Volume of CO in flue gas (ppm)	231.00	302.00
Volume of CO_2 percent in flue gas (%)	2.30	2.65
Carbon content per kg of fuel (kg/kg)	0.45	0.45
Heat loss due to partial combustion (kJ/kg)	5,744.00	5,744.00
Heat loss due to incomplete combustion (%)	0.13	0.14
Unaccounted losses		
Radiation, convection and Miscellaneous (%)	3.00	3.00
Efficiency (%)	63.39	59.57

Emission Estimation

The pollutants emitted from the boiler on daily basis is presented in Table 4.12.

Table 4.12 Daily emission estimation for boiler of dairy industry

Pollutants	Dairy	Wood Product
PM	1.07	4.71
SO_2	0.002	0.010
CO_2	426.36	1,873.40
CO	19.41	85.29
NOx	0.34	1.48
NH_3	0.36	1.59
CH_4	1.42	6.24
NMVOC	2.10	9.24
BC	0.24	1.05
OC	1.33	5.85

Scenario Development for energy efficiency opportunities in boiler:

Scenario 1: Increasing the feedwater temperature

The feedwater is supplied at a temperature of 55℃ and 61℃ to the boiler. The feedwater can be pre-heated using the excess heat of the flue gas before supplying to the boiler, which shall save energy of the boiler. Figure 4.4 illustrates the quantity of energy savings which can be saved by increasing the feedwater temperature. The detail procedure for the calculation of energy savings by increasing feedwater temperature is demonstrated in Annex 13 and Annex 16.

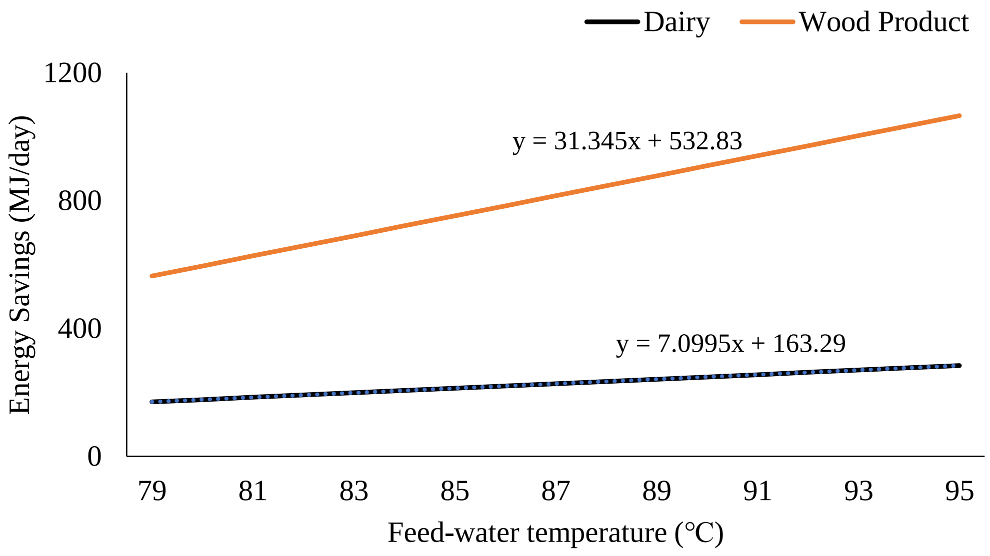

Figure 4.4 Energy savings by increasing feedwater temperature in the boiler of dairy industry

The quantity of energy savings in a day grows linearly with the increase in feedwater temperature. With the increment of 1℃ of temperature of feedwater, the energy saving ranges from 7 MJ to 31 MJ per day.

Table 4.13 shows the fuel mass and cost saving in a year in the studied fuelwood-based boilers for 10℃ rise in feedwater temperature. The annual fuelwood saving has been estimated to be 1.04 tonne to 4.60 tonne, which corresponds to NPR 11,993.90 to NPR 57,093.44.

Table 4.13 Annual fuel mass and cost saving in fuel-wood based boilers for 10℃ rise in feedwater temperature

Parameters	Dairy	Wood product
Energy saving per day (MJ)	70.99	313.4
Annual energy saving (MJ)	21,297	94,020

Parameters	Dairy	Wood product
Calorific value (kJ/kg)	20,420.00	20,420.00
Biomass saving (kg)	1,042.95	4,604.31
Biomass saving (tonne)	1.04	4.60
Rate per tonne (NPR)	11,500	12,400
Annual fuel cost saving (NPR)	11,993.90	57,093.44

Scenario 2: Decrease in oxygen level in the flue gas

The high concentration of oxygen in the flue gas suggests the higher quantity of heat loss due to flue gas. Figure 4.5 shows the quantity of energy savings that can be achieved at various oxygen level in the flue gas. The detail procedure for the calculation of energy savings by decreasing the oxygen level in the flue gas is demonstrated in Annex 14 and Annex 17.

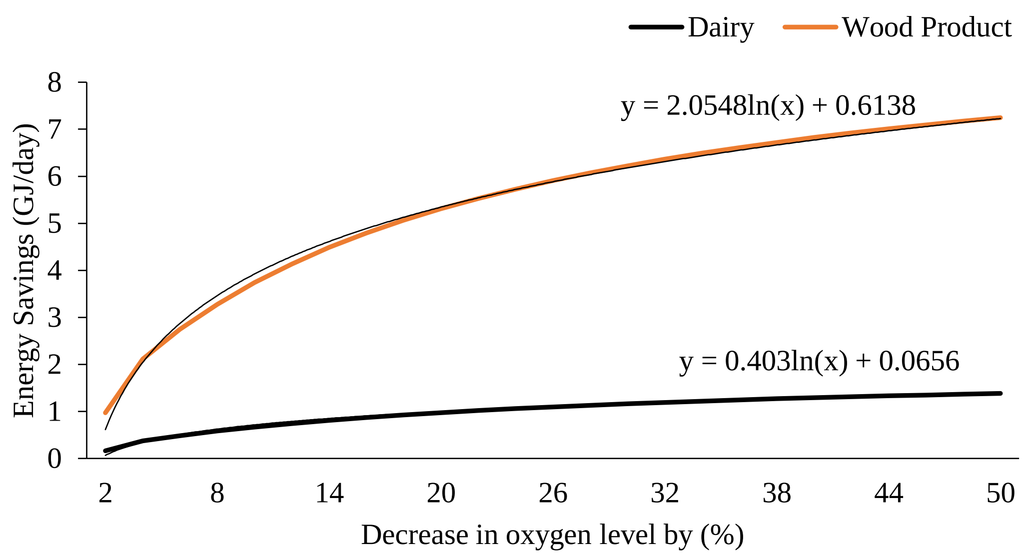

Figure 4.5 Energy savings by decreasing the oxygen level in the boiler of door and wood products industry

The quantity of energy savings per day grows logarithmically with the decrease in oxygen level in the flue gas. For the studied fuelwood-based boilers, 0.97 GJ to 5.31 GJ of energy can be saved in a day with the reduction of 20% of oxygen in the flue gas from the present value. Thus, it is recommended to install the oxygen trimming technology in the studied textile industry.

Table 4.14 shows the annual fuel mass and cost savings in the studied fuel-wood-based boilers due to decrease in oxygen level in the flue gas by 20% of the present value. The annual fuelwood savings has been estimated to be 1556.34 kg and 7798.53 kg. The corresponding monetary savings is estimated to be NPR 17,897.86 and NPR 96,701.76.

Table 4.14 Annual fuel mass and cost saving in fuel-wood based boilers for 20% decrease in oxygen level

Parameters	Dairy	Wood Product
Energy saving per day (GJ)	1.06	5.31
Annual energy saving (GJ)	317.80	1,592.46
Calorific value (kJ/kg)	20,420.00	20,420.00
Biomass saving (kg)	1,556.34	7,798.53
Biomass saving (tonne)	1.56	7.80
Rate per tonne (NPR)	11,500.00	12,400.00
Annual fuel cost saving (NPR)	17,897.86	96,701.76

Scenario 3: Increase the combustion air temperature by preheater

The combustion air can be preheated by the use of heat lost in flue gas, which consequently assists in enhancing the energy efficiency of the boiler. Figure 4.6 shows the quantity of energy savings that can be achieved at various elevated combustion air temperature. The detail procedure for the calculation of energy savings by increasing the combustion air temperature is demonstrated in Annex 15 and Annex 18.

