PHYSICAL AND COMBUSTION CHARACTERISTICS OF LEACHED CANE TRASH BRIQUETTES

BY

GEOFFREY KUBULI MAKHANU

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DECLARATION

Declaration by Candidate

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Signature:____________________________________ Date:____________________

Geoffrey Kubuli Makhanu

TEC/PGMT/03/15

Declaration by Supervisors

This thesis has been submitted with our approval as University Supervisors.

Signature:____________________________________ Date:____________________

Dr. Obadiah Maube

Department of Manufacturing, Industrial and Textile Engineering,

Moi University,

Eldoret, Kenya.

Signature:____________________________________ Date:____________________

Dr. Patrick Nziu

Department of Manufacturing, Industrial and Textile Engineering,

Moi University,

Eldoret, Kenya.

DEDICATION

To him who is our source of love and knowledge

To Ryan, Fahren and Einstein who transforms my love into strength

and to the reader for whom knowledge becomes wisdom

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ABSTRACT

Sugarcane trash briquettes as a fuel allows nature conservation to be combined with energy production. Sugar cane trash is high in potassium (0.50% to 0.42%) and chlorine (0.02%). Raw biomass is not suited for thermal conversion due to its' low energy density, high ash content and operational problems. Some inorganic elements are water-soluble and can be removed by leaching. The main objective of the study was to determine the effect of leaching to the physical and combustion characteristics of leached cane trash briquettes. The specific objectives were to determine the leaching characteristics of inorganic and organic matter from cane trash; fabricate the leached cane trash briquettes; evaluate the physical and combustion properties of the leached cane trash briquettes and analyze the combustion emissions. Sugarcane trash was collected from agricultural fields at Sony Sugar Company and reduced into sizes of 1 mm,5 mm and 10 mm following ISO 17827. The reduced sizes were subjected to leaching tests of varying temperature and time. Temperatures were 25 ^{o}C, 50 ^{o}C, 100 ^{o}C and time was 5, 30 and 60 minutes respectively. Leached briquettes were produced at a constant compaction pressure of 18 Mpa using starch as a binder. Briquettes from fine comminution of (1mm) leached for 60 minutes at 100 ^{o}C resulted in a fuel with substantial reduction in ash 33% (4.14 to 2.77), chlorine 100%(0.02 to 0), sulfur100% (0.06 to 0.02), potassium 75.24%(19.18 to 7.08), silicon 4.2%(16.64 to 15.93) and magnesium 44% (0.54 to 0.30). Briquettes were characterized in terms of Bulk Density ASTM-E871 (304.24±3.72) Kg/m^3%, Mechanical Durability ASTMD440 (96.52±2.01)%, Ash ASTM-E1755 (3.12±0.41) wt.%, Moisture ASTM-E871(0.537±0.41)%, Volatiles ASTM-E872 (76.75±2.64) wt.% and Calorific Value ASTM-E711(17.81±0.41) MJ/kg. The calorific value was higher for the most severe treatment of Hot Soak, Long Duration, Pulverized Sugar Cane Trash (H-L-P) at 21.23 MJ/kg and lowest for the least severe treatment of Cold Soak, Short Duration, Chopped Sugar Cane Trash (C-S-C) at 14.51Mj/kg, the Mechanical Durability was 99.2 for H-L-P and 91.16 for C-S-C treatments; bulk density was 312 kg/m3 for H-L-P and 297 kg/m3 for C-S-C treatments. Ash content reduced with treatment severity with H-L- P having 2.66% and C-S-C attaining 3.95%. Improvements include increased Mechanical Durability (89.5 to 96.52) %, Bulk Density (274 to 304.24) Kg/m^3 and reduced Ash Content (4.14 to 2.77) wt.%. Leaching had effect of reducing emissions. Effects include increasing Higher Heating Value (16.85 to 17.99) MJ/kg and reducing CO (1484ppm to 698ppm). Other reductions were NO (199.80ppm to 147.0ppm), SO2(0.8ppm to 0.62ppm), NOx (205.9ppm to 175.8ppm) and Total Suspended Particles (62.20 mg/Nm3 to 35.38 mg/Nm3). In conclusion, leaching process has effects of increasing carbon and volatile matter and decreasing ash, chlorine, sulfur, and nitrogen compounds. Leaching improved the fuel properties of the feedstock, which is possibly due to the lower chlorine activity in terminating free radical chain reactions. Leaching as a pre-treatment method that improves the ignition and burning features of cane trash briquettes is highly recommended.

TABLE OF CONTENTS

DECLARATION ii
DEDICATION iii
ACKNOWLEDGEMENTS iv
ABSTRACT v
TABLE OF CONTENTS vi
LIST OF TABLES xi
LIST OF FIGURES xiii
ABBREVIATIONS xv
CHAPTER ONE 1
INTRODUCTION 1
1.1 Background of the Study 1
1.2 Problem Statement 4
1.3 Justification of the Study 5
1.4 Objectives 7
    1.4.1 Main Objective 7
    1.4.2 Specific Objectives 7
1.5 Significance of the Study 7
1.6 Scope of the Thesis 8
1.7 Outline of the Thesis 9
CHAPTER TWO 11
LITERATURE REVIEW 11
2.1 Introduction 11
2.2 Cane Trash as Biomass Resource 12
    2.2.1 Recovery of Cane Trash 13
2.3 Leaching effects on Removal of Mineral Elements in Biomass 14
    2.3.1 Cane Trash Acquisition and Preparation 17
    2.3.2 Biomass Leaching Methods 21
        2.3.2.1 Repeated Fresh Water Leaching Extraction Method 22
        2.3.2.2 Counter Current Leaching Extraction Method 23
2.4 Binders in Biomass Briquetting 24
    2.4.1 Classification of Briquette Binders 25
    2.4.2 Binder Selection 25

  - 2.4.3 A Review of Starch as A Briquetting Binder 26
- 2.5 Manufacturing of Briquettes 28
  - 2.5.1 Drying of the Biomass 29
  - 2.5.2 Biomass Size Reduction 29
  - 2.5.3 Binder Addition 30
  - 2.5.4 Biomass Densification and Particle Bonding Mechanism 31
- 2.6 Briquetting Machines 35
  - 2.6.1 Hydraulic Piston Press 35
- 2.7 Properties of Briquettes 36
  - 2.7.1 Briquette Physical Properties 37
    - 2.7.1.1 Geometry 37
    - 2.7.1.2 Biomass Composition 38
    - 2.7.1.3 Moisture Content 39
    - 2.7.1.4 Compaction Pressure 40
    - 2.7.1.5 Particle Size 41
    - 2.7.1.6 Bulk Density 42
    - 2.7.1.7 Briquetting Temperature 42
  - 2.7.2 Briquettes Combustion Properties 43
    - 2.7.2.1 Volatile Matter 43
    - 2.7.2.2 Fixed Carbon 44
    - 2.7.2.3 Ash Content 44
    - 2.7.2.4 Calorific Value 46
    - 2.7.2.5 Specific Heat of Dry Biomass 47
  - 2.7.3 Determination of Physical and Combustion Properties 47
    - 2.7.3.1 Cane Trash Density Analysis 47
    - 2.7.3.2 Determination of Moisture Content 48
    - 2.7.3.3 Determination of Ash Content 48
    - 2.7.3.4 Determination of Volatile Matter 49
    - 2.7.3.5 Determination of Fixed Carbon 49
    - 2.7.3.2 Determination of Calorific Value 50
- 2.8 Biomass Combustion 50
- 2.9 Emission Formation 51
- 2.10 Combustion Analysis 52
- 2.11 Gaseous and Particulate Emissions from Leached and Unleached Biomass 53

2.11.1 Gaseous Emission Measurement 54
2.11.2 Particulate Emission Measurement 55
2.11.3 Smoke Index Measurement 56
2.12 Research Gaps 57
CHAPTER THREE 59
RESEARCH METHODOLOGY 59
3.1 Study Area 59
3.2 Materials and Equipment 59
3.3 Experimental Design 60
3.3.1 Procedure for the Leaching Experiments 61
3.3.2 Particle Size Distribution 63
3.3.3 Elemental Analysis of Feedstock 63
3.3.4 Quantification of Organic Matter Species in Leachate Samples. 64
3.3.5 Identification of Organic Acids in Leachate Samples 65
3.3.6 Cassava Starch Preparation and Characterization 65
3.4 Fabrication of the Leached Cane Trash Briquettes 65
3.4.1 Briquette Manufacturing Procedure 66
3.5 Evaluating the Physical and Combustion Properties of the Leached Cane Trash Briquettes 66
3.5.1 Measurements on Physical Properties of Briquettes 67
3.5.2 Mechanical Durability 67
3.5.3 Test to Determine Briquettes' Bulk Density 68
3.5.4 Measurement of Combustion Properties 68
3.6 Analyzing the Gaseous and Particulate Emissions of Leached Cane Trash Briquettes 70
3.6.1 Measurement of Gaseous Emission 71
3.6.2 Gaseous Emission Measurement Procedure 72
3.6.3 Particulate Emission Measurement Procedure 73
3.6.4 Statistical Analysis 75
CHAPTER FOUR 76
RESULTS AND DISCUSSION 76
4.1 Leaching Characteristics of Inorganic and Organic Matter from Cane Trash Briquettes samples 76
4.1.1 Elemental Concentration after Leaching 76

4.1.2 Elemental Analysis of Ash after Leaching.....77
4.1.3 Leaching Effects on Organic Matter.....78
4.1.4 Electrical Conductivity.....80
4.2 Physical and Combustion Properties of Leached Cane Trash Briquettes.....81
4.2.1 Bulk Density.....82
4.2.2 Mechanical Durability.....84
4.2.3 Higher Heating Value.....85
4.2.4 Moisture Content.....87
4.2.5 Ash Content.....91
4.2.6 Volatile matter.....92
4.2.7 Fixed Carbon.....93
4.2.8 Evaluation of Physical and Combustion Properties of Leached Cane Trash Briquettes.....96
4.2.9 Effects of leaching time on selected physical and combustion properties of cane trash briquettes.....96
4.2.10 Effects of leaching temperature on selected physical and combustion properties of cane trash briquettes.....98
4.2.11 Effects of Particle size on selected physical and combustion properties of cane trash briquettes.....100
4.2.12 Analysis of the Gaseous and Particulate Emissions from Leached Cane Trash Briquettes.....102
4.2.13 Carbon Monoxides.....103
4.2.14 Nitrous Oxide.....105
4.2.15 Sulfur-dioxide.....105
4.2.16 Oxides of Nitrogen.....106
4.2.17 Flue Gas Temperature.....106
4.2.18 Total Suspended Particles.....106
4.2.19 Efficiency.....107
4.3 Effects of Independent Variables on Gaseous and Particulates Emissions from Leached Cane Trash Briquettes.....108
4.3.1 Effects of leaching time to gaseous and particulates emissions.....108
4.3.2 Effects of leaching temperature to gaseous and particulates emissions.....109
4.3.3 Effects of particle size to gaseous and particulates emissions.....110

CHAPTER FIVE..112

CONCLUSIONS AND RECOMMENDATIONS 112

5.1 Conclusions...112

5.2 Recommendations..113

REFERENCES 115

APPENDICES 132

Appendix A: Treatments Done to Raw Cane Trash...132

Appendix B: Leaching Results for Physical and Combustion Properties.............134

Appendix C: Leaching Experimental Results..135

Appendix D: Experimental Apparatus 139

Appendix E: Antiplagiarism Certificate..143

LIST OF TABLES

Table 2.1: Potassium and chlorine content before and after 4 extractions (% of DM) 23
Table 3.1: The 33 Factorial Experimental Design 61
Table 4.1: Results from the tests of original un-leached and leached cane trash samples 76
Table 4.2: Mass of Ash Related Elements in Sample, mg/g Dry Cane Trash 77
Table 4.3: Properties of the leachates obtained from water washing of cane trash samples at equilibrium leaching conditions. 79
Table 4.4: Electrical conductivity of excess leachate and expressed liquids from the laboratory cane trash investigation 81
Table 4.5: Physical and Combustion Properties 82
Table 4.6: Maximum and Minimum Leaching Run Results 82
Table 4.7: ANOVA Statistical summary for bulk density 83
Table 4.8: ANOVA Statistical summary for mechanical durability 84
Table 4.9: ANOVA Statistical summary for HHV 86
Table 4.10: Moisture content Leaching Run Results 88
Table 4.11: ANOVA Statistical summary for MC 89
Table 4.12: Moisture reduction levels between pulverized and chopped cane trash samples after pressing/milling 90
Table 4.13: ANOVA statistical summary for Ash content 92
Table 4.14: ANOVA statistical summary for Volatile matter 93
Table 4.15: ANOVA statistical summary for Fixed Carbon 94
Table 4.16: Summary of the gaseous and particulate emissions from unleached and leached cane trash briquettes 102
Table 4.17: Maximum and Minimum Leaching Run Results 102
Table 4.18: Descriptive statistics of gaseous and particulate emissions from leached cane trash briquettes 103
Table 4.19: Statistical Analysis Summary for gaseous and particulate emissions 103
Table A1: Cane trash treatments 132
Table B1: Results of physical and Combustion Properties from the 27 Runs 134
Table C1: Leaching of K relative to the experimental variables 135
Table C2: Leaching of Ca relative to experimental variables 135
Table C3: Leaching of Mg relative to experimental variables 136

Table C4: Leaching of Si relative to experimental variables......................................136
Table C5: Bulk Density Leaching Run Results 137
Table C6: Volatile Matter Leaching Run Results..137
Table C7: Fixed Carbon Leaching Runs Results...138
Table C8: Recorded mean emissions for the leached cane trash briquette samples. .138

LIST OF FIGURES

Figure 2.1: Repeated leaching extraction method..23
Figure 2.2: Counter current extraction of biomass 24
Figure 2.3: Briquette Manufacturing Process 28
Figure 2.4: An example of briquette made using a manual piston press 33
Figure 2.5: Schematic diagram of the experimental setup...54
Figure 3.1: Schematic Presentation of the Leaching Process 62
Figure 3.2: Fabricating Process of the Leached Cane Trash Briquettes 65
Figure 3.3. Schematic diagram for drop test..67
Figure 3.4: Diagrammatic representation of the experimental setup...........................71
Figure 3.5: Eurotron 3000+ analyzer for determination of gaseous emissions 72
Figure 3.6: The Eurotron Unigas 3000+ flue gas analyzer functional blocks 72
Figure 3.7: Method 5 sampling train...74
Figure 4.1: Comparison of HHV for the leached and un-leached cane trash briquettes 87
Figure 4.2: Change in moisture content resulting from pressing the cane trash biomass material 90
Figure 4.3: Differences in Ash Content among the leached and un-leached cane trash briquette samples under their respective treatment conditions. 91
Figure 4.4: Differences in the levels of fixed carbon between the leached and un-leached cane trash briquettes samples...95
Figure 4.5: Effects of leaching time to bulk density and mechanical durability 97
Figure 4.6: Effects of leaching time to VM, HHV, AC, MC and FC..........................97
Figure 4.7: Effects of leaching temperature to Bulk density and Mechanical durability 98
Figure 4.8: Effects of leaching temperature to VM, HHV, AC, MC and FC..............99
Figure 4.9: Effects of particle size to Bulk density and mechanical durability 100
Figure 4.10: Effects of particle size to VM, HHV, AC, MC and FC 101
Figure 4.11: Effects of leaching time to TSP, Tgas and Efficiency 108
Figure 4.12: Effects of leaching time to CO, NOx, SO_2 and NO 109
Figure 4.13: Effects of leaching temperature to TSP, Tgas and Efficiency 109
Figure 4.14: Effects of leaching temperature to CO, NOx, SO_2 and NO..................110
Figure 4.15 Effects of particle size to TSP, Tgas and Efficiency 110

Figure 4.16: Effects of particle size to CO, NOx, SO_2 and NO................................111

Figure. D1: Jeffco Cutter Grinder (Jeffress Bros. Ltd, Queensland Australia) used for particle size reduction of cane trash samples...139

Figure D2: Heating bath, heater and pump used to maintain temperature during "Hot" laboratory scale experiments...139

Figure D3: Leaching tank 140

Figure D4: hydraulic press..140

Figure D5: Bomb Calorimeter 140

Figure D6: Muffle furnace...141

Figure D7: Digital Scale 141

Figure D8: Combustion analysis system set up 142

ABBREVIATIONS

AAEM – Alkali and Alkaline Earth Metals

AC – Ash Content

ANOVA – Analysis of Variance

ASTM – American Society for Testing and Materials

BD – Bulk Density

BL – Brown Leaves

DoE – Design of Experiments

EC – Elemental Carbon

EFB – Empty Fruit Bunch

EPA – Environmental Protection Agency

FC – Fixed Carbon

GL – Green Leaves

HAP – Hazardous Air Pollutants

HCW – Hot Compressed Water

HHV – Higher Heating Value

ISO – International Organization for Standardization

MC – Moisture Content

MD – Mechanical Durability

OC – Organic Carbon

OGC – Organic Gaseous Carbon

OSHA – Office of Occupational Safety and Health

PAH – Hydrocarbons with a Polycyclic Aroma

ppm – Parts Per Million

PSD – Particle Size Determination

SOFC	– Solid Oxide Fuel Cells
TC	– Total Carbon
TOC	– Total Organic Carbon
TSP	–Total Suspended Particles
VM	– Volatile Matter
VOC	– Volatile Organic Compound

