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DEPARTMENT OF ENVIRONMENTAL SCIENCE

INVESTIGATING THE CAUSES OF ELEVATED SULPHUR DIOXIDE EMISSIONS FROM COAL-FIRED BOILERS AT DELTA BEVERAGES LAGER SOUTHERTON PLANT, HARARE

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Submitted June 2025

DECLARATION

To be compiled by the student

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I, **Blessed Chigumbura,** proclaim that this dissertation is my original paper and has not been submitted before for any academic purposes at this institution or any other educational institute for any purpose.

Signature of the student…

Date ………….01 July 2025

To be compiled by the supervisor

This dissertation is suitable for submission to the faculty and has been checked for conformity with The faculty guidelines.

Supervisor signature…… Date……1 July 2025

Chairperson signature….. Date ..1 July 2025

DEDICATION

This study is committed to my parents, Mr and Mrs Chigumbura and family, for their continuous support economically, morally, and their help alongside prayers along the journey.

ACKNOWLEDGMENTS

Firstly, I want to thank God for keeping me healthy and protecting me in my educational journey.

I am profoundly grateful to my parents and sisters for their steadfast love, devotion, support, and sacrifices. Their confidence in me has remained an irreplaceable source of motivation. I also extend my profound sense of appreciation to my academic supervisor, Dr. Mabhungu.

ABSTRACT

The research is set out to investigate the causes of elevated sulphur dioxide emissions from the coal-fired boilers at Delta Beverages Lagers Southerton Plant. The plant is situated on the corner of Highfield's and Manchester Road, opposite the Nestle Company in Harare. It is also close to high-density areas, which are Mbare and Highfields.

The study employed both quantitative and qualitative data collection techniques. Quantitative data was collected using a semi-structured questionnaire and a desktop review of company reports on coal usage rate and corresponding SO_2 emissions. Qualitative data was collected using an observation checklist, which was used as a supporting document to support the data argument collected in the study. Descriptive statistics were used to analyse factors leading to elevated sulphur dioxide emissions and the perceived influence of maintenance practices on SO_2 emissions levels. Pearson's correlation analysis was used to analyse the relationship between coal usage rate and SO_2 emissions.

Key findings from the study included that poor combustion efficiency, problems associated with burners' performance, problems arising during the start-up or shutdown, problems arising after a boiler trip or restart are contributing factors to elevated sulphur dioxide emissions. The study also reveals that as the coal usage rate increases, SO_2 emission levels also increase with a correlation of $r=0.789$. The p-value for the relationship is less than 0.05 and also less than 0.01, which shows that the observed correlation of 0.789 is statistically significant. Additionally, the study shows that equipment calibration is not constantly performed but rather occurs sometimes. The study showed that maintenance practices also contribute to elevated sulphur dioxide emissions.

The findings of the research conclude that there are several factors contributing to sulphur dioxide emissions and that as the coal usage rate increases, sulphur dioxide emission levels also increase. These are the significant drawbacks to achieving lower sulphur dioxide emission.

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ACRONYMS

SO_2 – Sulphur dioxide

SI - Statutory Instrument

SHOS- Super high-organic-sulphur

CHAPTER 1: INTRODUCTION

This chapter sets the foundation for understanding the causes of elevated sulphur dioxide emissions from coal-fired boilers, particularly at Delta Beverages' lager Plant. It presents the problem statement and highlights the research gap that the study aims to address. The study's aim, objectives, and research questions are also highlighted, as well as the significance of the study. Details about the area study are also provided.

1.1 BACKGROUND OF THE STUDY

Combustion of coal in industrial boilers is the pillar of global energy production, especially in developing economies where coal remains a leading source of fuel for industrial processes (Speight, 2021). Reducing emissions of harmful substances and gases from coal-fired thermal power plants has become an imperative in the field of growing environmental awareness. However, this dependence on coal results in air pollution, acid rain, respiratory illness, and ecosystem degradation (Zhou et al., 2022). As the world is recognising the dangers of pollutants and the importance of environmental protection, the need for monitoring and controlling pollutants is becoming the top priority (Awewomom et al., 2024). Regardless of developments in emission control technologies and regulatory frameworks, sulphur dioxide emissions continue to be a significant problem, particularly in countries with evolving economies which based on coal for energy production (IEA, 2022).

Sulphur dioxide (SO_2) is a hazardous chemical generated by the combustion of fossil fuels (Andri et al., 2021). For many years, SO_2 has been widely employed in various industrial processes due to its excellent performance as a reducing agent, refrigerant, bleaching agent, and antioxidant (Makgato & Chirwa, 2020). As a result, it is a major atmospheric pollutant with significant effects on both the environment and human health. Emissions from power generation and manufacturing areas have remained the subject of extensive investigation and have received considerable attention in modern years, mostly SO_2 emissions from energy and manufacturing activity (O'Brien et al., 2023).

Coal naturally contains sulphur in variable concentrations, normally ranging from 0.2% to 5% by weight (World Coal Association, 2022). During combustion, this sulphur is oxidized to form sulphur dioxide, which is then emitted into the atmosphere. The increase in SO_2 emissions from coal-fired boilers can be attributed to numerous factors, including the coal usage rate, combustion conditions, and the state of the boilers (Bottle & White, 2023).

Sulphur dioxide (SO_2) emissions from coal-fired boilers have been comprehensively studied due to their noteworthy environmental and health impacts. Research has focused on understanding the sources, mechanisms, and mitigation strategies for SO_2 emissions (Madzarevic et al., 2025). The sulphur content of coal is a major determinant of SO_2 emissions (Zhang et al., 2021). Higher-sulphur coals, sometimes referred to as high-sulphur coals, have a sulphur level of at least 3% for example, bituminous and sub-bituminous coals produce more SO_2 during combustion (Chou, 2012). Super high-organic-sulphur (SHOS) coals are a unique type of high-sulphur coal that can have an organic sulphur content of 4% to 11% (Speight, 2021).

In areas where low-quality coal is primarily used due to its affordability and accessibility, SO_2 emissions incline to be significantly higher. For instance, countries like China and India, which rely greatly on local coal reserves with high sulphur content, have reported elevated levels of SO_2 emissions (Liu et al., 2020). The temperature and oxygen levels during combustion also impact the oxidation of sulphur to SO_2, and higher combustion temperatures and excess oxygen increase SO_2 formation (Smith et al., 2018). Studies show that SO_2 emissions are the main contributor to acid rain, which destroys ecosystems, soils, and water bodies (EPA, 2023). Hence, sulphur dioxide emissions can result in the acidification of soils, dams, rivers, and oceans, harming plant and marine life (Liu et al., 2020).

The 2018 Global Burden of Disease Study publicised that air pollution, including SO_2, accounts for millions of early deaths annually, mainly in low- and middle-income countries (Murray et al., 2018). In Europe and North America, strict regulations have been recognised to mitigate pollutants from coal-fired power plants (Speight, 2021). For example, the European Union's Industrial Emissions Directive aims to reduce such pollutants significantly (European Commission, 2018). According to the Health Effects Institute (2019), life expectancy is reduced on average by 20 months worldwide due to air pollution.