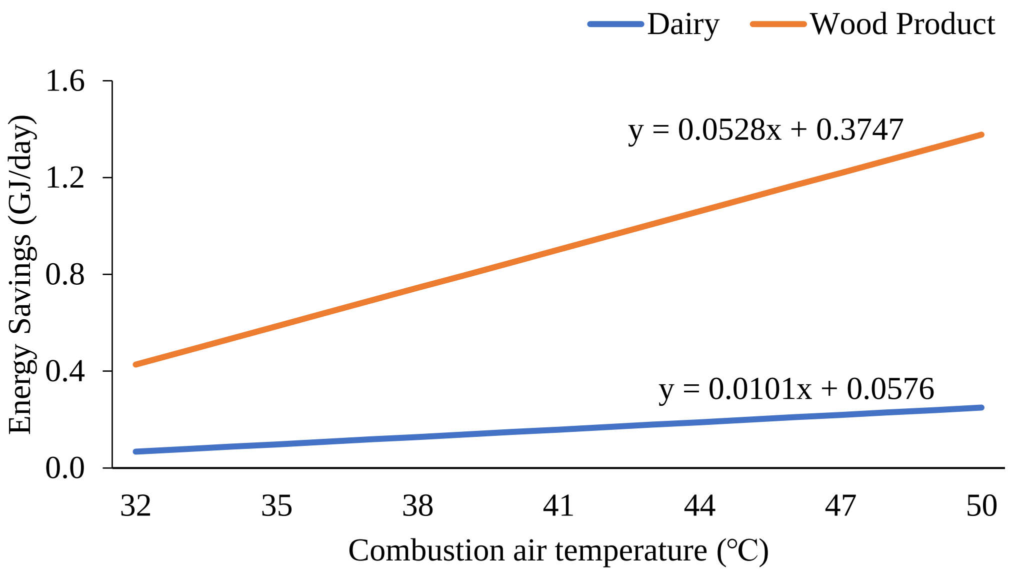

Figure 4.6 Energy savings by increasing combustion air temperature in the boiler of door and wood products industry

The quantity of energy savings in a day grows linearly with the increase in combustion air temperature. With the increment of 1°C of temperature of combustion air, the potential energy saving is estimated to be 10.1 MJ and 52.8 MJ per day.

Table 4.15 shows the annual fuel mass and cost savings in the studied fuel-wood-based boilers due to increase in the combustion air temperature by 10°C. The annual rice husk savings has been estimated to be 148.38 kg and 775.71 kg. The corresponding monetary savings is estimated to be NPR 1,706.42 and NPR 9,618.81, which is negligible in amount. Thus, this option is not recommended for the studied fuelwood-based boiler.

Table 4.15 Annual fuel mass and cost saving in fuel-wood based boilers for 10°C rise in combustion air temperature

Parameters	Dairy	Wood Product
Energy saving per day (GJ)	0.10	0.53
Annual energy saving (GJ)	30.30	158.40
Calorific value (kJ/kg)	20,420.00	20,420.00
Biomass saving (kg)	148.38	775.71
Biomass saving (tonne)	0.15	0.78
Rate per tonne (NPR)	11,500.00	12,400.00

Parameters	Dairy	Wood Product
Annual fuel cost saving (NPR)	1,706.42	9,618.81

4.4 Flue gas characteristics

Excess oxygen in flue gas and elevated temperatures indicate inefficient combustion, leading to energy losses. Excess oxygen in flue gas and high temperatures point to inefficient combustion, which results in energy losses. Figure 4.7 shows the oxygen level in flue gas of the studied industries. The Brewery and Textiles sectors recorded the highest levels of excess oxygen, at 19.40 percent and 18.50 percent, respectively, indicating an overabundance of air supply. All the studied boilers have oxygen level more than 17%, which indicates the excess air supplied to the boiler. This results in the higher heat loss by the dry flue gas.

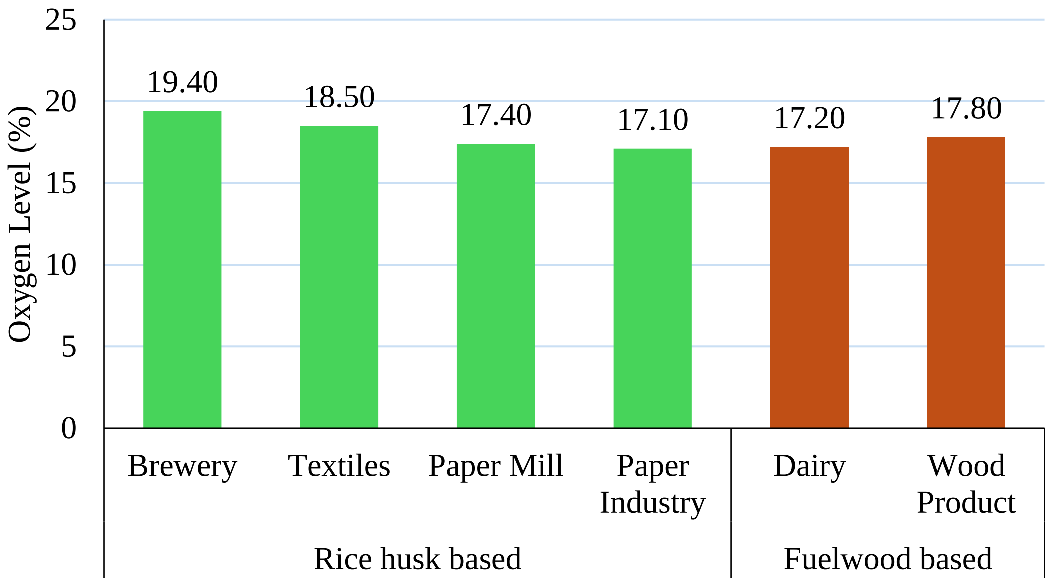

Figure 4.7 Oxygen level in flue gas

Figure 4.8 shows the comparison of CO level in the flue gas. The boiler of brewery industry recorded the highest level of CO in the flue gas i.e. 947 ppm. All the industries recorded CO level above 200 ppm, which indicates the incomplete combustion.

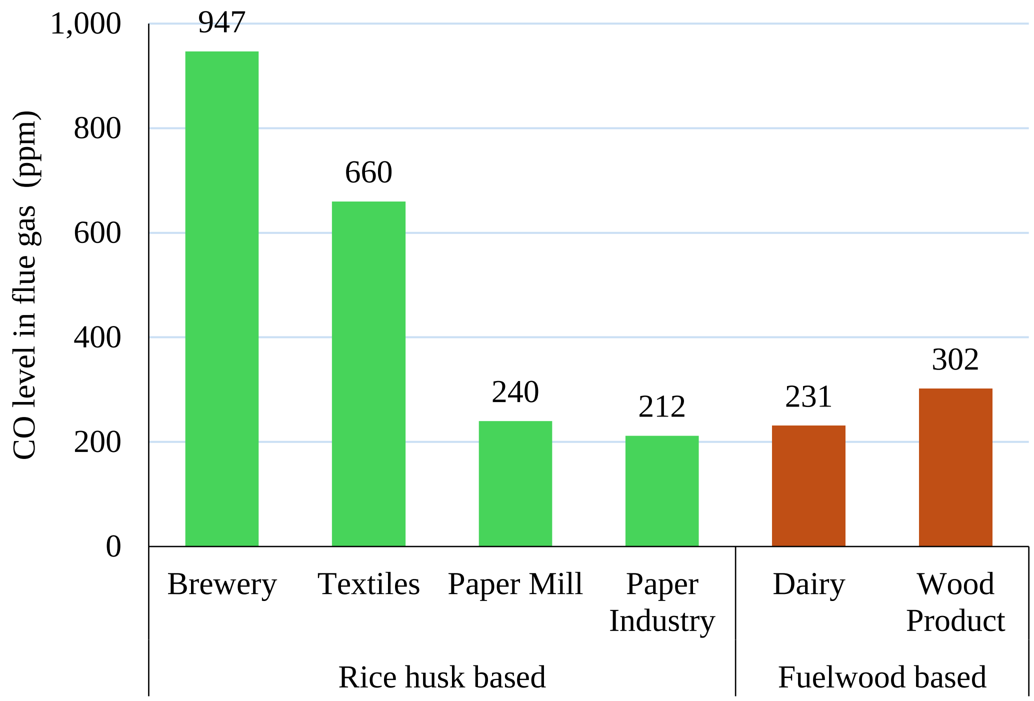

Figure 4.8 Comparison of CO level in flue gas

Figure 4.9 shows the comparison of temperature of flue gases emitted from the boilers. The boiler of paper industry recorded the highest temperature flue gas emission i.e. 224℃.