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Global fossil fuel deposits are declining at high rate because energy production and consumption on a global scale do not balance one another and the traditional energy sources may not be able to satisfy future demand. Throughout the last several decades, the global energy demand has been expanding at an alarming rate, and the uncontrolled use of fossil fuels has led to major challenges, including ozone layer depletion, global warming, and climate change (Rintoul et al. 2018). Undoubtedly, one of the biggest drawbacks of burning fossil fuels is environmental damage. Carbon dioxide (CO2), carbon monoxide (CO), and other gases produced by the intensive use of fossil fuels, a net carbon-emitting energy source, are principally to blame for global warming and ocean acidification (Rahman and Miah 2017). The melting of the polar ice caps, that is flooding on the low-lying areas and increase of sea levels are all caused by the rising of earth's temperature due to global warming (Wright et al. 2018). If these circumstances persist, Earth may soon experience serious consequences. Alternative natural renewable energy sources have received more attention as a way to create a balance between the energy demand and the finite traditional energy sources, such coal, oil, and natural gas (Bergstrom and Randall 2016). Many nations, including the United States, are making efforts to reduce greenhouse gas emissions by expanding the use of renewable energy sources (Nejat et al. 2015). Growing energy trends, a high demand for energy security, and the effects of climate change make a safe transition from fossil fuels to an energy source that is low-emission, sustainable, effective, and ecologically friendly all the more crucial. Conventional power plants that use traditional energy pollute the environment (Yank and Ngadi, 2016). There is need for alternative energy sources that is abundant, easy to find, renewable and sustainable. Biomass briquettes have proofed to be an attractive option in industrial combustion systems (Guo et al., 2015). Biomass material are derived from living or recently living biological organisms. Biomass energy can be turned into convenient forms, such as: solid, liquid, and gaseous forms, via different conversion processes. (Bergstrom and Randall 2016). Solid biofuels such as pellets, briquettes and cubes are a densified form of biomass and have received great attention in recent decades. Their growth has resulted in it becoming the second most commonly used renewable energy source (Van Loo and Koppejan 2012). There are several ways to convert biomass into useful products that largely depends on biomass characteristics and the end product (Sansaniwal, et al., 2017). The technologies applied in the conversion of biomass are mainly categorized under thermochemical or biological methods. The major options within thermochemical biomass conversion processes include combustion, gasification, pyrolysis, and liquefaction. The most practiced thermochemical conversion of biomass, industrially is the combustion process which is used for heat and in electricity generation. Most of biomass thermochemical conversions were carried out with or without the use of catalysts, even though the use of catalyst has distinct effects on the end-products (Kataki, et al.,2015). Biochemical biomass of conversion technologies refer to conversion of biomass through biological pre-treatments. These pre-treatments were aimed on turning the biomass into a number of products and intermediates through selection of different micro-organisms or enzymes. The process provides a platform to obtain fuels and chemicals such as biogas, hydrogen, ethanol, butanol, acetone and a wide range of organic acids (Chen and Qiu, 2015). However, this process was aimed at producing products that could replace petroleum-based products and as well as those obtained from the grains. Chen and Wang (2016) reported that biomass biochemical conversion technologies are clean, pure, and efficient when compared with the other conversion technologies.

Combustion is the simplest and direct technology available for biomass utilization (Oladeji, 2015). Sugar industry is one of the earliest and most successful users of biomass for commercial energy production. Nowadays biomass is considered to be the most promising source of renewable energy (Emerhi, 2011). Due to rising prices of coal, oil and natural gas, there is need to use non-sugar bearing components of sugarcane, called sugar cane trash, to produce energy (Rasugu, 2014). Sugar cane trash is herbaceous in nature. Usually, herbaceous crops have high ash content ranging from 20% to 30%. Sugar cane trash is high in potassium, silica, chlorine and other alkali and alkaline earth metals (Kassman et al, 2013). As compared to other commonly used energy sources, biomass is a quite laborious fuel. This results from its cumbersome nature. Besides, biomass fuel is heterogeneous and has a very low energy value related to the volume unit. However, burning biomass under poor combustion conditions can transform a significant portion of the fuel carbon into incomplete combustion products. Numerous literature (Want et al., 2018, Brozek, 2016, Mandal et al., 2019; Matus et al.; 2015 and Ndindeng et al., 2015) reports indicate the content of valuable nutrients in the ash from the combustion of biomass. Although, the elements in ash may also cause problems during combustion. The ash content in biomass is much smaller than in coals.

Their varying origins and chemical makeup have an impact on the burners' performance, among other things by increasing the accumulation of slag and ash in the stoves and the rate at which metal stove elements wear out owing to corrosion (Eriksson et al., 2018). These issues may result in higher maintenance expenses, decreased device availability and efficiency (Okot et al., 2018). Alkali metals and other inorganic components cause more emissions of particulates and oxides of nitrogen and sulfur, which are more harmful to the environment than other pollutants.

Additionally, trace elements in fuel gas harm catalysts used in solid oxide fuel cells and fuel/chemical synthesis (SOFC). Particulate matter from burning biomass fuel has been linked to a number of respiratory and cardiovascular problems (Orange et al., 2012). Particulate matter is created by the condensation of inorganic vapors from the incomplete combustion and fly ash, including potassium, sulfur, and chlorine (Gustafsson, 2011). Burning biomass naturally causes the production of hazardous gases in addition to particulate particles. Carbon monoxide (CO), different nitrogen oxides (NO, NO_2), and sulfur oxides (SOx) are among these harmful gases. The amount of sulfur and nitrogen present in the gasoline has a major impact on how quickly these emissions occur (Schmidl et al., 2011). These components are present in biomass fuel and produce difficulties during burning. Consequently, pretreatment is required before usage in order to improve fuel combustion.

Although previous study (Scot et al., 1997) identified the leaching potential for reducing these features, it has not yet established the ideal conditions for accomplishing this leaching. Under light of the foregoing, this research investigation used leaching pretreatment in a variety of temperature, particle size, and time settings to determine the most efficient conditions for removing problematic components from cane trash briquettes that cause slagging and fouling.

1.2 Problem Statement

Cane trash, along with other biomass fuels, contains elements including sulfur, nitrogen, chlorine, and heavy metals that, when burned, can produce hazardous air pollutants (HAPs). High concentrations of these elements in biomass can cause emissions of dioxins, furans, hydrogen chloride, sulfur oxides, and nitrogen oxides. Furthermore, incomplete combustion of biomass or biomass with high quantities of ash might result in increased particle emissions. The US Environmental Protection Agency (EPA) has determined that these emissions have a detrimental effect on both human health and the environment, including impacts such as smog, particle formation in the atmosphere, acid rain, and carcinogens. Additionally, due to their low energy density, raw biomass as cane trash is not well adapted for thermal conversions like combustion. Excessive ash might result in operational problems with the burners such slagging, agglomeration, and corrosion.

1.3 Justification of the Study

Sugar production on a commercial basis in Kenya was started in 1922 with the establishment of Miwani Sugar Mills in Western Kenya. Presently there are more than six operational millers in Kenya - Miwani, Chemelil, Mumias, Nzoia, Sony, Kabras, and West Sugar all in Western Kenya (Maina et al. 2011). The World Wildlife Fund (WWF) reported that the cultivation and processing of sugarcane is associated with negative environmental and social impacts through the loss of natural habitats, intensive use of water, heavy use of agro-chemicals, air and water pollution and loss of biodiversity (WWF, 2002).

According to Statistica Inc. Kenya (2023), as of 2021, the production of sugar cane in Kenya increased to roughly 7.1 million metric tons, up from 6.8 million metric tons in the previous year and was the highest amount in the last five years. This represented a growth of 4.23 percent. Every 10 tons of sugarcane harvested results in about three tons of cane trash. This means that a country's quantity of cane trash produced is directly proportional to the quantity of sugarcane harvested. Kenya's 7.1 million metric tons generate approximately 2.13 million tons of cane trash annually. While a large part of the cane trash are used as animal feed, other millions of metric tons are burned or left to decompose and produce methane gas. The World Health Organization (WHO) estimates that approximately 19,000 people die each year in Kenya due to air pollution (WHO, 2022). Sugarcane trash burning produces what the nearby communities refer to as " black smoke " which is particulate matter which when inhaled, can lead to increased risk of cardiovascular disease and lung cancer. It can also cause chronic conditions like asthma to worsen. Sugarcane trash fires are known to release polycyclic aromatic hydrocarbons (PAHs), some of which are thought to be carcinogenic, or cancer-causing. In contrast to the conventional practice of burning them in fields, which causes environmental pollution and other risks of fire escalation like burning sugarcane in nearby farms, this research offers an alternate use for cane trash. By establishing briquette manufacturing businesses, leached briquettes made from cane trash will increase farmers' revenue while also creating jobs. This is in agreement with Mati (2019) who argued that some of these leaves, that are commonly called cane trash in Kenya, can be collected to generate renewable energy. Awuor and Wambwa (2014) argues that more than ever there is need to scale up renewable energy to levels that would have a significant impact on the energy scene through deliberate interventions on policy and institutional environment; technology acquisition, development and integration; investment mobilization; and regional integration, networking, and capacity building. On their part Dweck and Leggett (1998) argue that renewable energy sources such as biomass can provide sustainable energy sources, based on the use of routinely available and indigenous resources.

1.4 Objectives

1.4.1 Main Objective

To determine the influence of leaching to the physical and combustion characteristics of leached cane trash briquettes.

1.4.2 Specific Objectives

1) To determine the leaching characteristics of inorganic and organic matter in sugar cane trash briquettes under the effect of leaching water temperature, leaching time and particle size.
2) Fabricate the raw and leached sugar cane trash briquettes.
3) Evaluate the physical and combustion properties of the leached sugar cane trash briquettes.
4) Analyze the combustion and emissions from leached cane trash briquettes.

1.5 Significance of the Study

Most prevalent leaching techniques are post-harvest and natural precipitation techniques. Liaw et al., (2013) analyzed the differences of leaching characteristics between batch and semi-continuous operation; meanwhile, Yu et al., (2010) investigated the effects of both the biomass to water ratio and leaching time during the washing process. Moreover, Bakker et al., (2003) studied the practical application of natural leaching for improving the thermal conversion of rice straw. Both techniques could effectively remove large quantities of alkaline compounds such as Chlorine, Sulfur and Potassium or Ash Content. The existing studies mainly focus on the ash sintering temperature removal of chemical compounds by leaching (Tonn et al., 2012).

However, a better understanding of the leaching characteristics of Alkali and Alkaline Earth Metals (AAEM) species in cane trash under various particle size, leaching water temperature, and leaching time circumstances is yet to be understood. These results will aid enterprises and offer a thorough database on leaching pretreatment for upcoming studies. This study also gives an insight on the available alternative for sustainable source of fuel from agricultural residues to alleviate the ever-increasing energy demand on already depleted forests. The study contributes in the attainment of the millennium development goals such as availability of cheap energy sources to reduce use of wood charcoal. The sustainable development goals would reduce poverty, by engendering micro-enterprises opportunities such as press production, locally fabricated briquetting machines and selling of briquettes. This study is aimed at improving health conditions by providing clean burning fuel and reduce inequality since the alternative fuel is affordable.

1.6 Scope of the Thesis

The raw material used was sugar cane trash. The variety of sugar cane (saccharum spp) used was CO 421 from Sony Sugar in Migori County. This variety was chosen because is the most dominant in the region. This research study is only concerned with the collecting, leaching, and briquetting of cane trash.

The study investigated how different leaching parameters such as particle size, leaching water temperature, and leaching time affect the leaching properties of Alkali and Alkaline Earth Metals (AAEM) species in cane trash. These parameters were selected because they can easily be varied under normal laboratory conditions and their effects could easily be monitored and recorded.

A briquetting hydraulic press (BHP) was used to make the briquettes, with a compaction pressure of 18 MPa and a compression ratio of 0.6 per second. This method was selected because it can generate final solid fuel in accordance with DIN 54385:2016-08 standard.

Leached cane trash briquettes were evaluated for their physical and combustion qualities. Physical properties which only include things like bulk density, moisture content and shatter index. The only combustion characteristics were the amount of ash, volatile matter, fixed carbon, and heating value. Physical qualities were investigated because they affect briquettes energy density, transportation, handling and storage. The combustion properties were investigated because: (1) Indicates the energy recovery from briquettes as is the case with the Calorific Value or Higher Heating Value (HHV). (2) the Volatile Matter (VM) enhances the sporadic burning and is also an indication of ignition rate in briquettes. (3) The Ash Content (AC) was studied because it causes increase in combustion remnants in the form of ash which lowers the heating effect of the briquettes and causes other operational problems in burners. The analysis of the leached cane trash briquettes' gaseous and particle emissions was completed. The type of gaseous emissions covered includes: Carbon Monoxide (CO), Nitrous Oxides (NO), Sulfur dioxides (SO_2) Oxides of Nitrogen (NOx),t5 these gases were investigated because they cause hazardous air pollution when burned.

1.7 Outline of the Thesis

This thesis analyses and presents the literature review and research methodology. Results and discussions of leaching characteristics of organic and in organic elements in leached cane trash briquettes were covered. The physical, proximate and ultimate properties of leached cane trash briquettes were experimentally determined and results discussed. The results and discussion of the gaseous and particulate emissions of the leached cane trash briquettes was also done. Therefore, chapter one is introduction to the whole study, chapter two is the literature review, chapter three is the methodology, chapter four is the results and discussion, chapter five is the conclusions and recommendations. Finally, references and appendices are presented. The referencing style used in this thesis was the American Psychological Association (APA) referencing system.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In the present global initiatives to cut greenhouse gas emissions and in efforts to replace fossil fuels, renewable energy sources are crucial. One of the most significant sources of renewable energy is biomass. Building intelligent energy systems using biomass as a primary energy source permits enhancing economic, environmental, and social benefits (Muazu et al., 2015). A possible feedstock that could aid in the switch to low carbon fuels is sugar cane trash. Numerous difficulties have been observed when burning agricultural feedstock, mostly in relation to energy value, ash, pollutants, corrosion, and combustion characteristics (Zhou et al., 2014).

The presence of alkali metals and other inorganic elements inherent in agricultural biomass when combusted creates elevated ash content. The ash content is 10 to 20 times greater than that of wood pellets. Corrosion, slag formation and emissions, all of which may have significant economic or environmental impact and ultimately limit the combustion potential of agricultural biomass (Orange et al, 2012). These limitations arise primarily from inorganic elements such as potassium (K) and chlorine (Cl) present in the raw material. Already, biomass has a significant impact on supplying the world's energy needs (Markson et al., 2013). The contribution can be greatly increased in the future by reducing greenhouse gas emissions (biomass is renewable and has less pollutants) and bringing about other environmental advantages. It can also contribute to energy security, trade balance improvement, rural community social and economic development, and better resource and waste management in our environment (Asamoah et al., 2016).

2.2 Cane Trash as Biomass Resource

Cane trash is the material left on the surface of the ground after harvesting sugarcane, and consists of all the leaves and the upper immature part of the stalk. Cane trash is also a potential energy resource of biomass containing one-third energy that of sugarcane (Pippo et al., 2013). However, its domestic applications are restricted due to lack of utilization awareness, technological impedance, harvesting difficulties and inadequate extension activities (Dhanushkodi et al., 2018). This review summarizes the end-use applications of cane trash suggested by worldwide researchers. The potential ways for utilization of cane trash for energy application were investigated and discussed with its merits, demerits and challenges for acceptance (Franco et al., 2013). In the present context, farmers utilize cane trash for open burning in the field (for destroying weeds and pests breeding places), mulching, compost making, fodder for livestock, burying infield to improve the fertility of soil and stacking for future use. Sugarcane produces nearly 8–10 tons of trash per ha. The utilization of this large quantity of trash for beneficial use is not possible for the farmers. Therefore, farmers usually burn the trash to clean the field for next crop, leading to pollution and energy waste (Jain et al., 2014). From reviewed data, it was found that the best end-use application of sugarcane trash is for energy generation.

Cane trash’s calorific value is similar to that of bagasse but has an advantage of having lower moisture content, and hence dries more quickly. Nowadays only a small quantity of this biomass is used as fuel, mixed with bagasse or by itself, at the sugar miller. Cane trash and bagasse are produced during the harvesting and milling process of sugarcane which normally lasts between 6 to 7 months. Cane trash can potentially be converted into heat and electrical energy (Alonso et al., 2014). Cane trash could be used as an off-season fuel for year-round power generation at sugar mills. There is also a high demand for biomass as a boiler fuel during the sugar-milling season. Sugarcane trash can also be converted in biomass pellets and used in dedicated biomass power stations or co-fired with coal in power plants and cement kilns.

2.2.1 Recovery of Cane Trash

The amount of trash recovered from sugarcane is dependent on factors such as harvesting system, (burned or unburned), topping height, cane variety, age of crop (stage of cut), climate and soil. The trash left in the field after harvesting is a function of the amount of tops and leaves available in the field prior to harvesting and of the harvesting system used (Paes and Oliveria, 2005).

There are a number of major technical and economic issues that need to be overcome to utilize cane trash as a renewable energy resource (Dhanushkodi et al., 2018). For example, its recovery from the field and transportation to the mill, are major issues. Alternatives include the current situation where the cane is separated from the trash by the harvester and the two are transported to the mill separately, to the harvesting of the whole crop with separation of the cane and the trash carried out at the mill. Where the trash is collected from the field it maybe baled incurring a range of costs associated with bale handling, transportation and storage. Baling also leaves about 10-20% (1-2 tons per hectare) of the recoverable trash in the field. A second alternative is for the cane trash to be shredded and collected separately from the cane during the harvesting process. The development of such a harvester-mounted cane trash shredder and collection system has been achieved but the economics of this approach require evaluation. A third alternative is to harvest the sugarcane crop completely which would require an adequate collection, transport and storage system in addition to a mill based cleaning plant to separate the cane from the trash. A widespread method for cane trash recovery is to cut the cane, chop into pieces and then it is blown in two stages in the harvester to remove the trash. The amount of trash that goes along with the cane is a function of the cleaning efficiency of the harvester. The blowers are adjusted to get adequate cleaning with a bearable cane loss.