The study was conducted at Delta Beverages Lager Southerton Plant, Harare, along Manchester Road. The boilers at Delta Beverages use coal as a source of fuel. The study covers the larger beer manufacturing plant in Harare. Delta Beverages Lager Southerton Plant is the largest and leading clear beer manufacturing company in Zimbabwe. During the manufacturing processes, pressurised hot steam from the coal-fired boilers is used, and the coal-fired boilers discharge SO_2 into the atmosphere. Delta Beverages Manufacturing Company's coal-fired boilers historically adhered to regulations governing sulphur dioxide emission standards. However, starting in 2023, SO_2 emissions from coal-fired boilers have been exceeding the recommended guidelines set by the regulation standard in respect of Statutory Instrument (S.I) 72 of 2009 as read together with section 63 item (b) (1) and (d) of the environmental management act of 2002, which regulate environmental emissions from certain specified processes within Zimbabwe. Therefore, this research aims to investigate the causes contributing to the recent increase in emissions from the coal-fired boilers.

1.2 PROBLEM STATEMENT

The primary problem addressed in this research is the high levels of SO_2 emissions from coal-fired boilers, which pose significant threats to human health and the environment. The Delta Beverages Lager Southerton plant generates process steam from coal-fired boilers, which emit SO_2 emissions, hence the requirement for these emissions to be measured in terms of the Pollution Control Regulations, 2009. Although measures have been put in place to control the SO_2 emissions, the emissions remain high with recoded data from past reports, which shows 682 mg/Nm^3, 790 mg/Nm^3, and 789.5 mg/Nm^3 which are considered to be above the required level. Hence, a cause of concern. It is therefore important to identify the causes of high levels of SO_2 emissions.

1.3 AIM

To assess the main causes of increased sulphur dioxide emissions from coal-fired boilers at Delta Beverages Lager Southerton plant.

1.4 OBJECTIVES

1. To determine the factors leading to elevated SO_2 emissions from coal-fired boilers.
2. To determine the perceived influence of maintenance practices on SO_2 emissions levels from coal-fired boiler operations.

1.5 RESEARCH QUESTIONS

1. What are the factors contributing to elevated SO_2 emissions from the coal-fired boilers at the manufacturing plant?
2. How do maintenance practices influence SO_2 emissions from coal-fired boilers?

1.6 SIGNIFICANCE OF THE STUDY

Finding the underlying reasons for increased SO_2 emissions and getting practical suggestions to deal with the problem will be advantageous to the Delta Beverages Lager Southerton plant. By employing the suggestions in practice, the plant will be able to improve its operational efficiency, avoid possible legal penalties, and comply with environmental standards. Lowering emissions may improve the plant's standing as an eco-friendly organization, which may improve ties with regulators. Also, lower air pollution will benefit local communities and improve public health, especially for vulnerable populations, including children, the elderly, and people with pre-existing medical conditions.

The study might support the industry-wide adoption of best practices, which would improve environmental sustainability and air quality inclusively. Hence, the decrease in air pollution will benefit the entire country.

1.8 DELIMITATIONS OF THE STUDY

The study will not examine the effects of transitioning to alternative energy sources, such as natural gas or renewable energy, for the Delta Beverages operations. The study will focus on the causes of high SO_2 emissions. The data will primarily be obtained from the Delta Beverages plant and will be limited to the geographical area.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

An examination of the relevant literature review is included in this chapter. It starts off by outlining the importance of coal-fired boilers as a primary contributor to SO_2 emissions. The literature review also outlines the factors that contribute to elevated SO_2 emissions. The factors are as follows: combustion conditions, coal usage rate, and how coal's sulphur concentration impacts SO_2 emissions. It also examines how maintenance practices influences the amount of SO_2 emissions produced from the boilers. The literature review covers the regulatory framework governing sulphur dioxide emissions. The literature review also discusses the health and environmental impacts of sulphur dioxide from coal-fired boilers.

2.2 SIGNIFICANCE OF COAL-FIRED BOILERS AS A MAJOR SOURCE OF SULFUR DIOXIDE EMISSIONS.

According to RGN Factories and Works pressurized Vessel Regulations 303, a boiler is any apparatus designed to continually convert any liquid into vapour, gas, or steam at a pressure greater than that of the atmosphere. The boilers are made of steel and feature a cylindrical stack rising into the environment, allowing emissions from the burned coal to escape (Speight, 2021). Nyashina postulated that since coal-fired power generation accounts for a major portion of total power generation, it was discovered that coal-fired industrial boilers account for more than 50% of global SO_2 emissions (Makgato & Chirwa, 2020). According to the report by the Environmental Protection Agency, coal-fired boilers are the major anthropogenic causes of SO_2 emissions and other pollutants. The primary source of air pollution is coal-fired power plants, despite coal being a plentiful fuel that can be converted into useful electricity at a reasonable cost (Madzarevic et al., 2025). Additionally, one of the main sources of pollutants is SO_2 from coal-fired boilers, which crosses international borders.

2.3 FACTORS INFLUENCING SULPHUR DIOXIDE EMISSIONS FROM COAL-FIRED BOILERS

The factors influencing SO_2 emissions from coal-fired boilers include Coal usage rate, role of sulphur content in coal in relation to sulphur dioxide emissions, combustion conditions such as temperature, combustion efficiency, and excess air.

2.3.1 Coal usage rate and its impacts on sulphur dioxide emissions

Coal is a solid, dark brownish or black, non-renewable, sedimentary rock that ignites easily and comprises a percentage of hydrocarbons and carbon (Liu et al., 2025). The rate of coal consumption and the amount of sulphur in the coal are related to sulphur dioxide emissions (Chou, 2012). Coal is used as a fuel in boilers, gasification, and steel manufacturing industries, and it increasingly plays an important role in the energy supply (Dai et al., 2020). It contains several functional groups, comprising carbon, oxygen, nitrogen, and sulphur also coal's sulphur content varies depending on its rank (Makgato & Chirwa, 2020).

According to a review done by Saikia (2014), the author suggested that Coal is classified based on sulphur content, low (<1.0 wt%), medium (1.0 to < 3.0 wt%), and high (>3.0 wt%) (Saikia et al., 2014). Prior studies conducted by other authors showed that coal's sulphur compounds have a direct effect on SO_2 emissions (Brown et al., 2017). This highlights the significance of coal source, coal quality, and coal usage rate in determining total emission levels. Additionally, during the combustion process, almost 85% of the sulphur contained in coal is transformed into SO_2 (Makgato & Chirwa, 2020). When boilers increase coal usage rate, it implies high sulphur dioxide emissions (Filonchyk & Peterson, 2023).

2.3.2 Impacts of Combustion conditions on SO_2 emissions

Combustion conditions greatly affect sulphur dioxide (SO_2) emissions from coal-fired boilers, with parameters like temperature, excess air, and combustion efficiency playing critical roles (Tamura et al., 2015). Temperature plays an essential role in the combustion efficiency of coal-fired boilers, influencing the formation and the reaction of SO_2 (Wull et al., 2020). High combustion temperatures maximise the rate at which coal burns, but they also produce significant SO_2 emissions (Tong et al., 2023). While high combustion temperatures can reduce the incomplete combustion of carbon, the improved conditions can lead to elevated SO_2 emissions (Salawu et al., 2023). As boiler load increases, so do gas temperatures throughout the combustion chamber, this causes a decline in the SO_2 binding coefficient (Ren et al., 2020).

Excess air in boilers refers to the volume of air consumed in combustion that surpasses the theoretical requirement for complete fuel combustion (Kristinsson & Lang, 2011). Excess air is essential for complete combustion, but the abundance of it can significantly lower boiler performance and increase energy usage (Ren et al., 2020). According to a study done by Madzarevic, he postulated that air above what is theoretically required can speed up combustion efficiency to higher levels; however, this escalates SO_2 emissions due to the oxidation of sulphur available in the coal (Madzarevic et al., 2025).