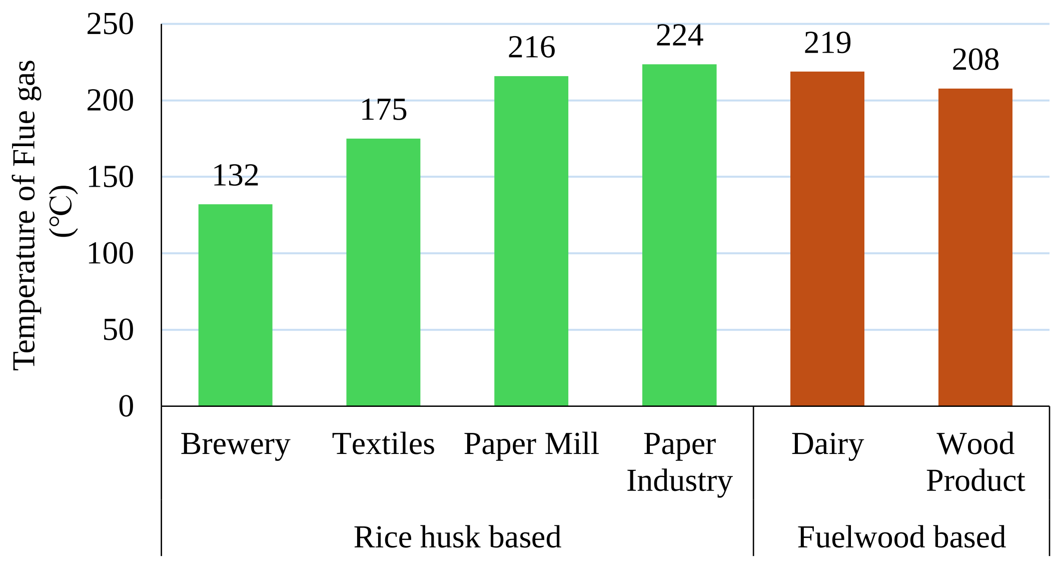

Figure 4.9 Comparison of temperature of flue gases

4.5 Heat losses in the boilers

Figure 4.10 depicts the share of individual heat losses (L1, L2, L3, L4, L5, L6) in total heat loss. It is observed that 82% of the total loss arises from heat loss due to dry flue gas. The main reason for this is the higher level of oxygen present in the flue gas.

Thus, it can be concluded that restricting the level of oxygen in the flue gas ensures the increment of efficiency. This can be achieved by installing the oxygen trimming technology and regulating the air flow to the boiler. The other major heat losses are radiation, convection and surface heat loss, which accounts for 6% and heat loss due to hydrogen in the fuel, which accounts for 6.26% of the total heat loss.

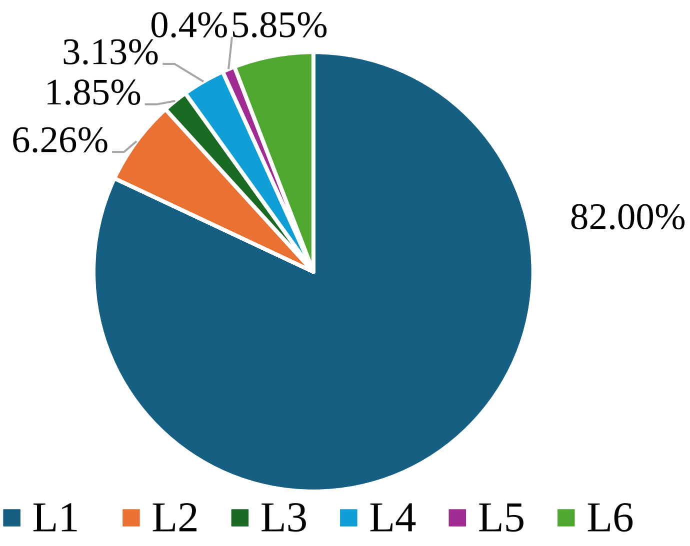

Figure 4.10 Share of individual heat loss in total heat loss

L1: Heat loss due to dry flue gas (%)

L2: Heat loss due to hydrogen in fuel (%)

L3: Heat loss due to moisture present in fuel (%)

L4: Heat loss due to moisture present in air (%)

L5: Heat loss due to incomplete combustion (%)

L6: Radiation, convection and Miscellaneous Losses (%)

4.6 Boiler efficiency analysis

The boiler efficiencies calculated by direct and in-direct method differ by 0.47% to 3.16%. This shows the accuracy of the data taken for direct and in-direct methods (difference less than 5%). Figure 4.11 shows the comparison of the efficiencies determined by direct and in-direct methods for rice husk-based boilers. The efficiency of rice husk-based boilers ranges from 31% to 46%, with brewery industry being the least efficient and paper industry being the most efficient among the four rice husk-based boilers. Figure 4.12 shows the comparison of the efficiencies determined by direct and in-direct methods for fuelwood-based boilers. The efficiency of fuelwood-based boilers ranges from 60% to 64%, with wood product industry being the lesser efficient and dairy industry having higher efficient boiler among the two. It is observed that the losses in the boilers are more than 35%, which indicates the energy saving opportunities in the boiler's operation. Additionally, the fuelwood boilers are more efficient than rice husk-based boilers.

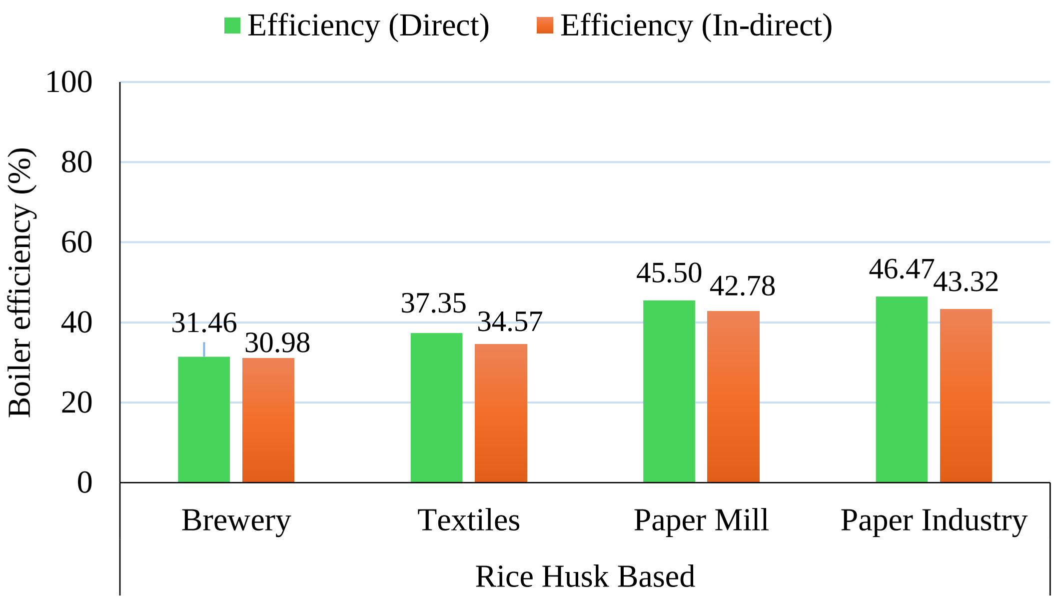

Figure 4.11 Direct and Indirect Efficiency of the rice husk-based boilers

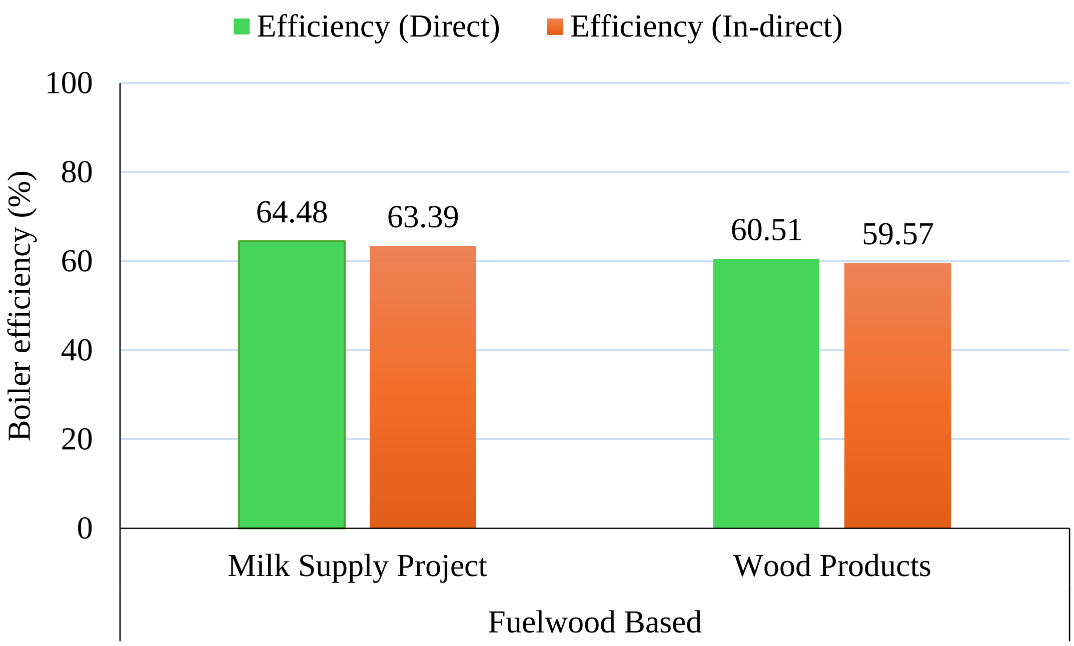

Figure 4.12 Direct and Indirect Efficiency of the fuelwood-based boilers

The literature on the boiler efficiency measurement reveals that the biomass based boilers are found to be operated with efficiency 56.08% (Ashfaq & Ghafoor, 2014), 68% (J. Yadav & Singh, 2011) and 68.34% (Awan et al., 2019). The calculated efficiencies of the boilers in this study are in the range of 30% to 65%. This shows the efficiency enhancement techniques can be applied to the boilers so that it can be operated at higher efficiency (up to 68%). The potential efficiency increment shall be brought by the energy saving scenarios estimated in the Scenario analysis section.