On the average 68 % of the trash is blown out of the harvester, and stays on the ground, and 32 % is taken to the mill together with the cane as extraneous matter. The technique used to recover the trash staying on the ground is baling. Several baling machines have been tested with small, large, round and square bales. Cane trash can be considered as a viable fuel supplementary to bagasse to permit year-round power generation in sugar mills (Bizzo et al., 2014). Thus, recovery of cane trash in developing nations of Asia, Africa and Latin America implies a change from traditional harvesting methods, which normally consists of destroying the trash by setting huge areas of cane fields ablaze prior to the harvest. To recover the trash, a new so-called “green mechanical harvesting” scheme will have to be introduced. By recovering the trash in this manner, the production of local air pollutants, as well as greenhouse gases contributing to adverse climatic change, from the fires are avoided and cane trash could be used as a means of regional sustainable development (Negrete, 2019).

2.3 Leaching effects on Removal of Mineral Elements in Biomass

Leaching of cane trash can lessen ash fouling and slagging, corrosion, and environmental effects for thermochemical conversion systems. According to research by Turn et al., (2003). Leaching was employed as a feedstock pretreatment to enhance the qualities of sugar cane trash. Changes in ash fusibility, heating value, key element concentrations, and other parameters were analyzed to describe crude and leached cane trash. Major and trace elements as well as organic species were examined in the leachates. The results from the experiment suggest leaching to be an effective method to improve the cane trash fuel property, thereby improving the combustion performance and reduce gaseous and particle emissions. This creates an opportunity to use cane trash as a fuel for residential heating applications.

The causes of ash to slag and foul during the combustion and thermochemical conversion of biomass fuels was reported by Wang (2003). The author made the case that considerations for mitigating these occurrences and control methods should include feedstock selection and burner temperature management. Additionally, the presence of chlorine and sulfur in biomass speeds up the volatilization of alkali metals and may be a factor in the generation of acid gases and aerosols. At typical working temperatures, the quick production of sintered and fused glassy deposits was caused by the low ash melting temperatures and volatilization of alkali metals from the ashes of straw and other herbaceous materials. Stove fouling is caused by the condensation of inorganic vapors and particle deposition on heat transfer surfaces, and significant chlorine and sulfur emission speeds up corrosion.

According to a further analysis of the literature by Liu and Bi (2011), using biomass feedstock results in uncontrolled ash chemistry, which lowers conversion efficiency and raises maintenance and product costs for non-slagging reactor designs. Prior to use, it is advantageous to modify the feedstock to lower the levels of alkali metals, chloride, sulfur, silica, and other elements. However, a thorough investigation and consideration must be given to the expense of extraction.

Furthermore, a study by Deng et al. (2013) found that improving the characteristics of biomass feedstock for high temperature operations involves leaching the biomass with water as a solvent. In addition, some studies (Sastry et al., 2013) have demonstrated a decrease in the production of ash deposits. Alkali metals and chlorine bound in water-soluble salts are often removed through leaching. By changing the chemistry of the ash, it decreases the amount of ash in biomass and modifies the slag-forming procedures. Leaching decreases inorganic material dilution, increasing feedstock heating value.

Leaching can reduce corrosion and emissions of acidic pollutants, according to research by Thy et al. (2013). Leaching, according to the authors, may be able to lessen the development of harmful species during thermal processing, like dioxins and furans.

On the other hand, according to Roy and Corscadden's (2012) research, leaching also plays a significant role in the extraction of organic contents by increasing the value of the subsequent processing steps through coproduct recovery. For instance, ethanol fuels and chemicals could be created by the fermentation of leachates. Leaching can thereby produce sugars, lipids, organic acids, alcohols, oils, tannins, polyphenols, and proteins in addition to enhancing feedstock quality.

On the other hand, a 2013 study by Liaw and Wu found that in some circumstances, the simultaneous removal of organics when trying to extract inorganic components may result in unfavorable loss of dry matter. The amount of overall energy and economic worth decrease as a result of this loss of dry matter. The study's authors went on to say that their goal was to increase the amount of information that was already known about the solid-liquid extraction of both inorganic and organic elements from biomass feedstock utilizing leaching pretreatments. Those components Ion concentration measurements as well as those for organic acids, carbohydrates, and trace elements are included. Others include the approximate and final elemental compositions of raw and processed feedstock, as well as thermal characterizations for heating value and ash fusibility.

2.3.1 Cane Trash Acquisition and Preparation

According to Turn et al., (2003) Sugar cane variety B52298 was hand-harvested from test plots at HC&S. Roughly one fourth of the harvested material was stripped of all leaf (dead and living) and top material, leaving only the stalk portion. The remainder was maintained as whole cane (WC) including all leaf and top material. Process operations included chopping and milling. The prepared samples were then used in the leaching pretreatment.

Research by Solangi et al., (2018) with the aim to determine and quantify the composition and energy content of sugarcane trash. The study was carried out in the geographical area of Naushahro Feroze district, Sindh, Pakistan. The quantification of the sugarcane trash was done by estimating the total cultivated area of the sugarcane crop and by the knowing of the average sugarcane trash (brown leaves, green leaves and tops) quantity produced per tonne and sugarcane crop. The total sugarcane cultivated area in the district was estimated by survey, interviews of farmers, landlords and administrators of different sugar mills, and through satellite pictures. The production of sugarcane trash per tonne of sugarcane crop was determined by taking 40kg of sugarcane crop of each variety from the selected fields. The sugarcane trash produced per 40kg of the crop was weighted. Green leaves (GL), brown leaves (BL) and tops of each variety were collected and weighted separately.

The results included quantification, proximate and ultimate analysis, and energy content of different sugarcane trash varieties. The total average sugarcane trash was found to be about 24% of the sugarcane crop. Average GL, BL, and tops produced per 40kg of sugarcane crop were 8%, 11% and 5% respectively. The characterization of the sugarcane trash consists of proximate and ultimate analysis. The results of proximate analysis of the sugarcane trash samples are presented in Figure 2, with moisture content

(MC), volatile matter (VM), ash and fixed carbon (FC) measured for each part of each variety. MC in the brown leaves of all examined varieties was less, and tops was more among the different parts of sugarcane trash. The average moisture content in BL, GL and tops was 5.0%, 6.6% and 37.0% respectively. The least MC was found in BL of Sibea with 2.3%, the GL of 246 with 4.7%, and the tops of 234 with 23.6% therefore, these parts of sugarcane trash were found more practicable. As far as the VM was concerned, it was found more in the BL and less in the tops.

The average VM in BL, GL and tops is 75.1%, 74.4% and 41.5% respectively. The average ash content (AC) was found more in the tops, and less in the BL as compared to different parts of sugarcane trash. The average AC in BL, GL and tops was 3.8%, 4.3% and 4.9% respectively. The average FC was found greater in the BL, and less in the GL as compared to different parts of sugarcane trash. The average FC in BL, GL and tops was 16.7%, 14.5% and 15.9%. The FC content was found less in the GL and more in BL than the other parts of sugarcane trash. Three samples of each part of sugarcane trash were examined. It was found that the percentage of carbon is greater than other elemental percentages in the samples with oxygen being the second major element. The carbon percentage of samples lied between 40% and 50%. The percentage of hydrogen ranged from 3.5% to 6%, nitrogen ranged from 0.25% to 1%, oxygen ranged from 34.5% to 42.5% and sulfur ranged from 0.13% to 0.21%. The average values of carbon in BL, GL, and tops were found 46.6%, 44.3% and 41.8% respectively. The respective hydrogen percentage was 5.0%, 4.8% and 4.4%. Likewise, the nitrogen percentage was 0.4%, 0.8% and 0.62% respectively. The oxygen percentage was 39.7%, 37.5% and 39.0% and the sulfur percentage was 0.2%, 0.2% and 0.2%. Energy higher heating value (HHV) of the sugarcane trash was determined with the help of a bomb calorimeter. Eighteen samples of all parts of sugarcane trash, namely BL, GL and tops were examined. The recorded results showed that the energy content of the sampled BL lied between 14.0 and 17.7MJ/kg. The heating value of the sampled GL lied between 10.0 and 13.7MJ/kg. The heating value in tops was found between 11.0 and 15.0MJ/kg. It is observed that BL had the highest average HHV and GL the lowest among the other parts of sugarcane trash. The average heating values were: 16.0MJ/kg for BL, 12.5MJ/kg for GL and 14 MJ/kg for tops.

The results obtained during quantification, proximate and ultimate analysis and HHV were compared with the work of other researchers in the same field. The total sugarcane trash quantity in weight percentage reported in (Nachiappan et al., 2011) was 25.0% and 23.0% in (Smithers, 2014) and the obtained value was 24.0%. The BL percentages reported in (Hassuani et al., 2005) and (Smithers, 2014) were 14.0% and 12.3% respectively, whereas, the measured value was slightly less with 11.0%. Regarding the results of proximate analysis, it was found that the MC in BL, GL and tops of sugarcane trash determined in (Hassuani et al., 2005) were 13.5%, 67.7% and 82.3% and the obtained values were 5.0%, 6.6% and 37.0%. The VM content VM in BL, GL, and tops of sugarcane trash determined in (Hassuani et al., 2011) were 84.5%, 67.7% and 79.3% and the obtained values were 75.1%, 74.4% and 41.5% respectively. The AC in BL, GL and tops of sugarcane trash determined in (Hassuani et al., 2011) were 3.9%, 3.7% and 4.3%, and the obtained values were 3.8%, 4.3 and 4.9%. The FC content in BL, GL and tops determined in (Hassuani et al., 2005) were 11.6%, 15.7 and 16.4% and the obtained values were 16.7%, 14.5% and 15.9%. Regarding the ultimate analysis parameters, the carbon percentage reported by Treedet and Suntivarakorn (2011) and (Hassuan et al., 2005) was 51.2% and 45.3% respectively and the measured values were 44.2%. The hydrogen content given in (Hassuan et al, 2005) was 6.2% and report by Treedet and Suntivarakorn (2011) was 5.2% and the measured value was 4.7%. The nitrogen given in (Hassuan et al., 2005) was 0.8% and that reported by Treedet and Suntivarakorn being (2011) 1.9%, and the measured one was 0.6%. The oxygen level reported in (Hassuan et al, 2005) was 43.3% and in (Treedet and Suntivarakorn, 2011) was 40.3%, while the measured value was 38.7%. The sulphur percentage reported in (Hassuan et al., 2005) was 0.1%, in in (Treedet and Suntivarakorn, 2011) was 1.4% and the measured value being 0.2%. The Higher heating value (HHV) of sugarcane trash reported in (Hassuan et al., 2005 was 17.1MJ/kg and in in (Treedet and Suntivarakorn, 2011) was 18.3MJ/kg, while the measured value was 16.0MJ/kg. It is found that all results are comparable with the reported values of other researchers.

The determination of stalk yield, dry matter and nutrients accumulation (N, P, K, Ca, Mg and S) in sugarcane trash was reported by Henrique et al., (2014). The cane parts were separated in stalks, tops and dry leaves. After that, the samples were weighed, chopped in forage chopper and then, subsamples of each plant compartment were sent to the laboratory to determine the level of moisture by means of weighing before and after drying in oven of forced air circulation. Afterwards, these materials were ground, and 10 g of samples were analyzed for macronutrients (N, P, K, Ca, Mg and S) using the methodology described by Malavolta et al. (1997). Results from this study revealed that tops have approximately seven times more moisture than dry leaves. Taking moisture into consideration, it is possible to infer that collecting only dry leaves as opposed to the whole trash would be more interesting, if the trash should be removed at the same time as the stalks, since this would avoid the transportation of the biomass with high level of moisture from the field to the industry. To contribute the comparative analysis between the crop residues compartments, the levels of macronutrients present in the tops and dry leaves in the sugarcane harvest were analyzed. The tops presented the largest content of N, K, P and Ca, whereas the dry leaves had the highest concentration of Mg. Considering the main macronutrients in fertilizer formulation, tops contain around two, seven and five times more N, K and P than the dry leaves, respectively. That is justifiable because these three macronutrients are mobile in the plants phloem (Epstein and Bloom, 2006), and part of them are remobilized to the active parts of the plants (tops and roots system) along the sugarcane growth cycle.

2.3.2 Biomass Leaching Methods

For most applications the high inorganic content causes problems. Particularly Cl and K are problematic. Chlorine (together with K) contributes to corrosion problems in thermal conversion and K and Na are correlated with low ash melting temperatures causing ash slagging and agglomeration. In most cases Cl and K content of herbaceous biomass needs to be reduced by 10 to 20 times to fall within acceptable levels set by current thermal conversion standards. Fortunately, K and Cl (and Na) can easily be removed by leaching with water, which has been proven for many types of biomass.

InterTask project on Fuel pretreatment of biomass residues in the supply chain for thermal conversion case study was reported by Meesters et al. (2018). Case study number 5 was on leaching as a biomass pre-treatment method for herbaceous biomass. Sugar cane trash and palm oil mill residues were used as the materials.

Tests were executed on Oil Palm Empty Fruit Bunch (EFB) and Sugar Cane Trash. Both are typically underutilized residues which currently have little uses. Though a whole range of factors determine the quality for thermal conversion of biomass, the most fundamental desirable characteristics are low chlorine content, low ash melting temperature, and low nitrogen content (Elbersen et al. 2017). Fortunately, K and Cl (and Na) can easily be removed by leaching. This has been shown under field conditions for cane trash, switchgrass, Miscanthus, reed and wheat and rice straw. Two methods of water leaching were experimented.

2.3.2.1 Repeated Fresh Water Leaching Extraction Method

Research by Meesters et al., (2018) reported extraction experiments with EFB and Cane Trash. The experiments showed that the conductivity of the extracted fluid was reduced by 90% in four consecutive extractions with fresh water (Figure 1). The potassium and chloride concentrations were then reduced by approximately 80% respectively 90%. In this study, the water absorption of biomass is established. Three kilos of dry matter absorbed approximately 6 litres of water. Nine litres of water was then used in 4 extraction cycles. After 30 minutes for EFB and 15 minutes for Cane Trash of recycling, the conductivity of the liquid was stable (equilibrium presumably achieved). For each subsequent extraction, the final conductivity, and Chemical Oxygen Demand (COD), and concentration of potassium and chloride was reduced by a factor of two compared to the previous extract. Extraction experiments with EFB and Cane Trash have shown that conductivity of the extracted fluid is reduced by 90% in four consecutive extractions with fresh water as shown in Figure 2.1. The potassium and chloride concentrations are then reduced by approximately 80% respectively 90% as indicted in Table 2.1.

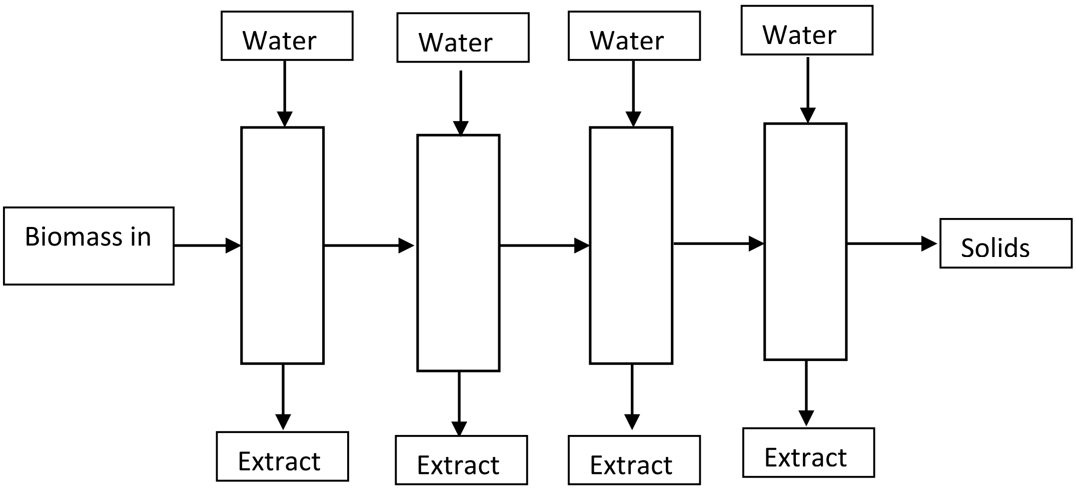


Figure 2.1: Repeated leaching extraction method

Table 2.1, Potassium and chlorine content before and after 4 extractions (% of DM)

Element		**Biomass material**	
		Empty Fruit Bunch (EFB)	**Cane trash**
K	Before	2.05	0.68
	After	0.40	0.07
Cl	Before	0.38	0.13
	After	0.02	0.033

The recovery of DM after extraction was 94% for EFB and 85% for trash.

2.3.2.2 Counter Current Leaching Extraction Method

Counter current extraction is a technology that can efficiently remove Cl and K using minimal amounts of water, making leaching as an upgrading technology for herbaceous biomass a viable option. Meesters et al., (2018) described the case of counter current extraction of sugar cane trash and oil palm residues as shown in Figure 2.2.