Boiler combustion efficiency is an indicator of the boiler's capacity to burn fuel. The burning efficiency is determined by two parameters: extra oxygen levels in the exhaust and the quantity of unburned fuel in the exhaust (Kaygusuz, 2012). With optimum conditions ranging from 70% to 90%, it indicates the burner's capacity to convert fuel into heat (Speight, 2021). The decline of SO_2 emissions depends on efficient combustion, which makes sure that all of the coal is consumed entirely (Filonchyk & Peterson, 2023). As a result, improved combustion conditions can increase combustion efficiency, lowering SO_2 emissions.

2.3.3 Impacts of boiler maintenance practices on SO_2 emission levels.

Boiler maintenance incorporates a comprehensive regime of inspecting, cleaning, testing, and adjusting the mechanisms of a boiler system (Huang et al., 2021). The maintenance procedures for increased efficiency are the key to ensuring the longevity and effectiveness of commercial and industrial boilers. Maintenance procedures are vital for ensuring that boilers run at their maximum capacity, maintain fuel efficiency, and comply with safety standards (Patil et al., 2022). When boilers work efficiently, they need less coal to yield the same amount of heat (Salawu et al., 2023). This leads to cost savings over time, which will benefit the company, with the extra benefit of reduced environmental impact due to lower emissions. A poorly maintained boiler will not work as designed, resulting in less-than-optimal burner performance and, therefore, increased emissions (Agarwal & Suhane, 2017).

Ignoring commercial and industrial boiler systems can lead to severe risks, including potential safety hazards, high emissions, and increased operating costs (Speight, 2021). Neglected boilers can compromise both property and human health due to high emission levels. Regular maintenance is an active method intended to effectively manage these hazards. Inspections find faults in the boiler system that could lead to accidents, health risks, and higher emissions (Andri et al., 2021). Technicians and engineers can identify and repair faults in the system that might lead to unsafe situations, such as pressure build-ups or equipment failures (Huang et al., 2021). Strategic maintenance programmes enable the organized assessment and quick repair of possible safety hazards, lowering the possibility of an emergency and high emission levels (Department of Environmental Sciences, Faculty of Bio Sciences, University of Veterinary and Animal Sciences, Lahore, Pakistan et al., 2022).

2.4 HEALTH AND ENVIRONMENTAL IMPACTS OF SO_2 EMISSIONS FROM COAL-FIRED BOILERS

The Safety Data Sheets (MSDS) display that SO_2 gas exposure at 20 ppm influences outcomes in eye irritation, oesophagus, sinuses, respiratory oedema, and also death in worst cases. High amounts of SO_2 can aggravate asthma attacks and worsen existing heart disease in sensitive, vulnerable populations (Nurhisanah & Hasyim, 2022). Another adverse consequence of this pollutant is breathing problems and damaged bronchioles and bronchus function, which result in coughing and shortness of breath (Muziansyah et al., 2015). Sulphur dioxide emissions produced during combustion react to form hydrogen sulphate (H_2SO_4), which precipitates as acid rain (O'Brien et al., 2023). Acid rain caused by sulphate acid deposition can be harmful to biomes, plants, and faunas, both aquatic and terrestrial (Makgato & Chirwa, 2020). Therefore, acid rain is tremendously destroying buildings, the ozone layer, agriculture, and natural ecosystems.

2.5 LEGAL FRAMEWORK FOR SO_2

The National Society Security Authority (NSSA) guidelines of boilers on occupational safety health regulations from the chapter 14:08 Factories and Works Boiler Regulations, 1976 contain information on Zimbabwe laws governing boilers. Additionally (EMA) Environmental Management Act encompasses regulations on SO_2 emissions. According to EMA, emissions should be assessed in terms of the Pollution Control Guidelines (2009). The SO_2 emissions should also be assessed according to recommended guidelines set by the regulation standard in respect of Statutory Instrument (S.I) 72 of 2009, third schedule section 3 as read together with section 63 item (b) (1) and (d) of the environmental management act 13 of 2002 which regulate environmental emissions from certain specified processes within Zimbabwe.

The EMA issues a license according to colour band category, which comes as follows: blue licence is discharge, which is considered to be environmentally safe, followed by green licence, which is considered to present a low environmental hazard. Followed by a yellow licence, considered to present medium environmental threats, lastly a red licence, which presents unfavourable environmental hazards. The procedure for emission measurement follows ISO 10396: 2007- Automated gas emission measurement.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter intends to show the study area, research design, data collection, sample size, and procedures followed in carrying out the research.

3.2 STUDY AREA DESCRIPTION

The research was conducted at Delta Beverages Lager Southerton plant in Harare. The study covers the larger beer manufacturing plant, and the coordinates are $17^{0}.52^{'}$ 13.56’’S, 31^{0} $00^{'}$46.41 $^{''}$E. Figure 3.1 below shows the study area map. The Delta beverages plant is situated on the corner of Highfield and Manchester Road, opposite the Nestle Company. It is also close to high-density suburbs, which are Mbare and Highfield. It is located in the capital’s heavy industrial side, suitably close to other manufacturing companies.