4.7 Scenario analysis

Three energy saving scenarios have been developed and magnitude of energy savings has been estimated for rice husk-based and fuelwood-based boilers.

4.7.1 Comparison of increase in feedwater temperature scenario

The individual scenario analysis of all the six industries is merged in common temperature range i.e. from 79℃ to 95℃. Figure 4.13 depicts the estimated energy savings in MJ per day by increasing the feedwater temperature in the selected temperature range.

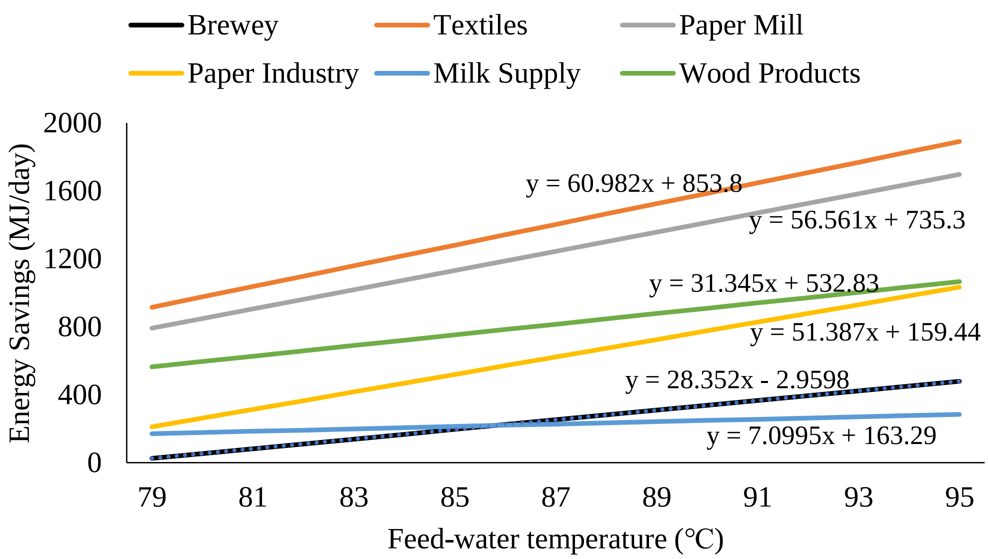

Figure 4.13 Comparison of increase in feedwater temperature scenario

The boiler of textile industry (rice husk-based) shows the highest capability of energy savings for the common temperature range of 79℃ to 95℃. For every degree Celsius increase in temperature, 60.98 MJ of energy can be saved by the boiler of textile industry. The energy saving potential of other rice husk-based boilers is estimated to be 56.56 MJ, 51.38 MJ and 28.35MJ for each degree Celsius increase in feedwater temperature. Furthermore, the boilers of fuelwood-based boilers have showed lesser energy saving potential, saving 31.34 MJ and 7.09 MJ energy for each degree rise in feedwater temperature.

4.7.2 Comparison of decrease in oxygen level

Higher oxygen level in the flue gas is the main reason for the heat loss in operational boiler. This is proved by the efficiency calculation of individual boilers. The decrease in oxygen level scenario of the six studied boilers are compared and analyzed in same reference. Energy savings by the decrease in oxygen level up to 50% is estimated and plotted, which is shown in Figure 4.14.

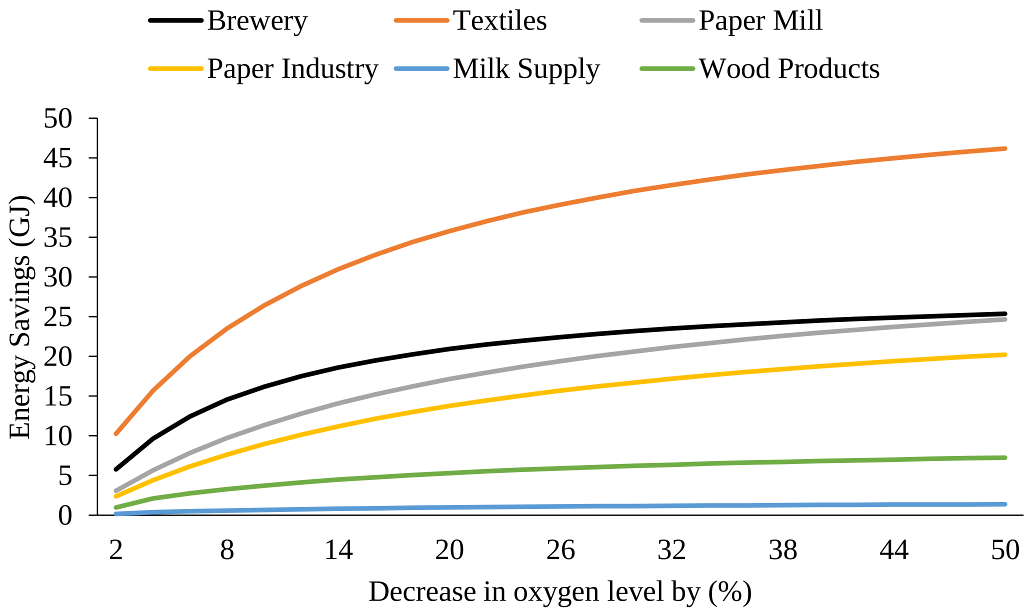

Figure 4.14 Comparison of decrease in oxygen level scenario

The boiler of textile industry (rice husk-based) posses highest capacity of energy savings by decrease of oxygen level up to 50% of the current value. Energy savings of 35.79 GJ corresponds to 20% decrease in oxygen level i.e. 14.8% O_2 level in flue gas. The installation of oxygen trim technology shall result in energy savings of 20.93 GJ, 16.22GJ and 12.98 GJ in rice husk-based boilers for 20% decrease in oxygen level. Furthermore, the installation of oxygen trim technology for reduction of oxygen level by 20% shall result in energy savings of 5.31 GJ and 0.97 GJ for fuelwood-based boilers.

4.7.3 Comparison of increase in combustion air using air pre-heater

The incoming combustion air is preheated for better fuel-air mixing in the combustion chamber of the boiler which results in complete combustion. Thus, scenario has been developed to estimate the energy savings by increasing the temperature of combustion air. The results of individual scenarios are analyzed in common elevated temperature range in Figure 4.15.

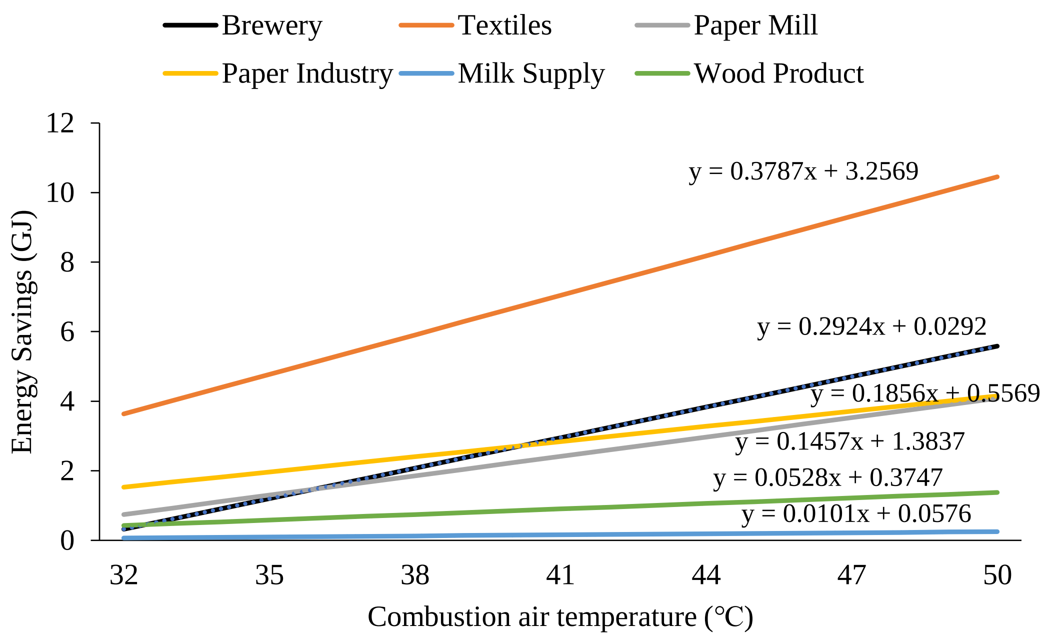

Figure 4.15 Comparison of increase in temperature of combustion air scenario

There is possibility of energy savings up to 10.45 GJ if the combustion air is preheated up to 50°C in the boiler of textile industry (rice husk-based). The rate of energy saving is estimated to be 0.38 GJ for every degree rise in temperature of combustion air of the boiler of textile industry. Similarly, the quantity of energy savings for other rice husk-based boilers are 5.58 GJ, 4.08 GJ and 4.15 GJ at 50°C combustion air temperature. Furthermore, the quantity of energy savings for fuelwood-based boilers are 0.25 GJ and 1.38 GJ at 50°C combustion air temperature.