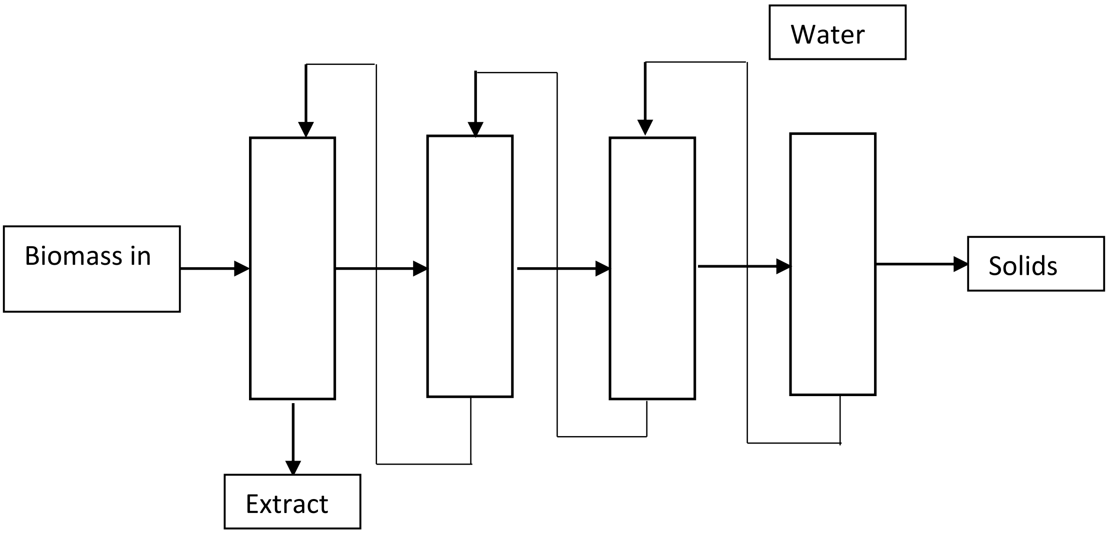


Figure 2.2: Counter current extraction of biomass

It is difficult to realize a counter current flow of solids against a liquid flow. Therefore, it was decided to apply a simulated moving bed. In a simulated moving bed, the solids are not really moving; instead, a series of valves take care that the liquid runs through the cleanest bed of solids first, and through the bed with the highest K and Cl concentration last. The high water usage could be reduced if the water is applied from the top instead of the bottom. This way, there is no need to completely fill the column with water, the column will act like a trickling filter. Simulations were executed to estimate the achievements of a counter current simulated moving bed extraction with trickling filtration. First of all, the ratio of extraction liquid compared to solids needs to be chosen. For a counter current liquid-liquid extraction, Kremser et al. (1984) have shown that high extraction efficiencies can be reached as long as the extraction factor (E) is chosen above 1.

2.4 Binders in Biomass Briquetting

When biomass is compressed at relatively high temperatures and pressures, naturally occurring structural binders or stabilizing substances like lignin and proteins are released and activated (Oyelaran et al., 2015). This enhances the biomass briquettes' structural particle bonding. To achieve the desired briquette hardness and durability, additional binders could be needed in some instances where the biomass does not contain a sizable amount of lignin or where densification circumstances make lignin insufficient as a natural binder. Organic and inorganic binders can be used to make briquettes.

2.4.1 Classification of Briquette Binders

The three major categories of briquette binders are organic, inorganic, and composite binders, as was already established. Organic binders often offer good binding qualities, including high impact and abrasion strength and high water resistance, according to Zhang et al., (2018).'s research. Unfortunately, they degrade rapidly at high temperatures because to low thermal stability and mechanical strength (Han et al., 2014). They are primarily distinguished by wide availability, affordability, good heating value, and low ignition temperature. Biomass (agricultural wastes, forestry wastes, etc.), tar pitch and petroleum bitumen (coal tar pitch, tar leftovers, etc.), lignosulphonate, and polymer binders are the four primary categories of organic binders (resins, polyvinyl, and starch). According to Miao et al., (2019), organic binders can be further classified into hydrophilic (such as biomass) and hydrophobic (such as asphalt and coal tar) binders based on how they react with water. Organic binders' weak thermal stability has made it difficult for businesses to use them for biomass briquetting (Yun et al.,2014).

2.4.2 Binder Selection

The availability, pricing, raw material characteristics, mixture moisture content, densification pressure, and required energy content of the briquettes are all important considerations when choosing binders for biomass briquetting (Olugbade et al., 2019).

The most crucial aspects taken into account while choosing binders in the majority of developing societies are the cost and accessibility of the binders. There has been research linking the type and quantity of binders used in biomass briquetting to the final briquettes' mechanical and combustion qualities (Lubwama et al., 2015, Aransiola et al., 2019, and Shone and Jothi ,2016). Also, different binders have different levels of influence on the characteristics of biomass briquettes. According to Aransiola et al., (2019) .'s investigation into the impact of various binders on the briquette qualities of carbonized corncob, briquettes made with corn starch had greater moisture content, relaxed density, and compressive strength than those made with corn starch plus gelatin. The strength and density of charcoal briquettes increased as the amount of African Elemi resin used as a binder rose (Kivumbi et al., 2021). Moreover, Lubwama and Yiga (2018) found that cassava starch created briquettes with higher physical and calorific qualities than clay binder in the creation of briquettes from rice and coffee husks using cassava starch and clay as binders. Therefore, it is crucial to consider how the type and amount of binders will affect the characteristics of the finished briquette when choosing binders for commercial biomass briquetting.

2.4.3 A Review of Starch as A Briquetting Binder

The majority of starch is collected from different crops, such as cereals, rhizomes, and roots, and it takes the shape of semi-crystalline granules that are specific to each crop source (Bertoft, 2017). The two main polysaccharide components of starch, amylose and amylopectin, establish intermolecular hydrogen bonds when heat and water are applied to the substance. This is accomplished by causing the starch molecules' granular structure to be disturbed, which then causes swelling, hydration, and solubilization (Ai and Jane, 2018).

This produces starch paste, a viscous solution that thickens as it cools. Increased viscosity occurs along with the change from granules to starch paste, increasing the paste's resistance to deformation and demonstrating high binding strength (Zobel 1984). Starch is still the most widely used biomass briquette binder in the literature due to its high energy content, good binding abilities in biomass densification, and chemical and structural characteristics (Chungcharoen and Srisang, 2020, Lubwama et al., 2015, Velusamy et al., 2021 and Okwu and Samuel 2018). However, because to its expensive price, low coking, and water-proof qualities, its usage in industrial briquetting has been restricted (Zhang et al., 2018). Native and modified wheat starches had a favorable impact on the mechanical, physical, and burning characteristics of charcoal briquettes, according to research by Borowski et al. (2017). However, differences in the briquette firing up time, burning time, temperature distribution, and smoke intensity were noted amongst the starch varieties. Starch was utilized by Wirabuana and Alwi (2021) to make briquettes from charcoal made from durian peel. The briquette had the best quality in terms of the parameters evaluated at 3% (w/w) starch concentration. Oyelaran, Bolaji, Waheed, and Adekunle (2015) showed improvements in the burning rates, specific fuel consumption, and thermal efficiency of the briquettes in their study examining the impact of cassava starch binder on groundnut shell briquettes. Shone and Jothi (2016) made briquettes out of dried teak and rubber tree leaves using cassava starch.

The leafy biomass does not cling effectively during compaction with lesser binder content, hence the authors suggested a 3:5 biomass binder ratio. While starch binders typically enhance the physical and mechanical characteristics of briquettes, Lubwama et al. (2015) showed that carbonized composite briquettes made from groundnut shells, coffee husks, and rice husks inhibited heat transfer. This implies that a more thorough analysis of the impact of binders on both the physico-mechanical and thermal properties of briquettes is need; an assessment that is currently lacking in the literature is required.

2.5 Manufacturing of Briquettes

In a research review by Sunday et al (2020), the process of briquette manufacturing and other influencing factors were studied. In this literature review, it was reported that the production process of briquettes involves the acquisition of the biomass feedstock, processing and eventual densification as shown in figure 1. The densification of biomass materials into briquettes usually starts with sorting and cleaning of the feedstock. This procedure is also called sieving, which is done to remove all unwanted materials ensuring that all the feedstock is of the required size (Oladeji, 2015). Figure 2.3 shows a flow diagram for briquette manufacturing process (Sunday et al, 2020).

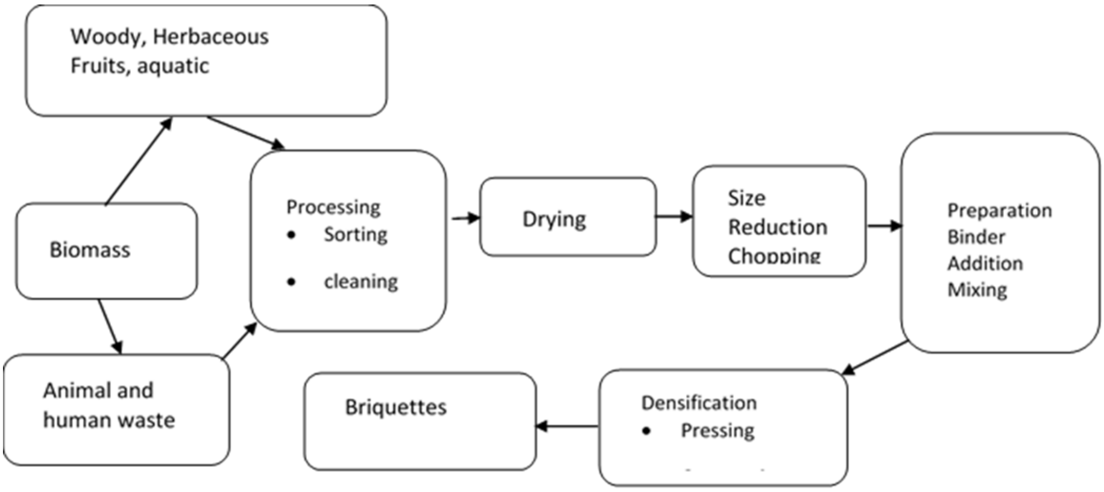


Figure 2.3: Briquette Manufacturing Process (Sunday et al, 2020)

To ensure that the feedstock is clean screening tools like sieves and magnetic conveyors are utilized to remove contaminants including soil, dirt, metal and plastic strings. These undesirable materials are created when residues are collected and stored. Another method of removing impurities produced by the application of alkali oxide, chemicals, and fertilizer in agricultural farms is to wash the materials with water. According to Said et al. (2013), washing biomass could enhance its ability to burn.

2.5.1 Drying of the Biomass

Although drying feedstock is necessary, especially if the feed is moist, some materials, such as coffee husk, peanut shells, and rice husk, may not often need to be dried (Bajwa et al., 2018). Drying of feedstock increases its efficiency but should not be excessively dried. Allowing a small amount of moisture helps in binding the biomass particles (Dinesha et al., 2018). In order to naturally dry feedstock without adding external heat, Salano et al. (2016) claim that the feedstock must be exposed to favorable climatic conditions to lower its moisture contents. Another method is industrially driven drying, which lowers the moisture content of biomass fuel to a predetermined range (5% to 15%) which is acceptable to begin densification. Grover and Mishra (1996) observed the usage of direct driers, in which hot air or flue gases are intimately combined with material, and indirect driers, in which heat is delivered to materials through a metallic surface, for biomass that needs to be forcefully dried. According to Purohit and Chaturvedi (2016), the drying process consumes the most energy and makes up roughly 70% of the total energy needed during the densification of biomass.

2.5.2 Biomass Size Reduction

Size reduction is a very important process prior to biomass briquetting. Tumuluru et, al (2010) noted that size reduction partially breaks down the lignin content of biomass and increases the total surface area leading to greater inter-particle bonding. Reducing biomass size also improves bulk density, which enhances biomass flow during densification (Pradhan et al 2018). There are a number of techniques for reducing particle size, including cutting, chipping, hammer milling, crushing, shredding, and grinding. Biomass that has been reduced in size was categorized as being chopped (50 to 250 mm), chipped (8 to 50 mm), or ground (8 mm) (Salano et al 2016). Another means of reducing the size of biomass before densification is through the use of sieve either by oscillatory screen method (ISO 17827-1) or by vibratory screen method (ISO 17827-2). The method to be used depends on the condition of the biomass feedstock. Tumuluru and Heikkila (2019) reported that woody and herbaceous biomass materials are ground in two stages. The biomass bundles are broken into larger pieces by the grinder in the first stage, which facilitates transportation in the conveyors. In the second stage, the biomass is further ground to a smaller size to prepare it for biochemical and thermochemical conversion processes. Hammer mills, knife mills, linear knife grids, and disk attrition are often used pieces of machinery that reduce the size of biomass prior to briquette densification. However, hammer mills are seen to be the most appropriate (Grover et al., 1996), with cutting mills coming in at a close second (Newbolt et al. 2018).

2.5.3 Binder Addition

Binders may be added either while the feedstock is being mixed or after the feedstock has been carbonized but before densification. Certain biomass materials won't aggregate unless a binder is added, especially if low-pressure compaction is used (Gendek et al., 2018). Adding a binder helps to densify the product or improves its mechanical or thermal qualities by co-processing biomass feedstock (Bajwa et al., 2018). Binder addition lessens the strain on the machinery used in production. It creates a bridge with biomass components to strengthen the inter-particle bonds (Pradhan et al, 2018). The amount of binder that needs to be applied depends on the raw materials and binding agent's ability to bind (Asamoah et al.,2016). The Inorganic, organic, and compound binders are the three types of binders used in the manufacturing of briquettes (Zhang et al, 2018).

Inorganic binders frequently used in construction include clay, lime, cement, plaster, and sodium silicate. As opposed to this, the organic binders are divided into four subcategories: biomass binders (such as tar, pitch, and petroleum bitumen binders), lignosulphonate binders, and polymer binders (Massaro et al., 2014). The compound binder is made up of two or more binders from from both the organic and inorganic binder categories. Although different briquette types may require different binders, the quality of the binders affects the briquette's strength, thermal stability, combustion performance, and cost (Altun et al., 2001). Because of its material constituents, one type of binder might have some advantages over the other. Comparatively, briquettes created with an inorganic binder have higher compressive strength, compaction ratio, and hydrophobic nature. But these briquettes exhibit a rise in ash content, a lower burn out temperature, and a lower calorific value (Onchieku et al., 2012). The binder must be plastic and elastic to produce fuel efficiently because doing so increases density, durability, and shear resistance (Bonassa et al., 2018).

2.5.4 Biomass Densification and Particle Bonding Mechanism

Similar to how Ahmed et al. (2014) describe densification in another review, the residues are subjected to pressure, heat, and a binding agent to create the briquettes seen in Figure 2. A series of processes known as "biomass densification" are used to turn biomass into fuel (Tumuluru et al., 2010). Essentially, it entails reducing the volume of loose material under pressure and agglomerating the material to keep the result in a compressed state (Eriksson et al, 1990). For the creation of a feedstock material appropriate as a commodity product, the densification process is essential. Several benefits of densification include (i) Increased handling and transportation effectiveness across the supply chain and infeed to the bio refinery, (ii) Enhanced feedstock uniformity and density through regulated particle size distribution, (iii) divided structural elements for better compositional quality, and (iv) Fulfillment of predetermined requirements for the conversion technology and supply system (Tumuluru et al, 2011).

Pelletizing and briquetting are the two most often utilized densification techniques for creating a homogenous feedstock commodity for bioenergy applications (Tumuluru et al, 2015). An agglomeration technique called briquetting is used to improve solid biomass and create finished goods with uniform features and traits. According to Surendra et al. (2011), it is a process that turns low-density biomass into high-density, energy-concentrated fuel. The goal is to increase the density, burn time, and calorific value (per unit volume) of raw biomass in order to make it easier to handle and carry (Tiwari, 2011). It lowers the cost of transportation by increasing bulk and energy density with comparatively little energy use (Ngusale et al 2014).

High pressure densification of biomass causes mechanical interlocking and enhanced adhesion between the particles, resulting in the formation of intermolecular interactions in the contact area (Grover et al, 1996). This is accomplished by applying mechanical force to the particles to bond them together, creating well-defined forms and sizes like briquettes (Kaliyan and Morey, 2010). The strength and persistence of the particle bindings, which are influenced by a number of process variables, including die diameter, die temperature, pressure, binders, and pre-heating of the biomass mix, determine the quality of densified biomass (Tumuluru et al, 2011). Manickam et al., (2006) reports on the particle bonding mechanism can be classified into five main sections, including

(i) attracting forces between solid particles, (ii) movable liquid surfaces' capillary pressure and interfacial forces, (iii) forces of cohesion and adhesion at non-movable binder bridges, (iv) reliable bridges, and (v) interlocked mechanisms.

SEMs were employed by Kaliyan and Morey [109] to comprehend the creation of solid-type bridges during the densification of maize stover and switchgrass. Results from the SEM pictures demonstrated that solid bridges were mostly responsible for the bonding between the particles. Natural binders in the biomass that were released during the densification process created the solid bridges between the particles. Ultraviolet auto fluorescence imaging of briquettes and pellets further demonstrated that natural binders like lignin and protein made up the majority of the solid bridges. It was discovered that for strong inter-particle bonding, activating the natural binders with moisture and glass transition temperature is crucial. More investigations utilizing methods like SEM and TEM at the micro level are needed. Tumuluru et al., 2011 recommended that additional research employing SEM and TEM techniques at the micro scale will be beneficial in figuring out how process variables interact with intra-particle cavities, material properties, and quality attributes of densified biomass.

However, according to Lim et al. (2012), densified biomass, like briquettes, has a number of benefits, including but not limited to increased energy density, ease of handling, transport, and storage. Improved combustibility, reduced particle emission, low volatility, and homogeneous size, density, and quality are further advantages. Figure 2.4 shows samples of briquettes made using manual piston press.

Figure 2.4: An example of briquette made using a manual piston press (Wu et al, 2019)

In contrast to granular waste, such saw dust, which includes microscopic particles, large waste particles require size reduction by shredding to simplify compression, according to a further literature study by Barasa et al. (2013). After that, the raw material is dried to remove moisture. The dry material can either be used to create carbonized briquettes or carbonized by pyrolysis to create carbonized briquettes. Pulverization is the process by which large char chunks are reduced to uniformly small pieces. Before briquetting, the processed raw material is next combined with a binder. The analysis showed that the quality of briquettes is determined by the type of biomass material (feedstock), pre-processing, briquetting process parameter, and technology.

There are two methods for briquetting: low pressure and high pressure. However, the method that makes use of high compaction pressure and temperature is crucial in creating briquettes that are more robust and have a higher energy density. Additionally, Barasa et al. (2013) noted that the screw press extruder, roller press, and piston press—all of which can be operated mechanically or hydraulically—are already available devices for briquetting. Additionally, since the products are intended to be alternatives to current fuels, money is needed for successful briquetting, and its economic viability must be assessed.