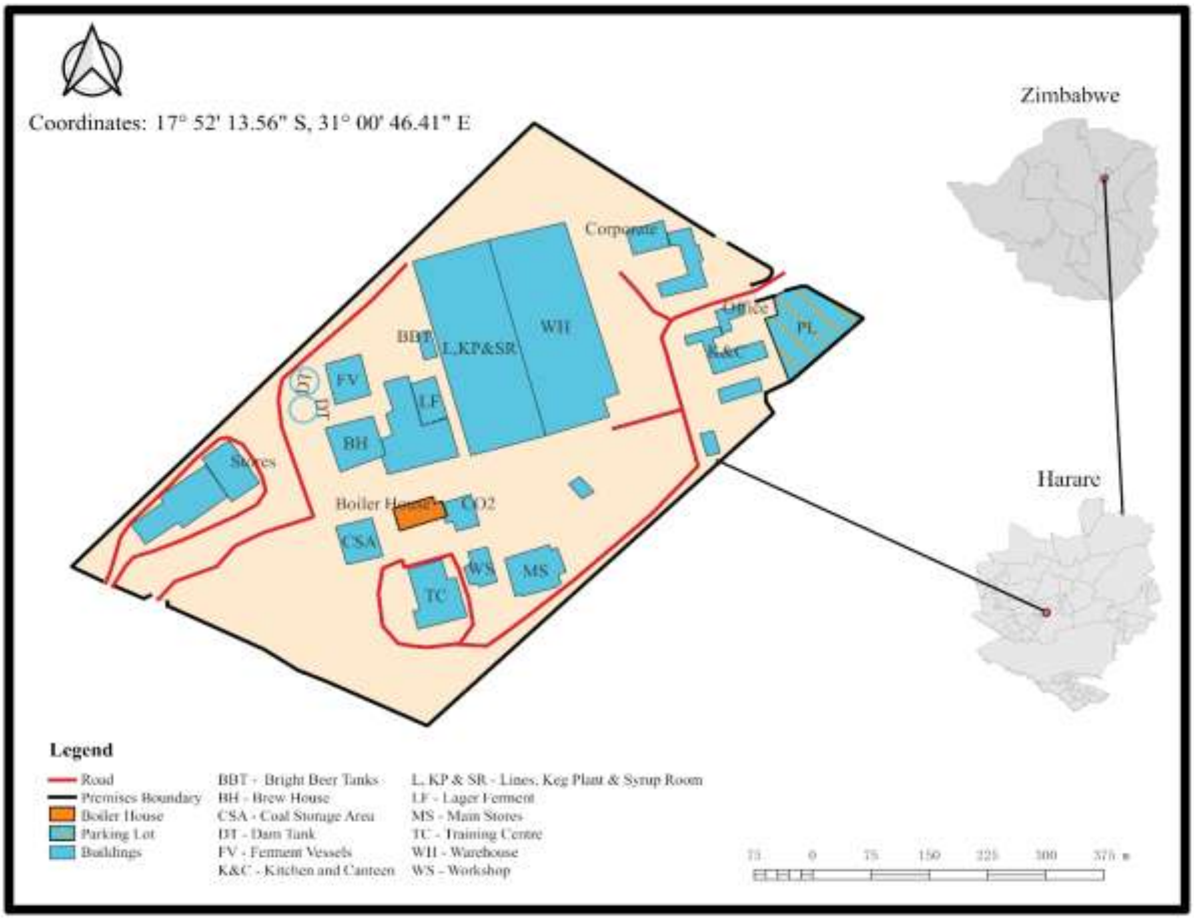

Figure 3.1 Study Area Map

3.3 RESEARCH DESIGN

A mixed-methods research design was employed in the research. The research design aims to collect both quantitative and qualitative data in one segment, and the data is analysed separately and then combined (Creswell & Creswell, 2018). The study assumed a convergent triangulation method where both quantitative and qualitative methods were rendered equal. Figure 3.2 below shows a convergent design extracted from Designing and Conducting Mixed Methods Research (Creswell & Plano Clark, 2018). Triangulation enriches the research since it puts forward a range of facts and diverse perspectives of the investigation (Noble & Heale, 2019). Quantitative results were obtained by a self-administered questionnaire (administered to workers in the boiler house section utilities department), and a desktop review of company reports on the relationship between coal usage rate and SO_2 emissions. Qualitative findings were obtained using an observation checklist. The questionnaire was used to collect data on factors leading to elevated SO_2 emissions and to assess the perceived influence of maintenance practices on SO_2 emission levels from coal-fired boiler operations (Appendix 1). A desktop review collected data from company reports on the rate of coal consumption and resultant SO_2 emissions.

Observations were used to physically direct observe boiler attendance, technicians, engineers, and steam fitters, and also observe maintenance practices, human errors, and areas for improvement; hence, this data was used to identify the causes of elevated SO_2 emissions (Appendix 2). The combination of methods employed in the research improves the reliability of findings in which quantitative data are cross-checked with qualitative data.

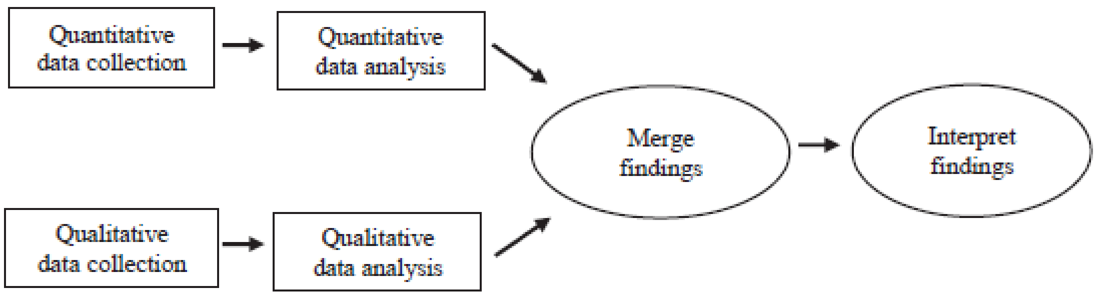

Figure 3.2 Convergence design

3.4 DATA COLLECTION

Data was collected using three instruments. First, factors leading to sulphur dioxide emissions and the perceived influence of maintenance practices on SO_2 emission levels were collected using a questionnaire. Second, a desktop review relied on company reports to identify the relationship between coal usage rate and SO_2 emission. Finally, the observation checklist was used to verify the data collected in questionnaires with conditions onsite.

3.5 SELECTION OF STUDY PARTICIPANTS

The study population includes boiler attendants, boiler technicians, steam fitters, engineers, and boiler room supervisors working in the boiler house section of the utilities departments at Delta Beveragers Lager Southerton plant. The sample size was 20 (n=20) and was used solely for the questionnaire survey. No sampling was conducted for the research due to the small number of employees in the boilerhouse. The employees were deemed eligible to participate in the survey.

3.6 RESEARCH INSTRUMENTS

The study employed three research instruments.The instruments include questionnaires that collected data on factors leading to elevated sulphur dioxide emissions and the perceived influence of maintenance practices on sulphur dioxide emissions. A desktop review that collected data from reports on coal usage rate and corresponding SO_2 emissions. Observation checklists were used as a supporting research instrument for data collected using the questionnaires.

3.6.1 Questionaire

Twenty questionnaires (n=20) were distributed. The semi-structured questionnaire (Appendix 1) was divided into four sections: (A) Demographic information, (B) factors leading to SO_2 emissions, (C) perceived influence of maintenance practices on SO_2 emissions levels from the coal-fired boiler operations, (D) additional comments. A semi-structured questionnaire is a type of research tool that contains open-ended and closed-ended questions. The open-ended questions allow participants to react to the questions in their expressions, whereas closed-ended questions provide a predefined list of possible answers. By mixing open-ended and closed-ended questions, it becomes simpler to look into the topic from multiple viewpoints and obtain a deeper understanding of the reasons behind increased SO_2 emissions (Semyonov & Lewin, 2021). The 5-point Likert scale questions, starting from very rarely to very often, were used to measure how frequently or to what degree operators have experienced or convey opinions about the causes of elevated SO_2 emissions.

A questionnaire has the advantage of rapidly reaching participants and producing accurate data (Roopa et al., 2012). A questionnaire reduces interviewer bias by letting respondents answer in their own words, guaranteeing objectivity and authenticity in data collection. The quality of the data collected is improved by allowing respondents to provide thoughtful answers. Nevertheless, it has limitations, such as being influenced by the respondent's comprehension and interpretation of the question and having trouble expressing emotions (Adams et al., 2008). A questionnaire was the best tool for collecting data, despite its disadvantages.

3.6.2 Desktop review

A desktop review collected data from Delta Beverages' larger reports done every quarter, which presents numerical measured data on coal usage rate and corresponding SO_2 emissions. The data collected contained information on coal usage rate in tons per day and average sulphur dioxide emissions concentration from the boiler stack in milligrams per cubic meter, mg/Nm^3.

3.6.3 Observation checklist

An observation checklist (Appendix 2) collected all information that could result in high SO_2 emissions. Gathering observational data entails observing, hearing, reading, and touching while documenting traits in their natural environment. To observe factors leading to elevated SO_2 emissions, emission control systems, maintenance procedures, and combustion processes, the researcher conducted a walkthrough of the boiler house and conducted non-participant observations. To accurately record all the data, this was done on regular business days. However, the tool is time-consuming and mostly relies on the researcher's judgment (Braun et al., 2012).

3.6 ETHICAL CONSIDERATIONS

The study will observe ethical guidelines set forth by Helsinki for research involving humans and subjects (World Medical Association, 2018).

3.6.1 Informed consent

All participants will be informed about the purpose of the research, procedures, risks, and benefits. This will clearly explain what the study is about, providing participants with comprehensive information regarding the research, outlining the contributions needed, as well as the potential benefits of the research. It will also inform them that participation is voluntary and give them a way to ask questions.

3.6.2 Confidentiality and anonymity

To protect the privacy of participants, all personal data will be kept secure and private. Data will have limited access and only be accessed by authorised personnel, and data will be kept in databases with passwords, since Delta Beverages is a company trying to achieve a world-class brewery production system.