4.8 Emission analysis

The emission of various pollutants from a rice husk-based boiler and fuelwood-based boilers are estimated using Table 3.3. Consumption of rice husk and fuelwood details are taken form the record book maintained by the industries. Total emission is calculated by multiplying the emission constant with the daily consumption of biomass. Table 4.16 shows the reduction in emission due to fuel and energy savings in the elevated feedwater temperature scenario in the studied rice husk-based boiler. 0.54% of emission is reduced due to the increment in temperature of feedwater at every 10℃.

Table 4.16 Emission estimation for increase in feedwater temperature in the rice husk-based boiler

Emission (kg/day)	Observed Case	Feedwater temperature (℃)			
		80	85	90	95
PM	22.42	22.40	22.34	22.27	22.21
SO_2	0.64	0.64	0.64	0.64	0.64
CO_2	5,976.18	5,969.98	5,953.64	5,937.29	5,920.94
CO	242.69	242.44	241.77	241.11	240.45
NO_x	12.25	12.23	12.20	12.17	12.13
NH_3	14.64	14.62	14.58	14.54	14.50
CH_4	34.27	34.24	34.14	34.05	33.96
NMVOC	24.99	24.96	24.90	24.83	24.76
BC	1.75	1.75	1.74	1.74	1.73
OC	7.18	7.17	7.15	7.13	7.11

Similarly, Table 4.17 shows the reduction in emission due to fuel and energy savings in the elevated feedwater temperature scenario in the studied fuelwood-based boiler. It is estimated that 1.06% of emission is reduced due to the increment in temperature of feedwater at every 10℃.

Table 4.17 Emission estimation for increase in feedwater temperature in the fuelwood-based boiler

Emission (kg/day)	Observed Case	Feedwater temperature (℃) at			
		65	70	75	80
PM	4.71	4.69	4.66	4.64	4.61
SO_2	0.01	0.01	0.01	0.01	0.01
CO_2	1,873.40	1,865.47	1,855.55	1,845.64	1,835.72
CO	85.29	84.93	84.48	84.03	83.57
NO_x	1.48	1.47	1.46	1.46	1.45

Emission (kg/day)	Observed Case	Feedwater temperature (°C) at			
		65	70	75	80
NH_3	1.59	1.58	1.57	1.57	1.56
CH_4	6.24	6.21	6.18	6.14	6.11
NMVOC	9.24	9.20	9.16	9.11	9.06
BC	1.05	1.04	1.04	1.03	1.03
OC	5.85	5.83	5.80	5.77	5.74

Table 4.18 shows the reduction in emission due to fuel and energy savings in the decrease in oxygen level scenario in the studied rice husk-based boiler. It has been estimated that 13.25 % of the daily emission can be reduced at every 2% decrement of oxygen level in the flue gas.

Table 4.18 Emission estimation for decrease in oxygen level in rice husk-based boiler

Pollutant emission (kg/day)	Observed Case (19.4%)	Oxygen level (%)			
		17.4	15.4	13.4	11.4
PM	22.42	15.32	13.29	12.32	11.76
SO_2	0.64	0.44	0.38	0.35	0.34
CO_2	5,976.18	4,082.51	3,541.46	3,285.17	3,135.67
CO	242.69	165.79	143.82	133.41	127.34
NO_x	12.25	8.36	7.26	6.73	6.42
NH_3	14.64	10.00	8.67	8.05	7.68
CH_4	34.27	23.41	20.31	18.84	17.98
NMVOC	24.99	17.07	14.81	13.74	13.11
BC	1.75	1.19	1.04	0.96	0.92
OC	7.18	4.90	4.25	3.94	3.77

Table 4.19 shows the reduction in emission due to fuel and energy savings in the decrease in oxygen level scenario in the studied fuelwood-based boiler. It has been estimated that 6.19 % of the daily emission can be reduced at every 2% decrement of oxygen level in the flue gas.

Table 4.19 Emission estimation for decrease in oxygen level in fuelwood-based boiler

Pollutant emission	Observed Case	Oxygen level (%)

(kg/day)	(17.8%)	15.8	13.8	11.8	9.8
PM	4.71	4.07	3.82	3.68	3.59
SO_2	0.01	0.01	0.01	0.01	0.01
CO_2	1,873.40	1,620.90	1,520.56	1,463.85	1,427.40
CO	85.29	73.79	69.23	66.64	64.98
NO_x	1.48	1.28	1.20	1.16	1.13
NH_3	1.59	1.38	1.29	1.24	1.21
CH_4	6.24	5.40	5.06	4.87	4.75
NMVOC	9.24	8.00	7.50	7.22	7.04
BC	1.05	0.91	0.85	0.82	0.80
OC	5.85	5.07	4.75	4.57	4.46

Table 4.20 shows the reduction in emission due to fuel and energy savings in the in the increase in combustion air scenario in the studied rice husk-based boiler. It has been estimated that 5.95% of the daily emission can be reduced at every 10°C increases in temperature of combustion air supplied to the boiler.

Table 4.20 Emission estimation for increase in combustion air temperature in rice husk-based boiler

Pollutant emission (kg/day)	Observed Case	Combustion air temperature (°C)			
		40	50	60	70
PM	22.42	21.27	20.00	18.74	17.47
SO_2	0.64	0.61	0.57	0.54	0.50
CO_2	5,976.18	5,669.37	5,332.22	4,995.07	4,657.91
CO	242.69	230.23	216.54	202.85	189.15
NO_x	12.25	11.62	10.93	10.23	9.54
NH_3	14.64	13.89	13.06	12.23	11.41
CH_4	34.27	32.51	30.58	28.65	26.71
NMVOC	24.99	23.71	22.30	20.89	19.48
BC	1.75	1.66	1.56	1.46	1.36
OC	7.18	6.81	6.40	6.00	5.59

Table 4.21 shows the reduction in emission due to fuel and energy savings in the in the increase in combustion air scenario in the studied fuelwood-based boiler. It has

been estimated that 1.8% of the daily emission can be reduced at every 10℃ increase in temperature of combustion air supplied to the boiler.

Table 4.21 Emission estimation for increase in combustion air temperature in fuelwood-based boiler

Pollutant emission (kg/day)	Observed Case	Combustion air temperature (℃)			
		30	40	50	60
PM	4.71	4.66	4.57	4.49	4.41
SO_2	0.01	0.01	0.01	0.01	0.01
CO_2	1,873.40	1,853.03	1,819.64	1,786.25	1,752.86
CO	85.29	84.36	82.84	81.32	79.80
NO_x	1.48	1.46	1.44	1.41	1.38
NH_3	1.59	1.57	1.54	1.52	1.49
CH_4	6.24	6.17	6.06	5.95	5.84
NMVOC	9.24	9.14	8.98	8.81	8.65
BC	1.05	1.04	1.02	1.00	0.98
OC	5.85	5.79	5.69	5.58	5.48

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions have been drawn from the study:

i. Heat loss by different means is estimated for efficiency calculation. 82% of the total loss arises due to heat escaped by the dry flue gas itself. The higher oxygen level (17.1% to 19.4%) in the flue gas has been proven to be the major reason for heat loss due to flue gas, thus signifying the need to trim down oxygen level in flue gas. Other significant losses are found to be heat loss due to hydrogen in the fuel, radiation, convection and miscellaneous losses and heat loss due to moisture present in air which accounts to 6.26%, 5.85% and 3.13% of the total losses respectively.

ii. The boilers are found to be operated at efficiency from 30% to 64%. The fuelwood-based boilers are found to be operated more efficiently than rice husk-based boilers. The efficiency of rice husk-based boilers lies on the range of 30% to 46% and the efficiency of fuelwood-based boilers lie on the range of 60% to 64%.

iii. Three energy saving scenarios have been developed and analyzed. In all three scenarios, the rice husk-based boilers show higher energy savings potential than the fuelwood-based boilers. In increase in feedwater temperature scenario, the potential savings for rice husk-based boiler lie on the range of 28.35 MJ to 60.98 MJ and for fuelwood-based boiler lie on the range of 7.09 MJ to 31.34 MJ for 1℃ rise in temperature. In decrease in oxygen level scenario, the potential savings for rice husk-based boiler lie on the range of 13.75 GJ to 20.27 GJ and for fuelwood-based boiler lie on the range of 0.97 GJ to 5.31 GJ for 20% oxygen level reduction. In increase in combustion air temperature scenario, the potential savings for rice husk-based boiler lie on the range of 4.08 GJ to 10.45 GJ and for fuelwood-based boiler lie on the range of 0.25 GJ to 1.38 GJ at 50℃. Thus, there is huge magnitude of potential energy savings in the operational industrial boilers.