Barasa et al., (2013) go on to state that this evaluation is accomplished by examining the many expenses associated with it, including economic indicators like Net present value (NPV), Payback period (PBP), Internal rate of return (IRR), and Benefit cost ratio (BCR). The cost of briquettes should ultimately be less expensive and more effective than the cost of the fuels they are likely to replace in order to benefit both the producer and the end consumers. Both rural and urban locations can use biomass briquettes for residential heating purposes.

2.6 Briquetting Machines

In Asian, American, and European countries, the briquetting technology is more advanced than in African countries (Obi et al., 2013) The use of biomass has some benefits that have sparked the creation of cutting-edge technology for the production of fuels and energy (Malladi, 2018). According to Wilaipon (2009), the technology can be split into high-pressure and low-pressure compaction. Low (5 MPa), middle (5-100 MPa), and high compaction pressures were the three categories used by Eriksson and Prior in 1990. While the other employs a binder, high-pressure compaction method uses a heating device. Ahmed et al., (2014) divided the technology into piston press technology and screw press technology based on the tools employed. Machines for densifying and compacting biomass come in a variety of designs. Their methods of operation change depending on which principle is used. The screw press extruder, roller press, piston press (which might be mechanical or hydraulic), and manual press are examples of these machines (Kaur et al, 2017).

2.6.1 Hydraulic Piston Press

A cylinder driven by a hydraulic system applies the energy to the piston. The hydraulic system pressure, which is typically limited to 30 MPa, is the reason why briquetting pressures with hydraulic presses are so low, according to Eriksson and Prior (1990). When the piston head is smaller in diameter than the hydraulic cylinder, it can apply more pressure, although in commercial applications, the pressure gearing up is not very significant. These machines typically have production rates of 50 to 400 kg per hour, and they can handle moisture concentrations over the 15% that is typically acceptable for mechanical piston presses. Due to the pressure limitations, it often creates briquettes with a bulk density lower than 1000 kg/m^3 (Tumuluru et al., 2011). The quality of the product is significantly higher here than with mechanical presses, and the briquettes produced generally have a uniform size and shape. Typically, 40 mm diameter x 40 mm height cylindrical shapes are used. Furthermore, a hydraulic press, which often works with paper, cardboard, and manure, can occasionally be used in place of a mechanical press (Eriksson and Prior, 1990).

2.7 Properties of Briquettes

The quality of briquettes is dependent on the raw materials and the briquetting process. The desired qualities for briquettes as fuel include good combustion, stability and durability in storage and in handling (including transportation), and safety to the environment when combusted (El-Haggar, 2007). Combustion and environmental safety are dependent mostly on the nature of the raw material. This nature includes the structure such as: size, fibrous and non-fibrous. Chemical such as lignin-cellulose content. Physical such as: particle size, density, and moisture content and purity such as elements like sulfur. Combustion is measured by parameters such as calorific value, ease of ignition, and ash content, while environmental concern is measured by the toxic emissions during combustion. The briquetting process, on the other hand, determines the durability and stability of briquettes.

Compressive strength, abrasion resistance, impact resistance, moisture absorption, and density are basically the parameters that determines durability and stability. They are considered as the most important quality parameters of densified biomass (Gilvari et al 2019). The quality of briquettes is characterized in terms of physical, mechanical, chemical, and thermal properties, depending on the measured parameters. It is also indicative of the effectiveness of the densification process and influences their ability to endure certain impacts because of handling, storage, and transportation.

According to research by Asamoah (2016), briquettes are made of different qualities and dimensions depending on the raw materials, mold, and technologies applied during production. Briquettes vary a lot in size and form, but usually they are of a cylindrical shape with a diameter of between 25 and 100 mm and lengths ranging from 10 to 400 mm. other briquettes shape such as square, rectangular, and polygonal briquettes also exist. Research by Ayhan. and Ayse (2010); the briquette quality depends on geometry, composition, particle size, material density, compaction pressure, and moisture content.

2.7.1 Briquette Physical Properties

2.7.1.1 Geometry

According to a study by Krian et al., (2011), the shape of briquettes with slots and flutes increases the surface area to volume ratio, which in turn boosts air supply for quicker igniting. For generating briquettes with a high degree of shape perfection, a hydraulic press is advised. For the densification of biomass resources, particle size and shape are crucial. It affects the briquetting process, production costs, and briquette quality (Zhang and Guo, 2014; Ndindeng et al., 2015). (Wang et al, 2018). (Grover and Mishra, 1996) state that biomass feedstock with a particle size of 6 to 8 mm and a powdery component of 10% to 20% (4 mesh) often produces the best results. The ideal particle size, however, continues to be a matter of debate. According to certain research, a feedstock material that has been ground more finely (by about 2 mm) provides a bigger surface area for bonding, which leads to the creation of briquettes that are denser, stronger, and more durable (Mitchual et al,2013) Others, however, observed that durability and other quality factors favored larger sized particles (Emerhi, 2011). Brunerová and Broek (2016) stated that the study's results did not support the view that smaller particle sizes are more suitable for briquette manufacture when assessing the optimal particle size of pine and spruce bark. The report also stated that although feedstock composition unquestionably influences the choice of ideal particle size, it hasn't been generally established. When there is a mix of fine and coarse particles, the distribution of particle sizes is frequently of greatest significance. The packing dynamics are improved by combining different particle sizes, according to Grover and Mishra (1996) and Yumak et al. (2010), and this also increases the strength and stability of briquettes.

2.7.1.2 Biomass Composition

Moreover, literatures review by Sastry et al (2013) reports that material composition and compression pressure are very vital in briquette making. Onuegbu et al (2011) reveals further that the composition of a material is among the factors that control burning rate, density, compression strength and calorific value of briquettes. Similarly, Akowuah et al., (2012) reports that the composition of carbonized feedstock to produce briquettes varies with species and greatly affects their quality. Biomass mainly consist of cellulose, hemicelluloses, and lignin including extractives like fats and resins. Heterogeneous branching polysaccharides make up hemicellulose, which is firmly bonded to the surface of cellulose microfibrils. It is amorphous by nature, possesses adhesive qualities, and has a strong propensity to become tougher when dehydrated (Tursi, 2019). Lignin is a complex amorphous aromatic polymer with a three-dimensional network made up of connected phenyl propane units that is found in plant cell walls. Lignin acts as an in-situ binder in the input material, facilitating the binding process at high temperatures when it softens (Kaliyan and Morey, 2009), allowing for the production of more durable materials (Gendek et al, 2018). Additionally, when burned, it produces more energy than cellulose (Tumuluru et al., 2011).

2.7.1.3 Moisture Content

According to a study by Grover and Mishra from 1996, a crucial element in the manufacture of briquettes is the feed biomass's moisture content. Moisture should be as minimal as feasible since it helps bonding by enhancing compression by raising van der Wall's forces. Because combustion efficiency is decreased by an increase in moisture content. For high-quality briquettes, the raw material needs to be dried to a moisture level that falls between 10% and 15%. The amount of moisture in the biomass feedstock is a crucial factor in determining the overall quality of the biomass briquette. The processes of starch gelatinization, protein denaturation, and fiber solubilization are made easier during the briquetting process by the moisture level of the biomass (Tumuluru et al,2010). It reduces friction between the leftover particles by acting as a lubricant (Dinesha et al, 2018). Furthermore, it acts as a binder and creates a solid link between particles using van der Waal forces (Mani et al, 2003). While densification may be aided by moisture concentrations between 12% and 20% (w.b.) at room temperature, densification may not be achievable above 20%. (w.b.). (Werther and others, 2000) Broek (2016) employed four moisture levels to analyze the effects of moisture on the final qualities of briquettes manufactured from platan tree chips: 5.7%, 7.7%, 15.7%, and 23.9%. Results indicated that briquettes manufactured from chips with a moisture content of 7.7% had the optimum characteristics. The study came to the conclusion that the briquettes' rupture force and density were severely failing at greater or lower moisture levels. Similar to this, Mat et al. (2015) found that the initial moisture content of spruce sawdust measured right before densification at 7.4%, 9.1%, 10.3%, 11.7%, 12.6%, 14.5%, 16.5%, 19.6%, and 22.0% w.b. affected physical and mechanical qualities. The study found that a starting moisture percentage of 12.6% created the best briquettes. Prior to densification, it is crucial to achieve a balance for the moisture content to guarantee the quality of the briquettes. For instance, low moisture content will prevent the feedstock's particle agglomeration from occurring properly. On the other hand, a high moisture content would require more energy during the drying process, increasing the cost of the finished product. According to Asamoah et al. (2016), optimal moisture content varies depending on the type of feedstock; as of now, a value in the range of 8% to 12% is regarded as the universal optimum densification value (Kaliyan et al, 2009). When lignocellulosic materials are exposed to the high temperatures and pressures found in briquetting machines, the proper quantity of moisture causes the materials to develop self-bonding characteristics (Oladeji, 2015).

2.7.1.4 Compaction Pressure

Ugwu and Agbo's (2013) research indicates that a briquetting machine, which can be either a screw or a piston press, is typically used to apply the compaction pressure. In order to densify the trash, which increases its volumetric calorific value and lowers the fuel's transportation costs, compaction pressure is necessary (Oladeji, 2015).

According to a further analysis by Markson et al. (2013), while utilizing a binder to briquette is sufficient at low compaction pressure, the particles must effectively bond during compression to keep the briquettes from collapsing. Porosity decreases as a result of an increase in briquette bulk density, which follows an increase in compaction pressure.

Both high and low compaction pressures can result in the densification of biomass. The type of feedstock, moisture content, particle size and pressure to be applied are often determined by these factors. A binding agent is needed to promote inter-particle bonding during densification under low compaction pressure. In order to facilitate inter-particle interaction, high-pressure densification makes use of the natural binding substances squeezed out of the biomass materials' particles, such as starch, protein, lignin, and pectin. Dinesha et al. (2018) claim that applying pressure causes plastic and elastic deformations as well as the filling of spaces, which results in the development of greater density briquettes. Briquettes' density, compressive strength, and durability are affected by the compaction pressure.

Pressure was changed from 5.1 to 15.3 MPa by Kpalo et al. (2019) to manufacture briquettes made from wastepaper and Mesua ferrea mixtures at various ratios. According to the study, for each ratio of briquettes, pressure at 15.3 MPa resulted in the maximum densities, while pressure at 5.1 MPa resulted in the lowest densities. Additionally, Chin and Siddiqui (2000) observed that the shear strength of biomass briquettes increased from 27.5 to 95.7 N (sawdust), 1.2 to 4.6 N (rice husk), 1.3 to 6.7 N (peanut shell), 10 to 73.3 N (coconut fiber), and 10 to 36.2 N when the densification pressure was adjusted from 1 to 10 MPa. According to Kaliyan and Morey (2009), high pressure promotes densification of biomass and proposes a range of at least 100-150 MPa. However, investigations have shown that low compaction pressure might result in the production of inexpensive, long-lasting briquettes. (2016) Yank et al.

2.7.1.5 Particle Size

According to research by Katimbo et al., (2014), a material's particle size is crucial when creating briquettes. Additionally, Ayhan and Ayse (2010) investigated how charcoal briquettes' combustion qualities are impacted by particle size and size distribution. According to a further analysis by Davies & Abolude (2013), an increase in particle size results in an increase in volumetric calorific value, a decrease in ash content, and an increase in thermal efficiency. However, despite the poor flow properties of very small particles, it was noticed in the study by Vassilev, S.V. et al. (2013) that adding 10 to 20% fine particles promotes cohesiveness, which in turn raises the compressive strength of briquettes.

2.7.1.6 Bulk Density

Densy is a particularly important metric, according to a study by Krian et al. (2011), because its value strongly correlates with the energy to volume ratio and the ease of handling during storage and transit. Furthermore, a study by Davies and Abolude (2013) confirmed that the density of the briquettes is influenced by the raw material's density, compaction pressure, binder ratio, and particle size.

2.7.1.7 Briquetting Temperature

Before and during the briquetting process, temperature has an impact on the die of the briquetting machine as well as the biomass feedstock. It facilitates the release of substances including lignin, cellulose, and hemicellulose, which serve as binders. High temperature and pressure are generally accepted to improve binding processes but need significant energy input, according to Yank et al., (2016). Grover and Mishra (1996) recommended keeping the preheating temperature in a screw press extruder between 280 and 290 ^{o}C and not above 300 oC to prevent the degradation of biomass feedstock. Okot et al., (2018) examined the densification of maize cob briquettes at temperatures ranging from 20 to 80 ^{o}C. The investigation came to the conclusion that densification at 80 ^{o}C might result in briquettes with the high density, durability, and mechanical strength needed to pass quality certification standards. The temperature range of 60-150 C was one of the process parameters used by Mandal et al. (2019) when briquetting pine needles. According to study findings, briquette production is best at a temperature of 150°C. Kaliyan and Morey (2009) suggested that the ideal temperature for preheating feedstock should be between 65 and 100 °C, but they also noted that temperatures as high as 300 °C might be used if needed. Grover and Mishra (1996) claim that increasing the temperature of the die will reduce friction between the feedstock and die wall, allowing for densification. Low pressure is used to create poor-quality briquettes. Low temperatures, on the other hand, will increase pressure and energy use. Additionally, it produces briquettes of greater quality at a slower rate.

2.7.2 Briquettes Combustion Properties

2.7.2.1 Volatile Matter

The volatile matter represents the components of carbon, hydrogen and oxygen present in the biomass that when heated turn to vapour, usually a mixture of short and long chain hydrocarbons. It is determined by heating a dried ground sample of biomass in an oven at 900oC for 7 minutes. The amount of volatile matter in the biomass can then be calculated as percentage of the weight loss of the sample. In almost all biomass, the amount of volatile matter is higher than in bituminous coal. Biomass generally has a volatile content of around 70-86% of the weight of the dry biomass (Loo, 2008), compared to coal, which contains only about 35% volatile matter. Consequently, the fractional heat contribution of the volatiles is more for biomass (Dermirbas, 1999). This makes biomass a more reactive fuel than coal, giving a much faster combustion rate during the depolarization phase. The volatile content has been shown to influence the thermal behaviour of the solid fuel (Loo, 2008), but this is also influenced by the structure and bonding within the fuel, and is therefore hard to quantify. Low-grade fuels, such as dung, tend to have a low volatile content resulting in smouldering combustion. The consequences of this for cooking on a woodstove are that the hot gases are less likely to impinge on the bottom of the pan and there will be less radiative heat transfer (because of the lack of flames), reducing the heat transfer efficiency (Burnham-Slipper, 2008). After the volatiles and moisture have been released, ash and fixed carbon remain. The relative proportion of volatiles, moisture, fixed carbon and ash are often quoted for biomass fuels.

2.7.2.2 Fixed Carbon

The percentage of fixed carbon is normally determined by difference from the other quantities (Dermibas, 1999), and is given by:

Fixed Carbon=100 %-(%ash+%moisture+% volatiles)

Essentially, the fixed carbon of a fuel is the percentage of carbon available for char combustion. This is not equal to the total amount of carbon in the fuel (the ultimate carbon) because there is also a significant amount released as hydrocarbons in the volatiles. Fixed carbon gives an indication of the proportion of char that remains after the devolatisation phase.

2.7.2.3 Ash Content

Ash is the non-combustible component of biomass and the higher the fuel’s ash content, the lower its calorific value (Loo, 2008). It is both formed from mineral matter bound in the carbon structure of the biomass during its combustion (Ragland, et al, 1991) (the inherent ash), and is present in the form of particles from dirt and clay introduced into the fuel during harvest, transport and processing (the entrained ash) (Loo, 2008). The ash content is determined by heating a dry sample of biomass in an open crucible in a furnace at 900^{o}C. Depending on the type of biomass, the ash content can vary between 0.8% for groundnut shells (Jekayinfa and Omisakin, 2005), for example, to as high as 23% for rice husks (for means of comparison pine wood has an ash content of around 1% (Dermibas, 1999). Tables of data for a range of biomass residues are given by Demirbas. Ash is known to cause problems in combustion systems, notably because of slugging and fouling, and its tendency to increase the rate of corrosion of metal in the system (Loo, 2008). There have been various empirical indices which have been developed to try and quantify this undesirable behaviour by relating it to the composition of fuels. These have mainly been for fuels such as coal, and have proved of limited value for biomass. However, one simple index which has become popular is known as the alkali index. This expresses the quantity of alkali oxide in the fuel per unit of energy. Above a certain determined threshold, fouling is more probable. Straws and grasses, for example, have relatively high alkali indices, which is consistent with the high ash content of these fuels. Although the alkali index does not fully describe the expected fouling behaviour, it is useful as a general guide (Jenkins et al, 1998). Further details on the effect of biomass composition on ash formation are given in the review by Jenkins et al. If the alkali metals are removed from the biomass, it is known to increase the fusion temperature of the ash, the temperature at which it conglomerates together. Experiments have shown that this can be done by washing or soaking the biomass in water to leach the alkali metals, and this gives significant reductions in the fusion temperature of ash. In fact, this simple technique has been shown to remove more than 80% of the alkali and most of the chlorine, which has the added advantage of reducing corrosion and acid gas emissions (Jenkins et al, 1996). This is significant for the briquettes produced by the low pressure wet technique, as described, because, as part of the procedure, most biomass is soaked in water for a significant period of time, thereby leaching the alkali metals and producing briquettes which will burn with the aforementioned benefits. Nevertheless, the ash-fusion behaviour is important in determining the propensity for the formation of slag deposits, which can occur at temperatures around 1300^{o}C (Ragland, 1991). In practical cooking situations such temperatures would probably not be reached, and slugging of cook stove surfaces is unlikely to be experienced. However, when fuels with high ash content are burnt in cook stoves, the residual ash, if not mostly removed, will adversely affect the clean air flow in the cook stove. This must be taken into account in cook stove design, so that the stove performance is not significantly impaired due to inadequate air flow due to a build-up of ash. On the other hand, a thin layer of ash helps in the distribution and preheating of incoming air, enhancing combustion efficiency. When biomass with a high ash content is burned regularly, the effect of the corrosive nature of ash on the cook stove durability would need to be considered (Ragland, 1991), for example with rice husk briquettes. Furthermore, ash can also have a significant influence on the heat transfer to the surface of the fuel, as well as affecting the diffusion of oxygen to the fuel surface during char combustion (Kim et al, 2001).