3.7 DATA ANALYSIS

Quantitative information from respondents was analysed using descriptive statistics, desktop review reports were analysed using Pearson correlations and observations were analysed using thematic analysis. Data analysis was performed using the statistical package for the social sciences (SPSS) version 20.0. Before analysis, a normalcy test was performed. A correlation analysis was used to analyse how the coal usage rate impacts SO_2 emissions from coal-fired boilers. Frequency and Percentages were used to summarize demographic information (such as gender, age, and years of experience). Using an observation checklist as a guide, the researcher conducted a walkthrough of the boiler house, recording all observations that potentially result in elevated SO_2 levels. An observation checklist was used by the researcher as a supporting document to support the data gathering argument. The observational data were analysed using thematic analysis. Thematic analysis follows the following procedures, which include getting to know the data, creating preliminary codes, looking for themes, evaluating possible themes, and naming themes. Thematic analysis was used due to its ease of use for beginners and accessibility. However, the tool is time-consuming and mainly relies on the researchers' judgment to produce a report (Braun et al., 2012).

CHAPTER 4: RESULTS

4.0 INTRODUCTION

The chapter provides a comprehensive presentation of the research findings and study results. The results are presented in tabular format.

4.1 SECTION A: DEMOGRAPHY

A 100% response rate was achieved in the boiler house section; questionnaires were distributed to twenty respondents at the Delta Beverages Lager Southerton plant's utilities department.
A summary of demographic features is listed in Table 4.1 below. Overall, the sample had 75% male participants and 25% female participants. A total of 55% of the men were found to belong to the 36-44 age group. The other age groups (26-35 and >45) represented 30% and 15% of the participants, respectively. 30% of the participants held other educational qualifications. The majority, 45% of the participants, were degree-holders. The boiler attendant accounted for the largest category of participants, 40%. Boiler technicians and boiler room supervisors accounted for 30%, with steam fitters making up for 15% and engineers accounted for 10% of the sample size. Most of the participants, 55%, had 7-10 years working experience in the boiler house section at Delta Beverages Lager plant, while 30% had 11-14 years of experience, and 15% had 15-18 years of experience.

Table 4.1 Summary of demographic characteristics

Demographic variable	Category	Frequency	Percentages
Gender	Male	15	75%
	Female	5	25%
Age	26-35	3	15%
	36-44	11	55%
	>45	6	30%
Marital Status	Married	17	85%
	Divorced	1	5%
	Widowed	1	5%
	Single	1	5%
Educational qualifications	Degree	9	45%
	Masters	5	25%
	Other	6	30%
Years of experience	7-10	11	55%
	11-14	6	30%
	15-18	3	15%
Specific job role	Boiler attendant	8	40%
	Boiler technician	4	20%
	Steam fitter	3	15%
	Boiler room supervisor	3	15%
	Engineers	2	10%

4.2 SECTION B: FACTORS LEADING TO ELEVATED SO_2 EMISSIONS

Table 4.1 below summarizes factors leading to SO_2 emissions, showing operational encounters, more specifically in terms of variables involved in higher SO_2 emissions. The mean value of 3.90 and a standard deviation of 0.852 indicate that the respondents often find poor combustion efficiency to be a contributing factor. The mean score for problems associated with burners' performance is 2.20, and the standard deviation is 0.894. This means that while burner performance issues are encountered, they are less in occurrence or extent than those of inefficient combustion.

A high mean of 1.70 and a low standard deviation of 0.470 for problems arising during the start-up or shutdown periods shows that these periods have high consistency. A mean of 2.25 with a standard deviation of 0.786 for problems arising after a boiler trip or restart occur indicates that, after these events, high SO_2 emissions levels are occasionally faced after these occurrences. The perception of reliability of the current sulphur dioxide monitoring system has an average score of 2.10, with a very low standard deviation of 0.447. The outcomes suggest that the respondents view these systems as occasionally reliable. An average score for frequency of calibration is 1.95, with a minimal standard deviation of 0.224. Minimum and maximum values are found to be 1 and 2, respectively. The very low standard deviation shows a strong consensus regarding this practice.

Table 4.2: Summary of factors leading to elevated SO_2 emissions

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Poor combustion efficiency	20	2	5	3.90	.852
Issues with burner perfomance	20	1	4	2.20	.894
During start up or shutdown	20	1	2	1.70	.470
Following a boiler trip or restart	20	1	3	2.25	.786
How reliable do you find the current sulphur dioxide monitoring systems	20	1	3	2.10	.447
How frequently do you calibrate or check the accuracy of these systems	20	1	2	1.95	.224
Valid N (listwise)	20				

4.3 SECTION C: ASSESSING COAL USAGE RATE AND ITS IMPACT ON SO_2 EMISSIONS.

Table 4.3 below shows a correlation matrix between coal usage rate and levels of SO_2 emissions. The Pearson Correlation is 0.789; this value shows a strong positive linear relationship between the coal usage rate and the sulphur dioxide emission levels. The positive correlation means that as coal rate usage increases, sulphur dioxide emissions also increase. Sig. (2=tailed) = 0.001, this p-value is less than 0.05 and is less than 0.01, which shows that the observed correlation of 0.789 is statistically significant.

Table 4.3: Correlation matrix between coal usage rate and levels of SO2 emissions.

Correlations

		Coal usage rate.	Sulphur dioxide emissions.
Coal usage rate.	Pearson Correlation	1	.789
	Sig. (2-tailed)		.001
	N	6	6
Sulphur dioxide emissions.	Pearson Correlation	.789	1
	Sig. (2-tailed)	.001	
	N	6	6

Correlation is significant at the 0.05 level (2-tailed)

4.4 SECTION D: PERCEIVED INFLUENCE OF MAINTENANCE PRACTICES ON SO_2 EMISSIONS.

Table 4.4 below shows the responses on the perceived relationship between maintenance practices and sulphur dioxide emissions. The majority of respondents strongly agree that failure to adhere to routine maintenance of equipment leads to elevated SO_2 emissions mean of 3.72. They strongly agree that implementing predictive maintenance strategies has a direct positive influence on monitoring SO_2 emissions mean of 3.69, and that poorly maintained exhaust systems and filters lead to elevated SO_2 emissions mean of 3.61. There is an average agreement for the question that regular and thorough maintenance of industrial equipment significantly decreases the SO_2 emissions mean of 2.88. The data shows a strong perceived relationship between maintenance practices and SO_2 emissions, mostly concerning the negative impact of the neglect of maintenance.

Table 4.4 Analysis of maintenance practice contributing to sulphur dioxide emissions

Factor	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Regular and thorough maintenance of industrial equipment significantly reduces SO_2 emissions.	20	1	5	2.88	.987
Neglecting routine equipment maintenance leads to an increase in SO_2 emissions.	20	1	5	3.72	.805
Implementing predictive maintenance strategies has a direct positive impact on controlling SO_2 emissions.	20	1	5	3.69	.928
Poorly maintained exhaust systems and filters contribute to substantially higher SO_2 emissions.	20	1	4	3.61	.973

4.6 OBSERVATION DATA

This section presents the result of a checklist survey on the performance of the coal-fired boiler operation to SO_2 emissions. The findings are organized and presented in a structured format, according to various aspects of the procedure.