iv. Emissions from rice husk-based boilers are estimated to be higher in magnitude than firwood-based boiler, as their consumption is in higher side. The estimated emission from rice husk-based boilers on daily basis is: 22.42

kg to 45.37 kg of PM, 5976 kg to 12094 kg of CO_2, 242 kg to 491 kg of CO and 12 kg to 24 kg of NO_x. Similarly, the estimated emission from fuelwood-based boilers on daily basis is: 1.07 kg to 4.71 kg of PM, 426 kg to 1873 kg of CO_2, 19 kg to 85 kg of CO and 0.34 kg to 1.48 kg of NO_x. Furthermore, the increase in feedwater temperature by 10℃ shall reduce the emission by 0.54% in rice husk-based boiler and 1.06% in fuelwood-based boiler. A 2% decrease in oxygen level in the flue gas shall reduce the emission by 13.25% in rice husk-based boiler and 6.19% in fuelwood-based boiler. Similarly, 10℃ increase in combustion air temperature shall reduce the emission by 5.95% in rice husk-based boiler and 1.8% in fuelwood-based boiler.

5.2 Recommendations

Following recommendations are made from the study:

i. Efficiency enhancing technologies like oxygen trim system and automatic air fuel ratio controllers shall be installed in the biomass based industrial boilers of Nepal. Environmental study and economic analysis can be incorporated to estimate the positive impact of energy saving technology.

ii. Detailed study shall be carried out in the boiler with seasonal variations and load fluctuations.

REFERENCE

Ashfaq, S., & Ghafoor, D. A. (2014). Performance evaluation of a biomass boiler on the basis of heat loss method and total heat values of steam. *Pakistan Journal of Agricultural Research, 51(1)*, 209–215.

Awan, M. B., Iqbal, T., Yaseen, S., Nawaz, S., & Ali, C. H. (2019). Techno-economic sustainability analysis of biomass fired industrial boiler: Biomass evolution as heat and power generation source. *IET Renewable Power Generation*, *13*(4), 650–658. https://doi.org/10.1049/iet-rpg.2018.5934

Awulu, J. O., Omale, P. A., & Ameh, J. A. (2018). Comparative analysis of calorific values of selected agricultural wastes. *Nigerian Journal of Technology*, *37*(4), 1141. https://doi.org/10.4314/njt.v37i4.38

Bhatt, B. P., & Tomar, J. M. S. (2002). Firewood properties of some Indian mountain tree and shrub species. *Biomass and Bioenergy*, *23*(4), 257–260. https://doi.org/10.1016/S0961-9534(02)00057-0

Bhattarai, N., & Bajracharya, I. (2016). Industrial Sector’s Energy Demand Projections and Analysis of Nepal for Sustainable National Energy Planning Process of the Country. *Journal of the Institute of Engineering*, *11*(1), 50–66. https://doi.org/10.3126/jie.v11i1.14695

Broughton, J. (2003). Boiler system refurbishment. *International Sugar Journal*, *105*, 466–474.

Castro Oliveira, M., Iten, M., Cruz, P. L., & Monteiro, H. (2020). Review on Energy Efficiency Progresses, Technologies and Strategies in the Ceramic Sector

Focusing on Waste Heat Recovery. *Energies*, *13*(22), 6096. https://doi.org/10.3390/en13226096

Davis F, Okwabi R, & Oman E. K. (2022). A REVIEW OF THE SIGNIFICANCE OF FEEDWATER TEMPERATURE ON THE HEALTH OF A STEAM BOILER. *ARPN Journal of Engineering and Applied Sciences*, *17*.

Ghimire, A., Pandey, B., Ghimire, R., & Thapa, B. S. (2023). Review of Industrial Heating and Potential Low-carbon Fuels in the Context of Nepal. *Journal of Physics: Conference Series*, *2629*(1), 012029. https://doi.org/10.1088/1742-6596/2629/1/012029

IEA. (2021). *Global Energy Review*.

IEA. (2024). *World Energy Outlook 2024*. IEA.

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. A. (2018). Waste heat recovery technologies and applications. *Thermal Science and Engineering Progress*, *6*, 268–289. https://doi.org/10.1016/j.tsep.2018.04.017

Khan, M. A. H., Khan, N., & Rone. (2022). Barriers and Drivers to Energy Efficiency Implementation in Industries of Rupandehi, Nepal. *Global Sci-Tech*, *14*(1), 13–25. https://doi.org/10.5958/2455-7110.2022.00002.7

Kirsanovs, V., Blumbergs, I., & Blumberga, D. (n.d.). *Experimental study on optimisation of the burning process in a small scale pellet boiler due to air supply improvement*.

Koppejan, J., & Van Loo, S. (2012). *The Handbook of Biomass Combustion and Co-firing*. Taylor & Francis Group. https://books.google.com.np/books?id=KE565zmFumQC

Oirere, S. B., Mutai, E. B. K., Mutuli, D. A., Mbuge, D. O., & Owuor, J. J. (2018). *ASSESSMENT OF WASTE MANAGEMENT STRUCTURES FOR TEA FACTORIES IN KENYA: A CASE STUDY OF NYANSIONGO TEA FACTORY*.

Poudyal, R., Loskot, P., Nepal, R., Parajuli, R., & Khadka, S. K. (2019). Mitigating the current energy crisis in Nepal with renewable energy sources. *Renewable and Sustainable Energy Reviews*, *116*, 109388. https://doi.org/10.1016/j.rser.2019.109388

Rahman, S., Ahamed, J. U., & Masjuki, H. H. (2010). Energy, exergy and economic analysis of industrial boilers. *Energy Policy*, *38*, 2188–2197.

Ram M. Shrestha, Nguyen Thi Kim Oanh, Rajendra P. Shrestha, Maheswar Rupakheti, Salony Rajbhandari, Didin agustian Permadi, Thongchai Kanabkaew, & Mylvakanam Iyngararasan. (2013). *Atmospheric Brown Clouds (ABC) Emission Inventory Manual*. United Nations Environment Programme.

Rastegarpour, S., Mariotti, A., Ferrarini, L., & Aminyavari, M. (2023). Energy efficiency improvement for industrial boilers through a flue-gas condensing heat recovery system with nonlinear MPC approach. *Applied Thermal Engineering*, *229*, 120554. https://doi.org/10.1016/j.applthermaleng.2023.120554

Saidur, R., Abdelaziz, E. A., Demirbas, A., Hossain, M. S., & Mekhilef, S. (2011). A review on biomass as a fuel for boilers. *Renewable and Sustainable Energy Reviews*, *15*(5), 2262–2289. https://doi.org/10.1016/j.rser.2011.02.015

Siraj, Md. T., Debnath, B., Kumar, A., Bari, A. B. M. M., Samadhiya, A., & Payel, S. B. (2023). Evaluating barriers to sustainable boiler operation in the apparel manufacturing industry: Implications for mitigating operational hazards in the emerging economies. *PLOS ONE*, *18*(4), e0284423. https://doi.org/10.1371/journal.pone.0284423

Suntivarakorn, R., & Treedet, W. (2016). Improvement of Boiler's Efficiency Using Heat Recovery and Automatic Combustion Control System. *Energy Procedia*, *100*, 193–197. https://doi.org/10.1016/j.egypro.2016.10.164

Suntoro, D., Sinaga, P., Yudanto, R. C., & Faridha. (2022). Energy Efficiency and Energy Saving Potential Analysis of Biomass Boiler at the PT Greenfields Indonesia Milk Processing Plant. *IOP Conference Series: Earth and Environmental Science*, *1034*(1), 012012. https://doi.org/10.1088/1755-1315/1034/1/012012

Water and Energy Commission Secretariat. (2024). *Energy Synopsis Report*. www.wecs.gov.np

WECS. (2021). *Energy Audit in Industrial Sector*. WECS. https://wecs.gov.np/pages/reports-and-publications?lan=en&id=115

WECS. (2024). *Energy Synopsis Report, 2024*. WECS.

Yadav, J., & Singh, B. R. (2011). Study on Comparison of Boiler Efficiency Using Husk and Coal as Fuel in Rice Mill. *SAMRIDDHI : A Journal of Physical*

Sciences, Engineering and Technology, *2*(02), 01–15. https://doi.org/10.18090/samriddhi.v2i2.1600

Yadav, R. D., Jha, A. K., & Bhattarai, N. (2020). *Thermodynamics Analysis of Rice Husk Fired Furnace*.