2.7.2.4 Calorific Value

The calorific value (or heating value) is the standard measure of the energy content of a fuel. It is defined as the amount of heat evolved when a unit weight of fuel is completely burnt and the combustion products are cooled to 298K (Markson et al., 2013). When the latent heat of condensation of water is included in the calorific value it is referred to as the gross calorific value (GCV) or the higher heating value. However, in stoves, any moisture that is contained in the fuel and which formed in the combustion process is carried away as water vapour, and so its heat is not available. It is useful, therefore, to subtract the heat of condensation of this water from the gross calorific value. The result is known as the net heating (NCV) or lower heating value. The heating value of a particular fuel relates to the amount of oxygen that is required for complete combustion. For every gram of oxygen burnt, 14,022 joules of energy are released. Consequently, fuels containing carbon with a higher degree of oxidation will have a lower heating value, because less oxygen is required for their complete oxidation. In contrast, when fuels contain compounds such as hydrocarbons, which have a lower degree of oxidation, this tends to raise the heating value of the biomass (Bridgeman et al., 2010). It is for this reason that biomass fuels, in which the carbon is present in a partly oxidized form, have a lower heating value than coal. There have been various attempts at correlating the heating value to the composition of the material, and it has been found that the higher heating value of biomass can indeed be calculated from elemental composition. For example, the Vondracek formula originally developed for coal has been found to give a good approximation (Buckley, 1991).

2.7.2.5 Specific Heat of Dry Biomass

This is a measure of the average energy required to raise the temperature of a unit volume of the solid by one degree. As heat is transferred into the solid, this affects the rate at which material within reaches a sufficient temperature for pyrolysis to occur. For a particular solid, specific heat capacity varies with moisture content, temperature (Ragland, 1991) and with the degree of thermal degradation, as pyrolysis progresses (Kanury, 1970). Ragland et al. give equations for the variation of heat capacity with moisture content. However, a measurement of the variation with respect to degree of thermal degradation is not discussed in detail in this literature, and therefore is an area that requires further work.

2.7.3 Determination of Physical and Combustion Properties

2.7.3.1 Cane Trash Density Analysis

The bulk density will be determined by calculating the ratio of the mass to the volume occupied. A container of known volume will be weighed. The container will then be filled with each sample and reweighed. The difference between the initial weight of the container and the final weight is the weight of the sample. The bulk density is then calculated from the equation 2.1.

$Bulk\ density = MT_C/VT_C$ ……………………………………………….2.1

Where:

TM = Total Mass of the sample and the container

MC = Mass of the container

VT_C = Volume occupied by the Cane Trash

MT_C= Mass of Cane Trash= TM-MC

2.7.3.2 Determination of Moisture Content

The moisture content of sugarcane Trash will be determined by the oven drying method. This will be carried out at temperature of 105 ± 5 ^oC in accordance with the ASTM D 1037 (1991). The moisture content will then be calculated using the equation 2.2

Moisture Content = $[(Wi - Wf) \times 100\ \%]/Wi$……………………………………….2.2

Where:

Wi = initial mass of Cane Trash

Wf = final mass of Cane trash

2.7.3.3 Determination of Ash Content

Ash content will be determined using the ASTM D 2017 (1998). 35 g of Cane trash will be placed in a pre-weighted crucible and incinerated in a muffle furnace at 7600 C until complete ashing is achieved. The crucible will then be transferred into desiccators for cooling. Three replicates will be made. The cooled samples will then be weighed. The ash content is calculated by using the equation 2.3.

$Ash\ content$ (%) = $[(W2 - W0) \times 100\ \%]/W1 - W0$ ……………………………2.3

Where:

W0 = Weight of the crucible, W1 = Weight of the crucible + sample for incineration and W2 = Weight of the crucible + sample after incineration

2.7.3.4 Determination of Volatile Matter

Volatile matter is determined as the loss in mass, less that due to moisture, when a sample is heated at 900 degrees Celsius for a period of 7 minutes. This procedure will be undertaken out of contact with air under standardised conditions. It will be required to report the volatile matter content on a dry-mass basis as well as on an as-received basis and a dry ash-free basis (provided that the ash content and as-received moisture content of the sample has also been determined. The volatile matter will be determined according to ISO 562/1974. 35g of the samples of the Trash will be incinerated in a crucible at temperature of 8000 C for 10 minutes and allowed to cool down in desiccators. The volatile matter content will then be calculated by using the equation 2.4.

$$\%\ Volatile\ Matter\ Content = [(initial\ weight - final\ weight) \times 100]\ /initial\ weight$$

…………………………………………………………………………………..2.4

2.7.3.5 Determination of Fixed Carbon

Fixed carbon is the solid combustible residue that remains after a sample is heated at 900 degrees Celsius for a period of 7 minutes and the volatile matter is expelled. The fixed-carbon content of the sample will be calculated according to the following equation 2.5.

FC=100-%Ash [dry basis]-%VM [dry basis] …………………………………….2.5

Where: FC = fixed carbon; %Ash = % Ash content and % VM =% Volatile Matter

2.7.3.6 Determination of Calorific Value

The heat produced by combustion of a substance at a constant pressure of 0.1 Mpa (1 Atm), with any water formed remaining as vapour.

The net calorific value will be determined by using the relationship indicted by equation 2.6.

$NCV = 18.7\,(1.0 - AC - MC) - (2.5MC)$ ………………………………………….2.6

Where:

NCV = net (lower) calorific value

AC = ash content

MC = moisture content

(Net Calorific Value (NCV) Calculations and Conversion Factors. Ref: Net Calorific Value (ASTM D5865-12)

2.8 Biomass Combustion

Three components are necessary for combustion: fuel, oxidizer, and heat source. Combustion will happen when these three components are united in the right setting (Weaver ,2012). Combustion halts if any element is eliminated. The fuel might be either a gas, liquid, or solid. For instance, wood is obviously the fuel, air is the oxidizer, and the flame from a match or a lighter often serves as the initial source of heat. In the chemical process of combustion, an object quickly combines with oxygen to produce heat. In the process of combustion, fresh chemical compounds are created from the fuel and oxidizer. Exhaust is the name for these materials (Deb et al., 2014). The majority of the exhaust is produced by chemical reactions between the fuel and the oxygen. Due to the heat that is delivered to the exhaust during combustion, it has a high temperature. Only CO_2 and H_2O are produced when C, H, and O are completely burned in a fuel. With gasoline, however, full combustion happens infrequently.

2.9 Emission Formation

Fuel burning produces pollutants that have a detrimental effect on the environment and ambient air quality. A wide variety of possible pollutants can be produced during the combustion of solid or liquid fuels. Flue gas or stack gas is the name for the exhaust gas produced during the combustion process. Gases or particles released during combustion are referred to as combustion pollutants. Carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter are typical fuel-burning pollutants (Zhou et al, 2014). Two classes of these pollutants can be distinguished, and these groups are detailed below. These emissions are influenced by the characteristics of the fuels, combustion, and the air-to-fuel ratio. According to the law of mass conservation, the combined mass of the products of combustion reactions must equal. In the combustion process, oxygen and biomass are mixed in a hot atmosphere to produce carbon dioxide, water vapor, and heat.

$CH_{1.44}O_{0.66}+1.03O_2 \longrightarrow 0.72H_2O+CO_2(+Heat)$ …………………..……..….2.7

It is worth noting that $CH_{1.44}O_{0.66}$ is the approximate chemical equation for the combustible portion of biomass.

$Volatiles+Air \longrightarrow CO+CO_2$ (+PAH+Unburned Hydrocarbons+Soot+Inorganic aerosols)

$Char + air \longrightarrow CO+CO_2$………………………………..…………..2.8

Volatiles (N, S,K etc) $\longrightarrow$ N, S, K based pollutants…………………….2.9

Sulfur combustion: $S + O2 + 3.76N_2 \longrightarrow SO_2+3.76N_2$………………………....2.10

Hydrogen combustion: $H_2+0.5O_2+(3.76/2)N_2 \longrightarrow H_2O+(3.76/2)N_2$ …………2.11

Carbon combustion: $C+O_2+3.76N_2 \longrightarrow CO_2+3.76N_2$ ……………..2.12

It is worth noting that because Nitrogen is normally taken up by plants during its growth hence it takes part in combustion.

Due to WHO and EU rules, many flue gas components constitute air pollutants and must be reduced or eliminated before the gases are released into the atmosphere.

2.10 Combustion Analysis

Combustion analysis is a step in a process designed to increase fuel efficiency, decrease unwanted exhaust emissions, and increase the safety of equipment that burns fuel (Ghazal, 2013). Flue gas concentrations and gas temperature are first measured, followed by possible measurements of draft pressure and soot level. A probe is put into the exhaust flue, and a sample of gas is pulled out to determine the gas concentration. A thermocouple placed to measure exhaust gas temperature. A gas sample taken from the exhaust flue is used to measure soot. Draft is the difference in pressure between the exhaust flue's inside and exterior. Following the completion of these observations, the data is analyzed using computed combustion parameters like efficiency of combustion and surplus air. Use of calculated combustion parameters like combustion and thermal efficiency to interpret the measurements. Efficiency calculated by the combustion analyzer is a modified equation that considers combustion efficacy and stack losses, and provides a sound estimation of the appliance's steady-state efficiency as shown by Equation 2.13.

$$\%\, Combustion\ Efficiency = 100\% - \left(\frac{stack\ heat\ loosses}{Fuel\ heating\ value}\right) x100 \ldots\ldots\ldots\ldots\ldots..2.13$$

A study by Schmidl et al. (2011) found that emissions of particulate matter, particularly fractions smaller than 10 m aerodynamic diameter, have become a significant environmental concern, particularly in the European Union. Recent research revealed that throughout a vast portion of Europe, burning wood during the winter is one of the main sources of primary particles in the atmosphere (Glasius et al., 2006; Puxbaum et al., 2007; Lanz et al., 2008; Caseiro et al., 2009; Szidat et al., 2009; Yttri et al., 2009; Bari et al., 2010b). Small-scale biomass combustion is the major source of main particulate organic material emissions in Europe's cold season, according to recent emission inventory studies (Schaap et al., 2004). Studies on source apportionment and emission inventories both rely on accurate information about the sources of emissions. The assessment of particle emissions from small-scale biomass combustion systems in central Europe, however, is lacking in knowledge. For two wood types, research was conducted in the United States (Rogge et al., 1998; McDonald et al., 2000; Fine et al., 2001; Schauer et al., 2001; Oros and Simoneit, 2001a and b); Scandinavia (from which the majority of studies have been conducted thus far; Kocbach Blling et al., 2009; Boman et al., 2011; Pettersson et al., 2011 (Bari et al., 2009). Schmidl et al. provided results on the chemical characterization of fine particle emissions from burning common wood types in a tiled stove for the mid-European Alpine region (2008a). According to the literature review by Schmidl et al. (2011), the fuel itself, airflow setting, fuel load, and combustion technique all have a significant impact on the quantity and make-up of particle emissions (Kjällstrand and Olsson, 2004; Jordan and Seen, 2005; Johansson et al., 2004; Fine et al., 2002, 2004a and b). The fact that combustion conditions in tiny household stoves, particularly when manually ignited, are highly varied prevents a systematic investigation of such influencing elements.

2.11 Gaseous and Particulate Emissions from Leached and Unleached Biomass

In order to ascertain the effects of leaching agricultural biomass on gaseous emissions and total suspended particles, Ravichadran and Corscadden (2014) conducted the research. Using leached and unleached briquettes made from agricultural biomass feedstock farmed in Nova Scotia, Canada, the research study examined the gaseous emissions and total suspended particles in the stack of a household wood burner as shown in Figure 2.5. All studies employ the following operating conditions: (1) full load, (2) medium (3) Lowest load. Each experiment took about 6 hours to complete. After 2 hours of ignition, emissions of gases and particulate matter were monitored during stationary combustion.

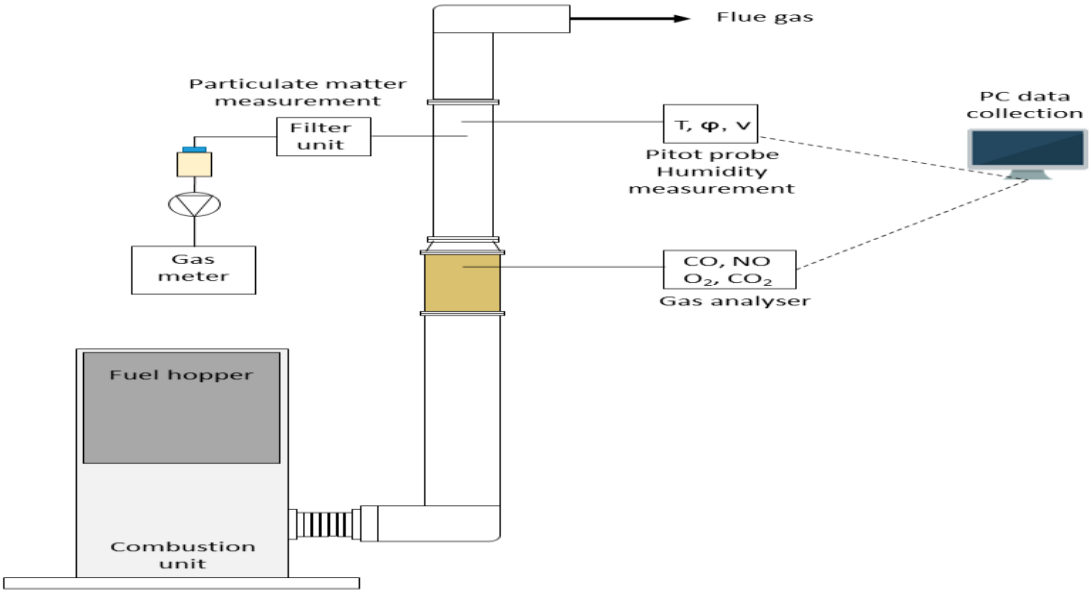


Figure 2.5: Schematic diagram of the experimental setup. (Source: Dragutinovic et al., 2021)

2.11.1 Gaseous Emission Measurement

The emissions were measured using a portable gas analyzer. A gas analyzer is a device that can examine the chemical gases in a sample of flue gas (Stanford Research Systems, 2005). Along with species identification, it also has the capacity to measure the quantity that it shows in numerical form. Each analyzer has a unique operating principle (Zhou et al 2014). The analyzer calculates surplus air, combustion efficiency, NOx and Co_2 gas concentration from the measured value using DIN 33962 (1997). (DIN33962, 1997). The fraction of real heat released from fuel combustion to the heat released on complete combustion was used to define combustion efficiency (Fan et al, 2010). A probe that is inserted in the chimney, 15 cm above the stove, was used to sample the flue gas. A type K thermocouple was also included in the probe to measure the temperature of the flue gas.

2.11.2 Particulate Emission Measurement

Additionally, particle matter from the flue gas was isokinetically sampled using a modified EPA Method 5. According to Ravichadran and Corscadden's (2014) a sampling train placed two meters above the stove was used to collect the particulate matter from the chimney. This shields the instrument from the heat and enables chimney connection. The heated rubberized glass assembly and heated probe with nozzle connection were both part of the sampling train. Whatman 934-AH grade 82 mm glass microfibre filter, which catches at least 99% of the particulate matter with an aerodynamic diameter of 0.3 m or greater from the flue gas, is housed inside the heated rubberized glass assembly (API 345).

After that, the flue gas is passed through a succession of impingers containing water and silica gel to remove moisture. The isokinetic control console, which is furnished with a manometer, vacuum pump, dry gas meter, and a control unit, is connected to the sampling train by a long umbilical line. The velocity (through pressure) of the flue gas can be read using the manometer and a pitot tube that has been put in the stack. The isokinetic condition can be attained by setting the vacuum pump (through orifice pressure) to sample the flue gas at the same velocity as the flue gas velocity. Total Suspended Particles (TSP) in the flue gas was determined by weighing the fiber glass filter and checking the dry gas meter. The TSP measured using Environmental Protection Agency (EPA) Method 5 and the actual particulate matter found in the chimney may differ, according to reviewed research. This difference is mostly caused by the fiberglass filter's pores allowing fine particulate matter and organic condensable components from the flue gas to escape (Bufver et al 2011).

2.11.3 Smoke Index Measurement

Additionally, Ravichadran and Corscadden's (2014) study measured the smoke index. This technique entails extracting a sample of gas from the heat exchanger's gas pipe's center and passing it through a particular filter paper. A graded reference scale from 0 to 9 is used to compare the spot's color to. The apparatus may examine up to three different smoke index readings. In order to print these values on the report, the analyzer computes the average value. Regulations and rules pertaining to air pollution, including ASTM D 2156-63 T, DIN51402, 2116, 2117, and 2297 VDI directives, are described here.

Results of four leached and unleached herbaceous feedstock briquettes were compared in the study. The following results were reached as a result of this experiment Ravichadran and Corscadden (2014).

1. In a natural draft stove, herbaceous biomass briquettes cannot burn on their own. The combustion system must be heated somehow, or it must burn wood or another type of briquette that can start burning right away without smoldering.
2. Leached feedstock briquettes have carbon dioxide levels (752 ppm) that are around 50% lower than those of unleached briquettes (1584ppm).
3. The relationship between NOX emissions and the amount of nitrogen bound in the gasoline was not entirely linear. Furthermore, NOx and flue gas temperature had a substantial correlation.