4.61 Coal usage rate

The plant displays competency in the documentation and verification of sulphur content that is present in the coal, guaranteeing ongoing observance. Coal usage rate documentation is available, and the boiler does not use fuel combination or change fuel types that would result in increased SO_2 emissions. There is no evidence of coal contamination, and the coal area storage is kept dry (refer to Figure 4.1), leading to increased combustion efficiency. One of the biggest limitations is that there is no internal process for testing coal chemical composition on a continuous basis. It therefore follows that Delta Beverages relies on supplier external information only and does not measure real-time differences or gaps.

Figure 4.1

4.62 Combustion processes

There is poor control of combustion processes in the boilers. Control of primary and secondary air is defective, and excess oxygen levels are not often continuously measured and maintained at optimum levels. In addition, combustion temperatures are not well controlled and maintained at an optimum range and hence results in elevated SO_2 emissions. The observer observed routine maintenance practices and adjustment of burners as shown in Figure 4.2, which is done by boiler technicians and engineers.

Figure 4.2

4.63 Emission control system

This section identifies the most significant weaknesses of the coal-fired boiler operation. It is evident from the observed findings that the boiler does not have a properly functioning flue gas desulfurization (FDG) system and that it is occasionally reliable. Therefore, all corresponding assessments, which include operating conditions, maintenance history, efficiency test, and backup system for the FDG system, are reduced. This indicates a simple reliance on the naturally low sulphur content of the coal instead of employing active emissions reduction technologies.

4.64 Stack Monitoring

The manufacturing plant has insufficient performance in stack monitoring, and emissions monitoring is conducted with sometimes and not always calibrated and operational equipment. The portable sulphur dioxide monitoring equipment was found to be overdue for calibration, although there is an ongoing recording of SO_2 emissions, along with maintenance of regular boiler stacks. Furthermore, there has been a trend analysis of SO_2 emissions during the period, which is a positive approach towards monitoring emission trends.

The findings indicate that Delta Beverages' coal-fired-boiler operation is partially managing its significant variables concerning fuel, combustion efficiency, and effectively monitoring its production.

CHAPTER 5: DISCUSSION

5.1 INTRODUCTION

This chapter describes a comprehensive discussion of the potential causes of increased sulphur dioxide emissions from coal-fired boilers at Delta Beverages. The descriptive statistics and correlation presented in Chapter 4 are applied in this chapter to interpret these findings, focusing on what is important, and drawing connections by contextualizing the study findings and relating them to pertinent academic literature in the field.

5.2 FACTORS LEADING TO ELEVATED SO_2 EMISSIONS

From the study, respondents consider poor combustion efficiency as a major cause of high SO_2 emissions, with a high mean score of 3.90. This suggests that low combustion efficiency is a significant contributing factor to SO_2 emissions. Poor combustion efficiency directly affects the complete oxidation of sulphur present in coal. When combustion is incomplete, sulphur might not completely convert to SO_2 but can also produce other sulphur compounds or be present as unburnt in the flue gases, resulting in high sulphur dioxide emissions into the atmosphere.

The research results were consistent with studies that highlight the important role of optimized combustion efficiency. Air above that supposedly required volume can increase combustion efficiency, but the oxidation of the sulphur contained in the coal is increased, and leads to higher SO_2 emissions (Madzarevic et al., 2025). The facts demonstrate a need for regular monitoring and inspections.

From the study, respondents indicated that issues with burner performance also contribute as a considerable cause, with a mean score of 2.20 and a standard deviation of 0.894. This shows that breakdowns or inadequacies in the burner system contribute to SO_2 emissions. Burners are used to bring coal and air into the combustion chamber in a controlled manner, ensuring effective mixing and full combustion.

This, however, aligns with the opinion made by Maghbooli & Bakhtiari, (2013), improving inadequate routine performance of direct fired heaters, validated that even slight deviations in the operation of the burner, such as improper atomisation or flame contact with tubes, can considerably disrupt combustion and result in an increase in SO_2 emissions. The research study highlights that burners must be inspected often to notice wear and tear. In addition, burners must be kept clean and free to prevent soot or ash buildup up which can block airflow and fuel flow.

The study participants indicate that during start-up or shutdown, and following boiler trip or restart, have mean scores of 1.70 and 2.25, respectively. This suggests that these operating procedures present negative encounters in maintaining low SO_2 emissions. The small standard deviation during start or shut down, 0.470, indicates a strong perception of its effect. In these operations, boiler operational conditions are unstable, making it challenging to maintain optimal combustion. Fluctuations in putting coal in the boiler, air supply, and temperature can lead to incomplete combustion with subsequent reduced sulphur capture during operation.

This finding is consistent with a report by Zhao (2019), which notes that quickly changing loads and unbalanced combustion conditions during start-ups or shutdowns, and sudden trips often result in spikes of emissions such as sulphur dioxide. This highlights the importance of strong operational processes in each of these phases.

Based on direct observations by the researcher, participant responses, and the calibration of the sulphur dioxide monitoring system varies. This suggests that there are some concerns concerning the accuracy of the monitoring system, as the observer observed that the portable sulphur dioxide monitoring equipment was due for calibration. This suggests a less frequent approach to the calibration of the equipment. Reliable and accurate monitoring systems are vital for efficiently detecting and handling SO_2 emissions. If monitoring systems are not constantly accurate or regularly calibrated, operators may not have an exact picture of emission levels, possibly resulting in delayed or inadequate corrective actions. This finding agrees with the literature by Swanson (2008), who emphasized that inadequate calibration practices can lead to significant under- or over-reporting of emissions, thereby handicapping operative emission reduction strategies.

5.3 INFLUENCE OF COAL USAGE RATE ON SO_2 EMISSIONS FROM COAL-FIRED BOILERS.

The findings of the analysis indicated a strong and statistically significant positive correlation, $r=0.789$, $p=0.001$, between the coal usage rate and corresponding SO_2 emissions. This result indicates that a higher rate of coal consumption results in high sulphur dioxide emissions. This result is supported by the literature by Smith et al. (2005), who consistently highlight that fossil fuel consumption, mostly coal, is a principal contributor of sulphur dioxide and other atmospheric pollutants.

5.4 INFLUENCE OF BOILER MAINTENANCE PRACTICES ON SO_2 EMISSIONS

The findings show that most of the respondents identified failure to service equipment as increasing SO_2 emissions, with a mean score of 3.72 and a standard deviation of 0.805. This proposes a high level of agreement among respondents that failure to conduct regular maintenance directly relates to high SO_2 concentrations. The results also confirm the literature by Patil et al. (2022). The absence of maintenance on combustion equipment and emission control systems is a notable driver of higher elevated sulphur dioxide in thermal power plants. The findings also show that implementing predictive maintenance strategies has a direct positive impact on controlling SO_2 emissions. Predictive maintenance includes using sensor data, historical trends, and analytical tools to predict when equipment failure might occur. This makes it possible to schedule maintenance to be planned when it is necessary and avoid unplanned shutdowns.

This finding is in line with Bhander & Jozewicz (2017), which emphasized that the capabilities of real-time monitoring and predictive analytics allow operators to proactively address equipment wear and tear that could potentially lead to increased emissions. Poorly maintained exhaust systems and filters were reported as a noteworthy contributor to higher SO_2. Exhaust systems and filters, mostly those associated with flue gas desulfurization systems and particulate matter removal, are the final barrier against the emission of pollutants. And when these are not well maintained, their ability to capture SO_2 emissions is degraded. This result is also in line with the literature by Schreifels (2011) that the elongated efficiency of control of SO_2 emissions relies on maintenance practices of scrubbers' filters and associated ducting.