ANNEXURES

Annex 1: Increasing the feed-water temperature in the boiler of brewery industry

Parameters	Observed case	Feedwater at various temperatures (°C)		
Steam working pressure (bar)	7.00	7.00	7.00	7.00
Steam temperature (°C)	182.20	182.20	182.20	182.20
Daily fuel consumption (tonne)	4.20	4.20	4.20	4.20
Working time in a day (hours)	13.00	13.00	13.00	13.00
Steam flow rate (kg/hr)	521.00	521.00	521.00	521.00
Feedwater temperature (°C)	78.20	79.00	80.00	81.00
Enthalpy of steam (kJ/kg)	2,734.00	2,734.00	2,734.00	2,734.00
Enthalpy of feedwater (kJ/kg)	326.95	330.69	334.88	339.07
Energy output (kJ/hr)	1,254,075.66	1,252,122.43	1,249,941.52	1,247,760.61
Daily energy Output (kJ)	16,302,983.52	16,277,591.54	16,249,239.76	16,220,887.98
Energy saving (MJ/day)		25.39	53.74	82.10

Annex 2: Decreasing the oxygen level in the boiler of brewery industry

Parameter	Observed Case	Decrease in oxygen level by		
		2%	4%	6%
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	19.40	19.01	18.62	18.24
Excess air supplied (%)	1,212.50	956.34	783.84	659.77
Mass of excess air supplied (kg/kg)	63.29	50.93	42.62	36.63
Temperature of flue gas (°C)	132.00	132.00	132.00	132.00
Feed-air temperature (°C)	30.90	30.90	30.90	30.90
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	7,038.09	5,664.46	4,739.46	4,074.15
Energy savings (kJ/kg of fuel)		1,373.63	2,298.64	2,963.94
Mass of fuel consumption (tonne/day)		4.20	4.20	4.20
Daily energy saving (kJ)		5,769,254.31	9,654,274.05	12,448,564.66
Daily energy saving (GJ)		5.77	9.65	12.45

Annex 3: Increasing the combustion air temperature in the boiler of brewery industry

Parameter	Observed Case	Feed-air temperature at various temperature (°C)		
		32	33	34
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	19.40	19.40	19.40	19.40
Excess air supplied (%)	1,212.50	1,212.50	1,212.50	1,212.50
Mass of excess air supplied (kg/kg)	63.29	63.29	63.29	63.29
Temperature of flue gas (°C)	132.00	132.00	132.00	132.00
Feed-air temperature (°C)	30.90	32.00	33.00	34.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	7,038.09	6,961.52	6,891.90	6,822.29
Energy savings (kJ/kg of fuel)		76.58	146.19	215.81
Mass of fuel consumption (tonne/day)		4.20	4.20	4.20
Daily energy saving (kJ)		321,622.09	614,005.80	906,389.52
Daily energy saving (GJ)		0.32	0.61	0.91

Annex 4: Increasing the feed-water temperature in the boiler of textile industry

Parameters	Observed Case	Feedwater temperature at (°C)		
		65	66	67
Steam working pressure (bar)	6.50	6.50	6.50	6.50
Steam temperature (°C)	260.00	260.00	260.00	260.00
Daily fuel consumption (tonne)	8.50	8.50	8.50	8.50
Working time in a day (hours)	12.00	12.00	12.00	12.00
Steam flow rate (kg/hr)	1,214.00	1,214.00	1,214.00	1,214.00
Feedwater temperature (°C)	64.00	65.00	66.00	67.00
Enthalpy of steam (kJ/kg)	2,957.00	2,957.00	2,957.00	2,957.00
Enthalpy of feedwater (kJ/kg)	267.90	272.09	276.28	280.46
Energy output (kJ/hr)	3,264,567.40	3,259,480.74	3,254,398.94	3,249,317.13
Daily energy Output (kJ)	39,174,808.80	39,113,768.88	39,052,787.23	38,991,805.58
Energy saving (MJ/day)		61.04	122.02	183.00

Annex 5: Decreasing the oxygen level in the flue gas in the boiler of textile industry

Parameter	Observed Case	Decrease in oxygen level by		
		2%	4%	6%
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	18.50	18.13	17.76	17.39
Excess air supplied (%)	740.00	631.71	548.15	481.72
Mass of excess air supplied (kg/kg)	40.50	35.28	31.25	28.05
Temperature of flue gas (°C)	175.00	175.00	175.00	175.00
Feed-air temperature (°C)	22.40	30.90	30.90	30.90
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	6,798.90	5,592.50	4,953.85	4,446.11
Energy savings (kJ/kg of fuel)		1,206.40	1,845.05	2,352.78
Mass of fuel consumption (tonne/day)		8.50	8.50	8.50
Daily energy saving (kJ)		10,254,369.94	15,682,891.89	19,998,642.02
Daily energy saving (GJ)		10.25	15.68	20.00

Annex 6: Increasing the combustion air temperature in the boiler of textile industry

Parameter	Observed Case	Feed-air temperature at various temperature (°C)		
		24	25	26
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	18.50	18.50	18.50	18.50
Excess air supplied (%)	740.00	740.00	740.00	740.00
Mass of excess air supplied (kg/kg)	40.50	40.50	40.50	40.50
Temperature of flue gas (°C)	175.00	175.00	175.00	175.00
Feed-air temperature (°C)	22.40	24.00	25.00	26.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	6,798.90	6,727.61	6,683.06	6,638.50
Energy savings (kJ/kg of fuel)		71.29	115.84	160.39
Mass of fuel consumption (tonne/day)		8.50	8.50	8.50
Daily energy saving (kJ)		605,930.45	984,636.97	1,363,343.50
Daily energy saving (GJ)		0.61	0.98	1.36

Annex 7: Increasing the feed-Water temperature in the boiler of Paper Mill

Parameters	Observed Case	Feedwater temperature at (°C)		
		66	67	68
Steam working pressure (bar)	4.58	4.58	4.58	4.58
Steam temperature (°C)	190.00	190.00	190.00	190.00
Daily fuel consumption (tonne)	6.00	6.00	6.00	6.00
Working time in a day (hours)	12.00	12.00	12.00	12.00
Steam flow rate (kg/hr)	1,126.00	1,126.00	1,126.00	1,126.00
Feedwater temperature (°C)	65.00	66.00	67.00	68.00
Enthalpy of steam (kJ/kg)	2,765.00	2,765.00	2,765.00	2,765.00
Enthalpy of feedwater (kJ/kg)	272.09	276.28	280.46	284.65
Energy output (kJ/hr)	2,807,016.66	2,802,303.22	2,797,589.79	2,792,876.35
Daily energy Output (kJ)	33,684,199.92	33,627,638.69	33,571,077.46	33,514,516.22
Energy saving (MJ/day)		56.56	113.12	169.68

Annex 8: Decreasing the oxygen level in the flue gas in the boiler of Paper Mill

Parameter	Observed Case	Decrease in oxygen level by		
		2%	4%	6%
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	17.40	17.05	16.70	16.36
Excess air supplied (%)	483.33	431.91	388.83	352.20
Mass of excess air supplied (kg/kg)	28.13	25.65	23.57	21.80
Temperature of flue gas (°C)	215.80	215.80	215.80	215.80
Feed-air temperature (°C)	28.00	28.00	28.00	28.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	5,810.55	5,298.37	4,869.17	4,504.30
Energy savings (kJ/kg of fuel)		512.18	941.37	1,306.25
Mass of fuel consumption (tonne/day)		6.00	6.00	6.00
Daily energy saving (kJ)		3,073,054.85	5,648,240.48	7,837,480.98
Daily energy saving (GJ)		3.07	5.65	7.84

Annex 9: Increasing the combustion air temperature in the boiler of Paper Mills

Parameter	Observed Case	Feed-air temperature at various temperature (°C)		
		29	30	31
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	17.40	17.40	17.40	17.40
Excess air supplied (%)	483.33	483.33	483.33	483.33
Mass of excess air supplied (kg/kg)	28.13	28.13	28.13	28.13
Temperature of flue gas (°C)	215.80	215.80	215.80	215.80
Feed-air temperature (°C)	28.00	29.00	30.00	31.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	5,810.55	5,779.61	5,748.67	5,717.73
Energy savings (kJ/kg of fuel)		30.94	61.88	92.82
Mass of fuel consumption (tonne/day)		6.00	6.00	6.00
Daily energy saving (kJ)		185,640.45	371,280.91	556,921.37
Daily energy saving (GJ)		0.19	0.37	0.56

Annex 10: Increasing the feed-Water temperature in the boiler of Paper Industry

Parameters	Observed Case	Feedwater temperature at (℃)		
		76	77	78
Steam working pressure (bar)	3.87	3.87	3.87	3.87
Steam temperature (℃)	178.00	178.00	178.00	178.00
Daily fuel consumption (tonne)	5.10	5.10	5.10	5.10
Working time in a day (hours)	18.00	18.00	18.00	18.00
Steam flow rate (kg/hr)	682.00	682.00	682.00	682.00
Feedwater temperature (℃)	75.00	76.00	77.00	78.00
Enthalpy of steam (kJ/kg)	2,696.00	2,696.00	2,696.00	2,696.00
Enthalpy of feedwater (kJ/kg)	313.52	318.14	322.32	326.51
Energy output (kJ/hr)	1,624,851.36	1,621,703.25	1,618,848.40	1,615,993.54
Daily energy Output (kJ)	29,247,324.48	29,190,658.46	29,139,271.13	29,087,883.79
Energy saving (MJ/day)		56.67	108.05	159.44