4. Varied feed stocks had different relationships with one another. Since the SO2 was frequently below the flue gas analyzer's detection limit (1 ppm) and occasionally surged, the SO2 was not proportionate to the sulfur content of the fuel. The spike was averaged across the steady state period.
5. The relationship varied depending on the feed stock. Since the SO2 was frequently below the flue gas analyzer's detection limit (1 ppm) and occasionally surged, the SO2 was not proportionate to the sulfur content of the fuel. The spike was averaged across the steady state period.
6. The potassium and chlorine concentrations of the fuel had a strong association with particulate matter. During leaching, the feedstock's fuel property dramatically increased. As a result, the TSP from leached and unleached feedstock differed significantly. The independent fuel qualities of the biomass briquettes were more significant than the percentage reduction in dependent emissions.
7. The findings of the experiment indicate that leaching is a useful technique for enhancing fuel characteristics, which enhances combustion efficiency and lowers gaseous and particulate emissions. This opens up the possibility of using agricultural waste energy crops as a source of fuel for home heating systems.

2.12 Research Gaps

From the review on the leaching of inorganic and organic matter from biomass, it is clear that:

1) Previous research has identified the leaching potential for reduction of organic and inorganic elements in cane trash, but has not yet determined the leaching characteristics of these elements.

2) Significant portion of organic matters can be leached from cane trash but little is known on its leaching characteristics and implications.
3) Lack of comprehensive analysis of the impact of binders on both physico-mechanical and thermal properties of cane trash briquettes.
4) Various studies had been carried out to investigate the effect of leaching parameters on the retention and leachability of alkali and alkaline earth metals (AAEM) species in cane trash. But the retention and leachability of P, N and S in cane trash fuel produced from leaching is not exhaustive.
5) Even though aromatic compounds are known to be leached from cane trash, the total organic matter that can be removed is unknown.

From the literature review carried, a number of research gaps in the field had been identified. However, it is impossible to address all the research gaps identified in this research. Therefore, this study seeks to establish the leaching characteristics of inorganic and organic matter from cane trash by varying the leaching parameters to determine the effective conditions for performing this leaching. This research study aimed at using leaching pretreatment in various conditions of temperature, particles size and time to ascertain the effective conditions possible to remove troublesome elements from cane trash.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study Area

The investigation was carried out at the Sony Sugar Laboratories in Kenya's Migori County. The availability of the experimental tools and raw materials led to the selection of this study region.

3.2 Materials and Equipment

The feedstock material used was raw cane trash. Collection, quantification and characterization of cane trash was done. The variety of sugar cane (saccharum spp) used was CO 421 from Sony Sugar in Migori County. This variety was chosen because is the most dominant in the region. The average sugar cane yield per acre is about 20 tons with the cane trash of around 4.8 tons. The quantification of the cane trash was done by estimating the total cultivated area of the sugar cane crop and by knowing of the average sugar cane trash (brown leaves, green leaves and tops) quantity produced per ton and sugar cane crop. The production of sugarcane trash per tons of sugarcane crop was determined by taking 40kg of sugarcane crop of each variety from the selected fields. The sugarcane trash produced per 40kg of the crop was weighed. Green leaves (GL), brown leaves (BL) and tops of each variety were collected and weighted separately. Approximately 1.2 tonnes (fresh weight) of cane trash was hand-harvested from plots at Sony Sugar Company in June 2022. One half of the material was processed using a forage chopper (John Deere, Model 34), the other half was processed using a Jeffco cutter (Jeffress Bros Ltd Engineers, Brisbane, Queensland, Australia) see Appendix D1. The two methods of size reduction were chosen for very specific reasons: forage chopping has been identified as the most probable harvesting technique to be employed in Sony sugar company dedicated feedstock supply strategy for utilizing cane trash as a power plant fuel and the Jeffco cutter was expected to provide sufficient size reduction to remove elemental transport limitations and thereby yield data which represent a practical limit for alkali removal by leaching. The working component of the Jeffco cutter is a rotating head containing four knife edges moving over the surface of a screen plate with 9.5 mm holes. The cutter head is driven by a 10 HP electric motor and rotates at 3450 rpm. The primary difference between the two size reduction methods was the resulting particle size distributions. The geometric mean particle diameter and geometric standard deviation for the Jeffco cut material was approximately 1 and 1.9 mm, respectively, whereas the forage chopper produced a coarser feedstock with a geometric mean particle diameter and geometric standard deviation of approximately 4.9 and 2.3mm, respectively. For comparison, bagasse obtained from Sony sugar was found to have a geometric mean particle diameter of 2.2 mm and a geometric standard deviation of 3.1 mm. This indicates that the particle size distributions of the Jeffco cut and forage chopped cane trash bracket that which results from particle size reduction practices commonly employed in sugar factories. After comminution, all material was stored in plastic bags until leaching treatments were performed. A number of leaching tests were then performed on the cane trash using various equipment; see Appendices D2, D3, and D4. Equipment utilized included the Jeffco cutter grinder, heating bath, water pump, leaching tank, hydraulic press, bomb calorimeter, muffle furnace and the digital scale. See Appendices D1-D7.

3.3 Experimental Design

A 3-Level Full Factorial Design was implemented using the design of experiments (DOE), which included the 27 experimental runs, as shown in Table 3.1. This method was chosen because the study was considering 3 factors each at 3 levels namely particle size [1 mm, 5 mm and 10 mm], leaching temperature [25 ^{o}C. 50 ^{o}C and 100 ^{o}C] and leaching time [20minutes, 40 minutes and 60 minutes]. The 3-level design models possible curvature in the response function and can handle the case of nominal factors at 3 levels. A third level for a continuous factor facilitates investigation of a quadratic relationship between the response and each of the factors. Appendix 1 illustrates the actual treatments that were done to the raw cane trash.

Table 3.1: The 33 Factorial Experimental Design

		Time [A] in minutes								
Particle Size in mm	Temperature in oC	20			40			60		
		Particle Size in mm	Temp. in oC	Time in minutes	Particle Size in mm	Temp. in oC	Time in minutes	Particle Size in mm	Temp. in oC	Time in minutes
1	25	1	25	20	1	25	40	1	25	60
1	50	1	50	20	1	50	40	1	50	60
1	100	1	100	20	1	100	40	1	100	60
5	25	5	25	20	5	25	40	5	25	60
5	50	5	50	20	5	50	40	5	50	60
5	100	5	100	20	5	100	40	5	100	60
10	25	10	25	20	10	25	40	10	25	60
10	50	10	50	20	10	50	40	10	50	60
10	100	10	100	20	10	100	40	10	100	60

It is worth noting that the reasons for the base values chosen for the time, particle size and temperatures include: (1) The particle sizes were chosen for the purpose of fundamental study in order to reduce the effect of mass transfer limitations during leaching. (2) Number and nature of the treatments. (3) Available resources and (4) Objectives of the experiment. () Comply with kinetics of leaching.

3.3.1 Procedure for the Leaching Experiments

For the experiment design, a 3 x 3 complete factorial design was employed. In controlled batch leaching of the raw cane trash, experiments were developed to look into the potential effects of leaching temperature, particle size, and residence duration. To produce nine trials per feedstock size for a total of twenty-seven experiments, three distinct particle sizes, three different residence periods, and three different water temperatures were chosen as the experimental variables. Three replica of each experiment were conducted. To get a homogeneous sample for every one of the three feedstock sizes. Using a Jeffco cutter grinder, diameters 1 mm, 5 mm, and 10 mm were cut. Fisher Scientific's Isotemp Programmable Muffle Furnace was used to dry 250 grams of each cane trash size for 24 hours at 105 ^{o}C. This was carried out in order to remove and analyze moisture content. see appendix D6. Then, in a hot water bath, 15 grams of each oven-dried feedstock sample were introduced to 30 millitres of ultra-pure water (resistivity > 18.2 M-cm). Three experimental temperatures of 25 ^{o}C, 50 ^{o}C, and 100 ^{o}C were applied to the water. A Julabo Refrigerated and Heating Circulator was used to keep the desired temperature. The samples were manually stirred for five minutes, and then a circular steel mesh was shoved through the leaching tank's top to completely immerse the sample in water. Following the three experimental residence durations of 20, 40, and 60 minutes. After every 10 minutes of leaching time, a fixed 100 ml of sample was drawn from the leaching bath and an equal amount of fresh ultrapure water was added to the mixture. This process continued till the leaching reached equilibrium (no further increase in the total amount of organic matter and AAEM species leached from biomass by measuring the electrical conductivity of the leachate). A schematic representation of the leaching process is shown in Figure 3.1.

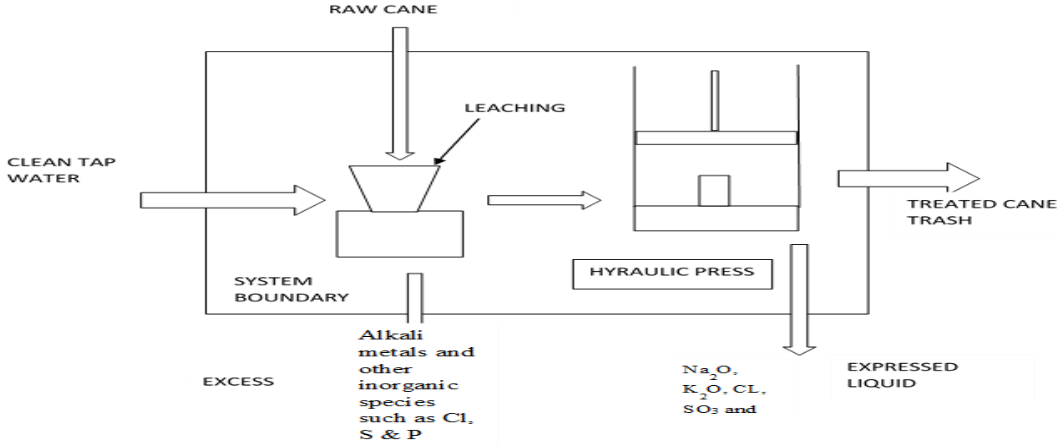


Figure 3.1: Schematic Presentation of the Leaching Process

The leachate samples were then examined for pH, total organic carbon (TOC), concentrations of AAEM species like Na, K, Mg, and Ca (as Na^{+}, K^{+}, Mg^{2+}, and Ca^{2+}), and other species like Cl, S, and P (as Cl^- , SO_4^{2-} and PO_4^{3-} in the solutions, respectively). Electrical conductivity of the leachate was determined following ASTM D1125-14 standard using Pro 30 conductivity meter. Conductivity of the leachate indicated the leaching equilibrium.

The leaching tests were carried out three times for each sample.

3.3.2 Particle Size Distribution

The particle size distribution was calculated using a camsizer model AS200 Digit CA. The camsizer operates on a digital image processing principle. Between a long light source and two digital cameras, the particles fall. More than 60 photos per second of the projected particle shadows are captured and evaluated. In this manner, each and every particle in the flow of bulk materials is monitored and assessed. The software supplied by the equipment maker was used to record and analyze the particle size distribution of the sample on a volume basis. Particle size distribution was done following ASTM-E3340. This is the Standard Guide for Development of Laser Diffraction Particle Size Analysis Methods. This guide sets out the general approach to the particle size distribution measurement of powders, suspensions, or slurries using an appropriate wet or dry methodology by the laser diffraction technique. It is recommended for use in measurements of broad particle size distributions.

3.3.3 Elemental Analysis of Feedstock

After being oven-dried, the leached and unleached feedstock were ground in a mini-wily mill with a 40 mesh. These ground samples underwent analyses for ash, nitrogen, sulfur, and alkali metals (K, Na, Ca, and Mg). Using ASTM E1755-01, the ash content of each feedstock was examined (Standard Test Method for Ash in Biomass). The mass percentage of residue left over from the oven-dried sample's dry oxidation at 575 ^{o}C is referred to as the ash content. Nuclear Absorption Using a Varian SpectrAA 200FS, spectroscopy was used to examine the elements potassium (K), calcium (Ca), sodium (Na), and magnesium (Mg). A porcelain dish containing 1 gram of each feedstock was heated in an electric furnace for roughly 20 minutes. The samples were then fired for 6 hours at 550°C in a muffle furnace. After one hour of desiccator cooling for the ash samples, 10 ml of 5% HCl was added to the dishes. The plates were washed through a Whatmann 1 filter in a conical funnel into a 50 ml volumetric flask after 10 minutes. The concentration of the alkali metals, measured in mg/g, was then determined from the samples of the extracted feedstock.

Total chlorine was analyzed for each feedstock sample using ASTM E776-16 (Standard Test Method for Forms of Chlorine in Refuse Derived Fuel by the Oxygen Bomb Combustion/Ion Selective Electrode Method). The sample's total chlorine concentration was displayed in ppm. Total nitrogen and sulfur were analyzed using the LECO-3000 CNS; 0.2 grams of each feedstock sample were packed in tin foil, wrapped, and inserted into the auto-sampler. Three blanks and three standards were first inserted into the sampler. Every tenth sample, a standard was additionally loaded with a blank. For each sample the analysis was done three times.

3.3.4 Quantification of Organic Matter Species in Leachate Samples.

After being collected, samples of water leachate were immediately tested for the presence of organic matter using a Total Organic Carbon (TOC; Shimadzu TOC-VCPH) analyzer. The amount of TOC leached was then standardized to the Total Carbon present in the corresponding cane trash sample to allow for direct comparison. The same IC approach was used to determine the AAEM species concentrations in the leachate samples. With the aid of another IC system (DIONEX ICS-1100) fitted with a suppressed conductivity detecting system, chloride, sulfate, and phosphate were all examined. IonPac AS22-fast 4 150 mm column and IonPac AG22-fast 4 30 mm guard column were used to separate the anions, with 22.5 mm sodium carbonate and 7 mm sodium bicarbonate serving as the eluent.

3.3.5 Identification of Organic Acids in Leachate Samples

Using an IC (DIONEX ICS-3000) fitted with a suppressed conductivity detection system, anions for organic acids (formate, acetate, and oxalate) in leachate from leaching tests were quantified. IonPac AS20, a column with a 2 mm diameter and 250 mm length, and IonPac AG20, a guard column with a 2 mm diameter and 50 mm length, were used to achieve separation. The eluent used was 5 mm potassium hydroxide.

3.3.6 Cassava Starch Preparation and Characterization

Cassava was crushed and sieved through 0.5 mm mesh sieve. The measure of crushed cassava was 2kg of cassava flour to 20 litres of water. The mixture underwent gentle heating while stirring until the slurry thickened. Stirring was done continuously to ensure that the solute dispersed in the water and prevent ‘’hot spots’’ building up in certain parts of the container to avoid uneven expansion.

3.4 Fabrication of the Leached Cane Trash Briquettes

Figure 3.2 illustrates the fabricating process of the leached cane trash briquettes.

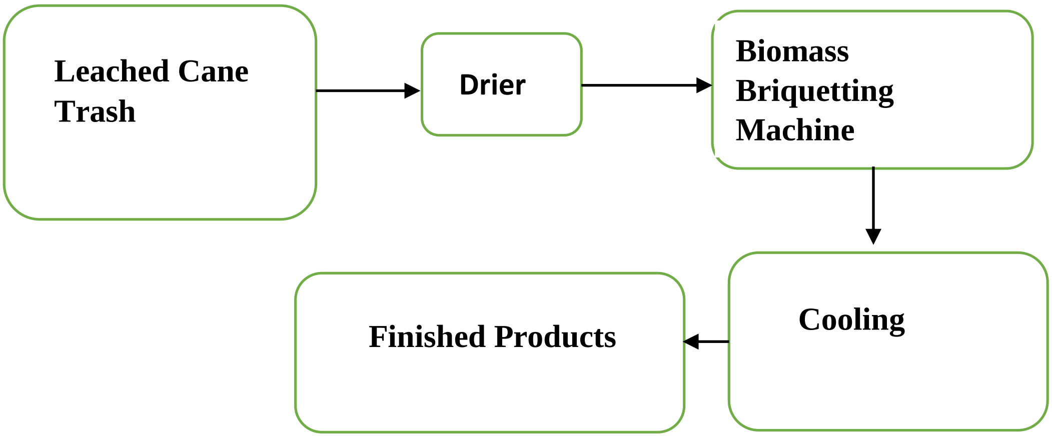


Figure 3.2: Fabricating Process of the Leached Cane Trash Briquettes

3.4.1 Briquette Manufacturing Procedure

The aforementioned Cassava starch was employed as a binder because it is widely available. Cassava binder was mixed with the leached cane trash. The cane trash to the cassava binder ratio used was 20:3 (Sotannde et al., 2010). The mixture was stirred until homogeneity was achieved. The mixture of leached cane trash and binder was spread out on nylon material and put within the mold chamber of the press. The cane trash binder mixture was hand-fed into the steel mould for doughnut briquettes and covered at both ends with the disks. The cane trash cassava binder mix inside the mould was then placed under the hydraulic press. A briquetting hydraulic press (BHP) was used to make the briquettes, with a compaction pressure of 18 MPa and a compression ratio of 0.6 per second. The pressed mixture was kept under pressure for duel time of 5 minutes. The 50 mm diameter and 50 mm length of the briquettes were made. After compression, the briquettes were taken out and allowed to air dry for a day to get rid of any extra moisture. There were three briquettes made for each run of the leaching operation.

The hydraulic press was chosen because it can generate final solid fuel in accordance with DIN 54385:2016-08 standard. A hydraulic press is utilized is as shown in Appendix D4.

3.5 Evaluating the Physical and Combustion Properties of the Leached Cane Trash Briquettes

Evaluation of the leached cane trash briquettes' physical and combustion characteristics was carried out in accordance with ASTM, ASABE and ISO protocols. Physical characteristics like bulk density and mechanical durability were among these qualities. Moisture content, ash content, volatile matter, fixed carbon, and heating value were all taken into account while determining the combustion qualities.