The fundamental principle remains that dependable and well-implemented maintenance programs are at the core of emission reduction. This can also range from routine lubrication and cleaning to extensive boiler overhauls. In other words, if a boiler's systems are all working at peak performance, the entire operation, from coal input to emission output, functions more efficiently, obviously leading to reduced SO_2 emissions.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The findings of the study reveal that it is not one specific factor but rather there are several factors contributing to the high levels of sulphur dioxide emissions from the coal-fired boilers. The study revealed that as the coal usage rate increases, sulphur dioxide emissions also increase. The study findings also reveal that perceived influence on maintenance practices is important and that failure to conduct regular maintenance directly relates to high SO_2 concentrations.

6.2 Recommendations

- Delta beverages might be able to calibrate the equipment regularly to have an accurate reading of real SO_2 emissions.
- Investing in modernising the emission control technologies, such as the flue gas desulfurization (FGD) system and dry and wet scrubbers.
- Operators need continual training in the combustion principles of combustion, in the operation and management of boilers, system troubleshooting, and in the operation of modern control systems.
- Purchase of an automatic controlled oxygen trim system that continuously reads flue gas oxygen and adjusts the air-to-fuel ratio in real time and improves burner System Inspection programs.
- Ensuring the coal delivered to the plant meets the high-quality standards expected to power the complex generation.

REFERENCES

Adams, A., and Cox, A. L. (2008). *Questionnaires, in-depth interviews, and focus groups*. In Cairns, Paul and Cox. Anna L., eds, Research Methods for Human Computer Interaction. Cambridge, UK: Cambridge University Press, pp. 17–34.

Andri, Basuki, B. H., Seputro, E. S., & Kusuma, E. (2021). Efforts to Reduce SO_2 Emission in Paiton Coal-Fired Power Plant. *IOP Conference Series: Materials Science and Engineering*, *1096*(1), 012125. https://doi.org/10.1088/1757-899X/1096/1/012125

Bottle, J., & White, A. R. J. (2023). Coal analysis. In *The Coal Handbook* (pp. 133–161). Elsevier. https://doi.org/10.1016/B978-0-12-824328-2.00002-9

Brown, M. A., Li, Y., Massetti, E., & Lapsa, M. (2017). U.S. sulfur dioxide emission reductions: Shifting factors and a carbon dioxide penalty. *The Electricity Journal*, *30*(1), 17–24. https://doi.org/10.1016/j.tej.2016.12.007

Chou, C.-L. (2012). Sulfur in coals: A review of geochemistry and origins. *International Journal of Coal Geology*, *100*, 1–13. https://doi.org/10.1016/j.coal.2012.05.009

Creswell, J., & Plano Clark, V. (2018). *Designing and conducting mixed methods research*. Sage Publications Inc.

Dai, S., Bechtel, A., Eble, C. F., Flores, R. M., French, D., Graham, I. T., Hood, M. M., Hower, J. C., Korasidis, V. A., Moore, T. A., Püttmann, W., Wei, Q., Zhao, L., & O'Keefe, J. M. K. (2020). Recognition of peat depositional environments in coal: A review. *International Journal of Coal Geology*, *219*, 103383. https://doi.org/10.1016/j.coal.2019.103383

Department of Environmental Sciences, Faculty of Bio Sciences, University of Veterinary and Animal Sciences, Lahore, Pakistan, Khan, A., Arooj, F., Kashif, S.-R., Sana, S., & Sidra, S. (2022). Air Quality Assessment of Industrial BoilersExhaust and its Impact upon Workers' Health. *Journal of Environmental Science and Management*, *25*(1), 57–63. https://doi.org/10.47125/jesam/2022_1/07

Filonchyk, M., & Peterson, M. P. (2023). An integrated analysis of air pollution from US coal-fired power plants. *Geoscience Frontiers*, *14*(2), 101498. https://doi.org/10.1016/j.gsf.2022.101498

Huang, S., Zuo, W., Vrabie, D., & Xu, R. (2021). Modelica-based system modeling for studying control-related faults in chiller plants and boiler plants serving large office buildings. *Journal of Building Engineering*, *44*, 102654. https://doi.org/10.1016/j.jobe.2021.102654

Liu, C., Yang, Y., Chen, L., Wu, J., Sun, Y., Han, M., Guo, X., He, M., & Jin, Z. (2025). Rare earth resource in fly ashes from coal power plants of China: Based on machine learning model and unit-based estimation. *International Journal of Coal Geology*, *303*, 104743. https://doi.org/10.1016/j.coal.2025.104743

Madzarevic, A., Jovancic, P., Djenadic, S., Miletic, F., Ristovic, M., & Crnogorac, M. (2025). Anticipated sulfur dioxide emissions from coal-fired power plants. *Thermal Science*, *29*(1 Part A), 145–158. https://doi.org/10.2298/TSCI240308167M

Makgato, S. S., & Chirwa, E. M. N. (2020). Recent developments in reduction of sulphur emissions from selected Waterberg coal samples used in South African power plants. *Journal of Cleaner Production*, *276*, 123192. https://doi.org/10.1016/j.jclepro.2020.123192

O'Brien, E., Masselot, P., Sera, F., Roye, D., Breitner, S., Ng, C. F. S., De Sousa Zanotti Stagliorio Coelho, M., Madureira, J., Tobias, A., Vicedo-Cabrera, A. M., Bell, M. L., Lavigne, E., Kan, H., Gasparrini, A., & MCC Collaborative Research Network. (2023). Short-Term Association between Sulfur Dioxide and Mortality: A Multicountry Analysis in 399 Cities. *Environmental Health Perspectives*, *131*(3), 037002. https://doi.org/10.1289/EHP11112

Ren, Y., Wu, Q., Wen, M., Li, G., Xu, L., Ding, X., Li, Z., Tang, Y., Wang, Y., Li, Q., & Wang, S. (2020a). Sulfur trioxide emissions from coal-fired power plants in China and implications on future control. *Fuel*, *261*, 116438. https://doi.org/10.1016/j.fuel.2019.116438

Ren, Y., Wu, Q., Wen, M., Li, G., Xu, L., Ding, X., Li, Z., Tang, Y., Wang, Y., Li, Q., & Wang, S. (2020b). Sulfur trioxide emissions from coal-fired power plants in China and implications on future control. *Fuel*, *261*, 116438. https://doi.org/10.1016/j.fuel.2019.116438

Saikia, B. K., Khound, K., & Baruah, B. P. (2014). Extractive de-sulfurization and de-ashing of high sulfur coals by oxidation with ionic liquids. *Energy Conversion and Management*, *81*, 298–305. https://doi.org/10.1016/j.enconman.2014.02.043

Salawu, E. Y., Akerekan, O. E., Afolalu, S. A., Kayode, J. F., Ongbali, S. O., Edun, B. M., Airewa, I., & Awoyemi, O. O. (2023). Condition monitoring and reliability assessment, an essential tool for Boiler Plant Maintenance—A review. *E3S Web of Conferences*, *430*, 01228. https://doi.org/10.1051/e3sconf/202343001228

Speight, J. G. (2021). *Coal-fired power generation handbook* (2nd edition). Wiley-Scrivener.

Tong, Y., Gao, J., & Ma, J. (2023). Emission Characteristics, Speciation, and Potential Environmental Risks of Heavy Metals from Coal-Fired Boilers: A Review. *Sustainability*, *15*(15), 11653. https://doi.org/10.3390/su151511653

Zhou, X., Gao, Y., Wang, D., Chen, W., & Zhang, X. (2022). Association Between Sulfur Dioxide and Daily Inpatient Visits With Respiratory Diseases in Ganzhou, China: A Time Series Study Based on Hospital Data. *Frontiers in Public Health*, *10*, 854922. https://doi.org/10.3389/fpubh.2022.854922

APPENDICES

APPENDIX 1 RESEARCH QUESTIONNAIRE

Researcher: B. Chigumbura: Bindura University of Science Education

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INVESTIGATING THE CAUSES OF ELEVATED SULPHUR DIOXIDE EMISSIONS FROM COAL-FIRED BOILERS AT DELTA BEVERAGES LAGERS SOUTHERTON PLANT, HARARE, ZIMBABWE.