Annex 11: Decreasing the oxygen level in the flue gas in the boiler of Paper Industry

Parameters	Observed Case	Decrease in oxygen level by		
		2%	4%	6%
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	17.10	16.76	16.42	16.07
Excess air supplied (%)	438.46	395.05	358.12	326.31
Mass of excess air supplied (kg/kg)	25.96	23.87	22.09	20.56
Temperature of flue gas (°C)	223.60	223.60	223.60	223.60
Feed-air temperature (°C)	21.50	21.50	21.50	21.50
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	5,771.99	5,306.64	4,910.72	4,569.79
Energy savings (kJ/kg of fuel)		465.35	861.27	1,202.21
Mass of fuel consumption (tonne/day)		5.10	5.10	5.10
Daily energy saving (kJ)		2,373,292.13	4,392,454.28	6,131,245.56
Daily energy saving (GJ)		2.37	4.39	6.13

Annex 12: Increasing the combustion air temperature in the boiler of Paper Industry

Parameter	Observed Case	Feed-air temperature at various temperature (°C)		
		29	30	31
Theoretical air required (kg/kg)	4.82	4.82	4.82	4.82
Oxygen percentage (%)	17.10	17.10	17.10	17.10
Excess air supplied (%)	438.46	438.46	438.46	438.46
Mass of excess air supplied (kg/kg)	25.96	25.96	25.96	25.96
Temperature of flue gas (°C)	223.60	223.60	223.60	223.60
Feed-air temperature (°C)	21.50	23.00	24.00	25.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	5,771.99	5,729.15	5,700.59	5,672.03
Energy savings (kJ/kg of fuel)		42.84	71.40	99.96
Mass of fuel consumption (tonne/day)		5.10	5.10	5.10
Daily energy saving (kJ)		218,484.54	364,140.89	509,797.25
Daily energy saving (GJ)		0.22	0.36	0.51

Annex 13: Increasing the feed-water temperature in the boiler of dairy industry

Parameters	Observed Case	Feedwater temperature at (°C)		
		56	57	58
Steam working pressure (bar)	9.50	9.50	9.50	9.50
Steam temperature (°C)	163.00	163.00	163.00	163.00
Daily fuel consumption (tonne)	0.33	0.33	0.33	0.33
Working time in a day (hours)	8.00	8.00	8.00	8.00
Steam flow rate (kg/hr)	212.00	212.00	212.00	212.00
Feedwater temperature (°C)	55.00	56.00	57.00	58.00
Enthalpy of steam (kJ/kg)	2,792.27	2,792.27	2,792.27	2,792.27
Enthalpy of feedwater (kJ/kg)	230.23	234.42	238.60	242.79
Energy output (kJ/hr)	543,152.48	542,265.05	541,377.62	540,490.18
Daily energy Output (kJ)	4,345,219.84	4,338,120.38	4,331,020.93	4,323,921.47
Energy saving (MJ/day)		7.10	14.20	21.30

Annex 14: Decreasing the oxygen level in the flue gas in the boiler of dairy industry

Parameters	Observed Case	Decrease in oxygen level by		
		2%	4%	6%
Theoretical air required (kg/kg)	5.04	5.04	4.82	4.82
Oxygen percentage (%)	17.20	16.86	16.51	16.17
Excess air supplied (%)	452.63	406.76	367.91	334.60
Mass of excess air supplied (kg/kg)	27.86	25.55	22.56	20.96
Temperature of flue gas (°C)	218.70	218.70	218.70	218.70
Feed-air temperature (°C)	25.30	25.30	25.30	25.30
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	5,927.31	5,435.27	4,799.85	4,458.14
Energy savings (kJ/kg of fuel)		492.04	1,127.46	1,469.17
Mass of fuel consumption (tonne/day)		0.33	0.33	0.33
Daily energy saving (kJ)		162,371.64	372,061.99	484,826.63
Daily energy saving (GJ)		0.16	0.37	0.48

Annex 15: Increasing the combustion air temperature in the boiler of dairy industry

Parameter	Observed Case	Feed-air temperature at various temperature (°C)		
		27	28	29
Theoretical air required (kg/kg)	5.04	5.04	5.04	5.04
Oxygen percentage (%)	17.20	17.20	17.20	17.20
Excess air supplied (%)	452.63	452.63	452.63	452.63
Mass of excess air supplied (kg/kg)	27.86	27.86	27.86	27.86
Temperature of flue gas (°C)	218.70	218.70	218.70	218.70
Feed-air temperature (°C)	25.30	27.00	28.00	29.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg)	5,927.31	5,875.21	5,844.56	5,813.91
Energy savings (kJ/kg of fuel)		52.10	82.75	113.40
Mass of fuel consumption (tonne/day)		0.33	0.33	0.33
Daily energy saving (kJ)		17,193.49	27,307.30	37,421.12
Daily energy saving (GJ)		17.19	27.31	37.42

Annex 16: Increasing the feed-water temperature in the wood product industry

Parameters	Observed Case	Feedwater temperature at (°C)		
		62	63	64
Steam working pressure (bar)	4.58	4.58	4.58	4.58
Steam temperature (°C)	183.00	183.00	183.00	183.00
Daily fuel consumption (tonne)	1.45	1.45	1.45	1.45
Working time in a day (hours)	12.00	12.00	12.00	12.00
Steam flow rate (kg/hr)	624.00	624.00	624.00	624.00
Feedwater temperature (°C)	61.00	62.00	63.00	64.00
Enthalpy of steam (kJ/kg)	2,648.00	2,648.00	2,648.00	2,648.00
Enthalpy of feedwater (kJ/kg)	255.35	259.53	263.72	267.90
Energy output (kJ/hr)	1,493,013.60	1,490,404.03	1,487,791.97	1,485,179.90
Daily energy Output (kJ)	17,916,163.20	17,884,848.38	17,853,503.62	17,822,158.85
Energy saving (MJ/day)		31.31	62.66	94.00

Annex 17: Decreasing the oxygen level in the flue gas in the wood product industry

Parameter	Observed Case	Decrease in oxygen level by		
		2%	4%	6%
Theoretical air required (kg/kg)	5.04	5.04	4.82	4.82
Oxygen percentage (%)	17.80	17.44	17.09	16.73
Excess air supplied (%)	556.25	490.55	436.81	392.03
Mass of excess air supplied (kg/kg)	33.09	29.77	25.88	23.73
Temperature of flue gas (°C)	207.70	207.70	207.70	207.70
Feed-air temperature (°C)	23.90	23.90	23.90	23.90
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	6,689.29	6,019.61	5,233.24	4,796.73
Energy savings (kJ/kg of fuel)		669.68	1,456.05	1,892.57
Mass of fuel consumption (tonne/day)		1.45	1.45	1.45
Daily energy saving (kJ)		971,038.50	2,111,278.50	2,744,220.80
Daily energy saving (GJ)		0.97	2.11	2.74

Annex 18: Increasing the combustion air temperature in the boiler of wood product industry

Parameter	Observed Case	Feed-air temperature at various temperature (deg. Celsius)		
		25	26	27
Theoretical air required (kg/kg)	5.04	5.04	5.04	5.04
Oxygen percentage (%)	17.80	17.80	17.80	17.80
Excess air supplied (%)	556.25	556.25	556.25	556.25
Mass of excess air supplied (kg/kg)	33.09	33.09	33.09	33.09
Temperature of flue gas (°C)	207.70	207.70	207.70	207.70
Feed-air temperature (°C)	23.90	25.00	26.00	27.00
Specific heat capacity of flue gas (kJ/kg·°C)	1.10	1.10	1.10	1.10
Energy lost due excess air (kJ/kg of fuel)	6,689.29	6,649.26	6,612.86	6,576.47
Energy savings (kJ/kg of fuel)		40.03	76.43	112.82
Mass of fuel consumption (tonne/day)		1.45	1.45	1.45
Daily energy saving (kJ)		58,049.09	110,820.98	163,592.88
Daily energy saving (GJ)		0.06	0.11	0.16

Annex 19: Acceptance Mail from IOEGC

[IOEGC16] Editor Decision

Inbox ×

Kobid <conference-noreply@ioe.edu.np> Tue 1 Apr, 21:46

to me

Nirmal K C:

We are pleased to inform you that your manuscript titled "Energy Saving Opportunities in Industrial Boilers of Nepal" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

Annex 20: Plagiarism Check

Nirmal KC

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Tribhuvan University

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