Introduction

My name is *Blessed Chigumbura*. I am a final year student at Bindura University of Science Education (Registration No: B212832B), studying towards obtaining a Safety, Health and Environmental Management (SHEM) degree. As part of my curriculum requirements, I am undertaking research entitled *Investigating the causes of elevated sulphur dioxide emissions from coal-fired boilers at Delta Beverages lagers Southerton plant, Harare, Zimbabwe.*
The purpose of this questionnaire is to solicit information from boiler operators on the causes of elevated sulphur dioxide emissions. This will assist *at Delta Beverages' Lager Southerton plant in Harare* to avoid penalty costs from regulatory bodies and keep the environment clean. Your answers to this questionnaire will be CONFIDENTIAL and will not be given to anyone else without your written permission. Your honest response will be greatly appreciated.

Instructions

Pick one answer per question by simply ticking your answer or filling in where appropriate.

SECTION A: Socio-demographic Information

1. Gender?

   - Female
   - Male

2. Age in years?

   - 20-25
   - 26-35
   - 36-44

- >45

3. Marital Status

- Married
- Divorced
- Widowed
- Single

4. Highest educational level?

- Masters
- PhD
- Other

5. Years of experience in delta lagers----------------years.

6. Specific job role: boiler attendance, boiler technician, engineers, steam fitter, boiler room supervisor (please specify--------------------)

Section B: **Factors Leading to Elevated SO_2 Emissions**

7. Poor combustion efficiency

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

8. Fluctuations in boiler load

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

9. Inadequate air-fuel mixture control

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

10. Issues with burner performance

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

11. Other (please specify): ___________________________

How often have you observed elevated SO_2 emissions in specific situations?

12. During start-up or shutdown

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

13. Following a boiler trip or restart

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

14. How reliable do you find the current SO_2 emissions monitoring systems?

Not at all

- Slightly
- Moderately
- Very well
- Extremely well

15. How frequently do you calibrate or check the accuracy of these systems?

- Yes always
- Yes, sometimes
- No

16. How would you rate the consistency of the coal quality you typically use?

- Very low
- Low
- Moderate
- High
- Very high

17. How often do you receive information about the specific characteristics (e.g., sulphur content) of the coal batches you are using?

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

18. How significant do you believe the impact of the following sulphur content, ash content, calorific value, moisture content, and coal particle size distribution quality parameters is on SO_2 emissions?

- Very rarely
- Rarely
- Sometimes
- Often

- Very often

19. To what extent do you agree that there are adequate measures in place to ensure the quality of the coal being used is suitable for minimizing SO_2 emissions?

  - Not at all
  - Slightly
  - Moderately
  - Very well
  - Extremely well

20. How often are you informed about changes in coal supply or quality?

- Very rarely
- Rarely
- Sometimes
- Often
- Very often

Section C: Do you agree that there is a relationship between maintenance practices and SO_2

21. Regular and thorough maintenance of industrial equipment significantly reduces SO_2 emissions.

  - Strongly disagree
  - Disagree
  - Neutral
  - Agree
  - Strongly agree

22. Neglecting routine equipment maintenance leads to an increase in SO_2 emissions

  - Strongly disagree
  - Disagree
  - Neutral

- Agree
- Strongly agree

23. Implementing predictive maintenance strategies has a direct positive impact on controlling SO_2 emissions.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

24. Poorly maintained exhaust systems and filters contribute to substantially higher SO_2 emissions.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

Section D: Additional Comments and Suggestions

25. Are there any other factors not mentioned above that you believe significantly influence SO_2 emissions from these boilers? Please describe……………………………………………………………………………………………

…………………………………………………………………………………………………

APPENDIX 2 OBSERVATION CHECKLIST

Researcher: B. Chigumbura: Bindura University of Science Education

E-mail: blessedchigumbura00@gmail.com Cell: 0778 625 417

INVESTIGATING THE CAUSES OF ELEVATED SULPHUR DIOXIDE EMISSIONS FROM COAL-FIRED BOILERS AT DELTA BEVERAGES LAGERS SOUTHERTON PLANT, HARARE, ZIMBABWE.

This is normally used when the questionnaire of any other tool is used. There is no need for introductions.

Observer, tick under the appropriate column to record observations.

	YES	NO
Fuel Quality and Composition		
Is the sulphur content of the coal being used documented and within regulatory limits?		
Are there records available for supplier testing of coal quality?		
Has the boiler used any blend of coal or different fuel types that may affect SO_2 emission levels		
Are there any indicators of coal contamination or mixing with lower-quality coal?		
Is the coal storage area kept dry to minimize moisture content that can affect combustion?		
Is there a procedure in place for the regular testing of coal chemical composition?		
Combustion Process		
Is the combustion air (primary and secondary) properly adjusted?		
Are excess oxygen levels monitored and maintained within optimal ranges?		
Are combustion temperatures being monitored and maintained at optimal levels to minimize SO_2 emissions?		
Is there a system in place for regular maintenance and tuning of burners?		

Are there visual inspections for smoke or particulates from the stack during operation?		
Emissions Control Systems		
Does the boiler have an installed flue gas desulfurization (FGD) system?		
Is the FGD system operational and maintained according to the manufacturer's specifications?		
Are there regular monitoring and maintenance records available for the emissions control systems?		
Has the FGD system been tested for efficiency and effectiveness in removing SO_2?		
Is there a backup emissions control system in place in case of equipment failure?		
Stack Monitoring		
Is the emissions monitoring equipment calibrated and functioning properly?		
Are SO_2 emissions being continuously monitored and recorded?		
Is there a record of periodic stack testing for SO_2 emissions?		
Has there been a recent trend analysis of SO_2 emissions over time?		
Are there any anomalies in emissions data that require further investigation?		

END OF OBSERVATION CHECKLIST

APPENDIX 3: APPROVAL LETTER

DEPARTMENT OF ENVIRONMENTAL SCIENCE

Bag 1020 BINDURA,Zimbabwe

Tel:263-71-6505

Cell :0778371588 Email:vamugure @gmail.com

BINDURA UNIVERSITY OF SCIENCE EDUCATION

15 May 2025

Dear Sir/Madam

REOUEST FOR PERMISSION TO COLLECT DATA FOR ACADEMIC RESEARCH PROJECT.

PROJECT TITLE: INVESTIGATING THE CAUSES OF ELEVATED SULPHUR DIOXIDE EMI SSIONS FROM COAL-FIRED BOILERS AT DELTA BEVERAGES LAGER SOUTHERTON P LANT, HARARE.

ACADEMIC SUPERVISORS:Mrs L.Mabhungu

This letter serves to inform you that **Blessed Chigumbura,Registration Number (B212832B)**is a fourth year student at Bindura University of Science Education,in the Department of Environmental Science.During her fourth year of study she is supposed to d o a research project in her area of specialisation.

Please assist in any possible way.Data collected will be used for academic purposes only an d will not be published without your prior consent.

Thank you for your assistance.

Yours faithfully.

Yours faithfully.

Mr T. Nyamugu

DEPARTMENT OF ENVIRONMENTAL SCIENCE