3.5.1 Measurements on Physical Properties of Briquettes

The physical properties of the densified products were one of the important factors to measure the quality of the briquettes. As reviewed by Kaliyan and Valence Morey (2009), three relevant tests namely Mechanical Durability ASTMD 440, bulk density ASTMD 873 and moisture content ASTM-871, abrasive resistance and water resistance test were conducted.

3.5.2 Mechanical Durability

The Mechanical Durability might help in simulating the forces encountered when emptying the briquettes from trucks onto ground, or shifting from one place to another (Sunday et al., 2020). On top of that, the safe height of briquette production also could be determined through this particular experiment testing.

The method adopted in the research done by Sengar et al. (2012) and Birdwatcher et al. (2014) was selected in this study. The sample was dropped onto the concrete floor from 1 m high for 10 times continuously. Table top with an adjustable platform together made up the designated height of 1 m, as illustrated in Figure 3.3.

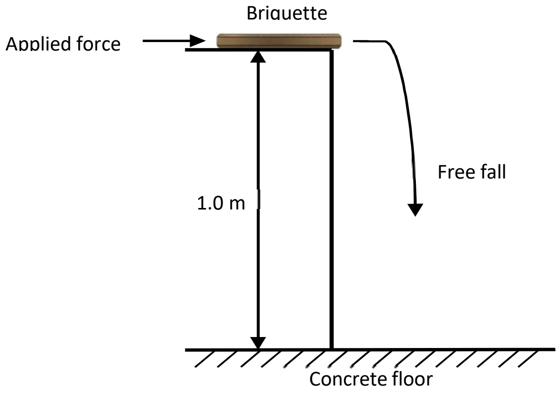


Figure 3.3. Schematic diagram for drop test

Mechanical Durability of the briquettes was calculated by using the equations 3.1 and 3.1 as illustrated below, whereby the weight of the sample briquettes was recorded before and after shattering, and thus the percentage of Mechanical Durability could be calculated.

$$Weight\ loss\ (\%) = \frac{(W1-W2)x100\%}{W1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

$$Mechanical\ Durability = 100\% - weight\ loss(\%) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where W_1 is initial weight (g) where as W_2 is the final weight (g)

3.5.3 Test to Determine Briquettes' Bulk Density

This test was based on the standard of the American Society of Agricultural and Biological Engineers (ASABE s269.4), which describes the methods for determining briquette density (ρb) in briquettes and pellets [22]. The direct method was used, which consists of measuring the volume of each briquette and its weight to obtain the briquettes density value (ρb) as the mass ratio between the volume, as shown in Equation 3.3.

$$\rho b = \frac{M}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

in which M is the mass and V the volume of the briquette. The volume determination was made with a calibrator (Vernier KANON with 0.05 mm accuracy), by measuring the length and diameter of the briquettes. To measure the mass, a precision scale (Ohaus PA224 - Pioneer Analytical Balance, 220 g × 0.1 mg) was used, and briquette density units in $kg \cdot m^{-3}$were determined.

3.5.4 Measurement of Combustion Properties

The characteristic and energy content of sugarcane trash was determined by taking three samples of each variety. Proximate and ultimate sample analyses were carried out for the determination of their physical and chemical characteristics, and indirect computation of energy content. The energy content or heating value of the samples was also directly determined using bomb calorimeter. In proximate analysis, moisture, volatile matter, ash, and fixed carbon content were determined.

The moisture content (MC) of the samples was computed by the percentage of loss in weight. The equipment used was a drying oven, china crucible of 32cc volume, electronic micro balance and desiccators following the ASTM-E871. The MC of the samples was determined by Equation 3.4.

$$MC[\%] = \left(\frac{(wi - wfi1)}{(wi - wc)}\right)x100 \ldots\ldots 3.4$$

where W_i is the initial sample weight, W_{fi} is the final sample weight and W_c is the crucible weight.

The volatile matter (VM) was found by percentage in weight loss by ASTM-E872. The equipment used was chromium-nickel crucible with lid and an electrically operated electric furnace. The VM content of the samples was determined by Equation 3.5.

$$VM[\%] = \left(\frac{(wi - wfi1)}{(wi - wc)}\right)x100 \ldots\ldots 3.5$$

Similarly, the ash content (AC) of the samples was calculated by the mass percentage of the remains after process of dry oxidation at 575 ºC for a time period of 3 hours by adopting ASTM-E1755. The equipment used was a crucible, electric muffle furnace, drying oven and desiccator. The AC of the samples was determined by Equation 3.6.

$$Ash[\%] = \left(\frac{(Mash - Mcont)}{Mod - Mcont}\right)x100 \ldots\ldots 3.6$$

where M_{ash} is the final mass of the ash, M_{contt} is the tare of the container, and M_{od} is the initial mass of 105ºC dried sample and container.

The fixed carbon (FC) was calculated from the resultant of the summation of the percentage of MC, VM and AC subtracted from 100 as in Equation 3.7.

$$FC\,[\%] = 100 - MC\,[\%] - VM\,[\%] - Ash\,[\%] \ldots\ldots 3.7$$

The higher heating value (HHV) of sugarcane trash samples was determined using adiabatic bomb calorimeter by adopting ASTM-E-711. The calibration of the calorimeter was done by the burning of benzoic acid. After that, the burned sample was weight. Finally, the HHV was determined by the difference of the temperature before and after combustion taking place.

Moreover, the quantification of sugarcane samples and their characteristics were compared with the results of other studies. The comparison was done in order to know the quantity and quality of sugarcane with respect to other areas of the world, whether the results obtained provide similar trends or variations from other researchers

3.6 Analyzing the Gaseous and Particulate Emissions of Leached Cane Trash Briquettes

The schematic diagram of the experimental setup for the gaseous and particulate measurement is shown in Figure 3.4. Measurement of the gaseous and particulate emissions was done following the DIN and ASTM and EPA method 5 procedures

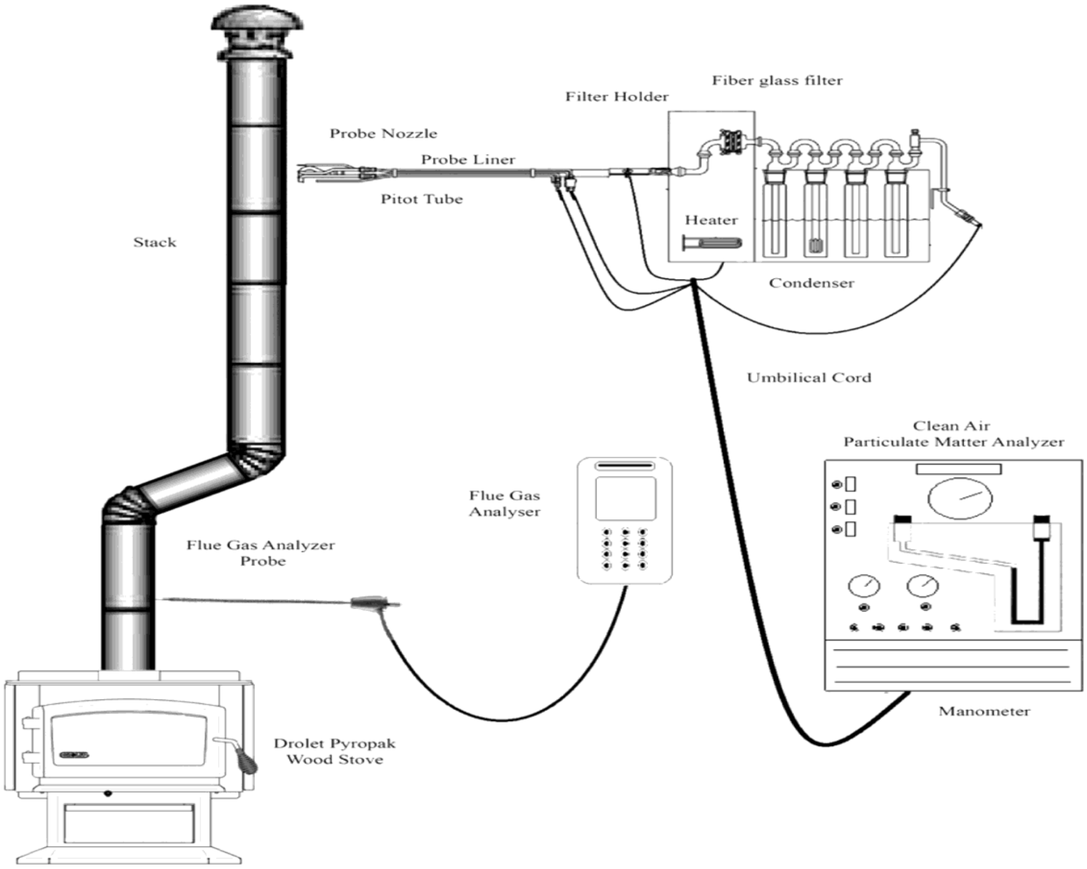


Figure 3.4: Diagrammatic representation of the experimental setup

3.6.1 Measurement of Gaseous Emission

This study used the gas analyzer for emission measurement following ASTM D6522-20 standard. Gas analyzer is an instrument which is capable of analyzing gases present in the flue gas sample. The analyzer does not only identify the species but it also has capability to give measurement value of the quantity which it displays in numerical form. The portable gas analyzer is suitable in the harsh measuring environment. It is also accurate and reliable for the measuring values together with small dimensions and low weight, making it very promising equipment for the measuring emissions and other flue gas. Figure shows the Eurotron 3000+ analyzer that was used for gaseous emissions measurements.

Figure 3.5: Eurotron 3000+ analyzer for determination of gaseous emissions

3.6.2 Gaseous Emission Measurement Procedure

The 3000+ series analyzer is based on the functional block as shown in Figure 3.

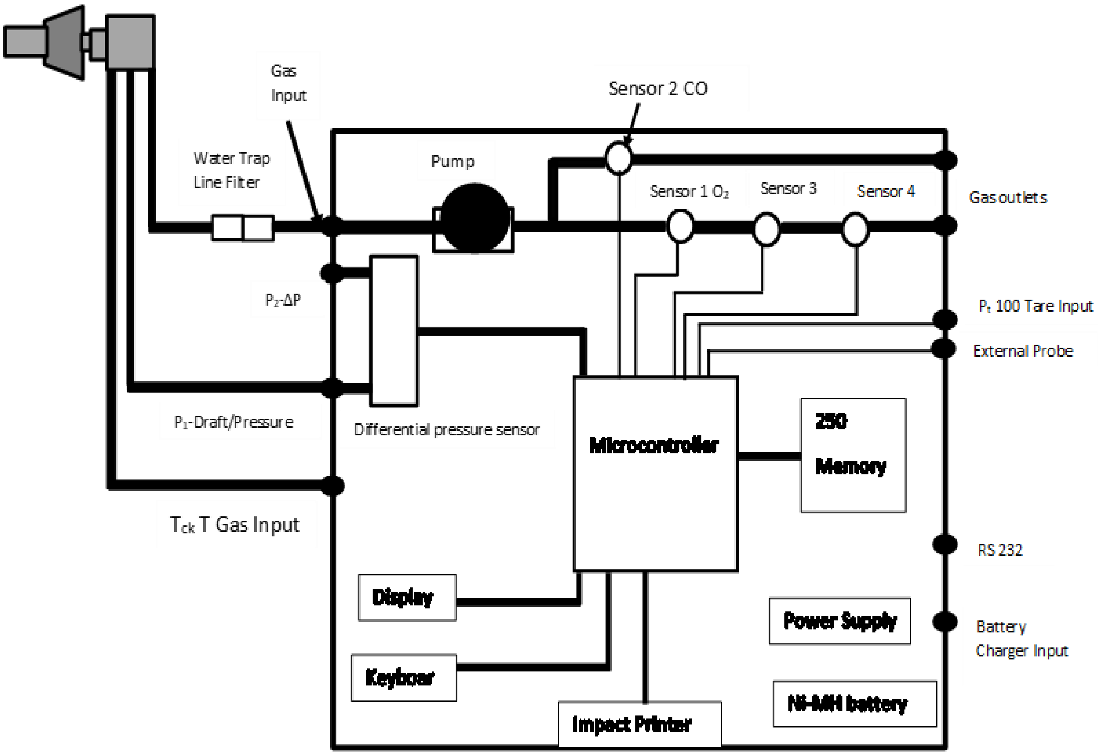


Figure 3.6: The Eurotron Unigas 3000+ flue gas analyzer functional blocks

The Eurotron Unigas 3000+ flue gas analyzer has four electrochemical sensors to measure O_2, CO, NO and SO_2 in the flue gas. The analyzer uses DIN 33962 (1997) to calculate excess air, combustion efficiency, NOx and CO_2 gas concentration from the measured value DIN 33962(1997). The combustion efficiency here is defined as a percentage of the actual heat released from fuel combustion to the heat released on complete combustion (Fan et al., 2010).

The flue gas was sampled through a probe which was installed in the chimney, 15 cm above the stove. The probe was also equipped with a type k thermocouple to measure the flue gas temperature. The O_2 sensor is essentially an electrochemical cell, with two electrodes and electrolyte solution. The behavior is similar to a normal battery and therefore the sensitivity decreases with time. The expected life does not relate to the operative time and is lost after approximately 24 months. The toxic gas measurements (CO, SO_2, NO and NO_2) use electrochemical cells. The gas sensors are electrochemical cells composed by two electrodes (anode and cathode) and an electrolyte solution. The sampled gas goes through a selective diffusion membrane. The oxidation process produces an output electrical signal proportional to the gas concentration. The signal is evaluated by the electronics, converted to digital, processed by the microprocessor, displayed and printed with a 0.1% volume resolution.

3.6.3 Particulate Emission Measurement Procedure

EPA method 5 sampling train was used for measuring the particulate emissions as indicated on Figure

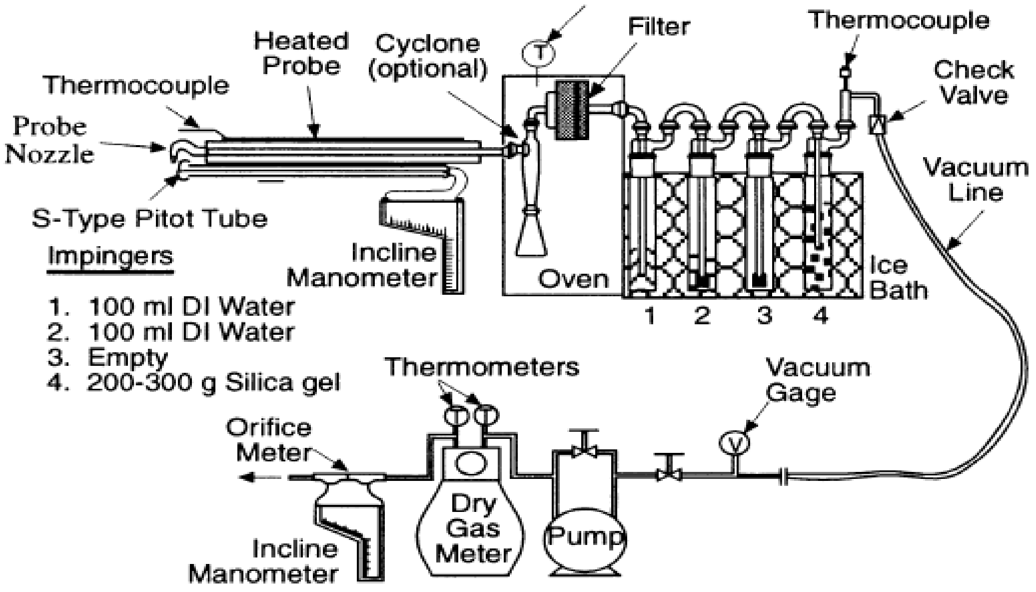


Figure 3.7: Method 5 sampling train (Source: CARB Contract No. 04-330)

Particulate matter from the flue gas was isokinetically sampled using a Clean Air Method 5 particulate matter analyzer. The particulate matter was collected from the chimney through a sampling train, installed two meters above the stove. The sampling train has a heated probe which is connected to the nozzle on one end and a heated rubberized glass assembly. The heated rubberized glass assembly holds a glass microfiber filter (Whatman 934-AH grade 82 mm), which collects at least 99% of the particulate matter with an aerodynamic diameter of 0.3 μm or larger from the flue gas (APTI 345, 1995). The flue gas then passes through a series of impingers that contain water and silica gel to absorb moisture from the flue gas. A long umbilical cord connects the sampling train to the isokinetic control console that is equipped with a manometer, vacuum pump, dry gas meter and a control unit. Using the manometer and a pitot tube installed in the stack the velocity (via pressure) of the flue gas can be read. Using standard formula, the vacuum pump (via orifice pressure) was set to sample the flue gas at the same velocity as the flue gas velocity, so that the isokinetic condition is achieved.

By weighing the fiber glass filter and the dry gas meter reading the Total Suspended Particulates (TSP) in the flue gas was calculated.

3.6.4 Statistical Analysis

Using Minitab Software Ink. V20, the data for the physical, proximal, ultimate, and emission properties were examined. This program was chosen because it is more functional, easier to use, and readily available. For each of the 27 briquettes, the tests were repeated three times. Using the statistical model given by Equation 3.8, a three level complete factorial design was used for the numerical analysis.

$$Y_{ij} = \mu + B_j + AB_{ij} + Ck + AC_ik + BC_jk + ABC_{ij}k + \Sigma_{ij}k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.8$$

Y_{ij} is the response variable, µ is the general mean, and ijk is the Y_{ijk}-related random error. Similarly, for j and k, [i=1, 2, and 3. The variables are A, B, and C.

Results were compiled using one-way analysis of variance(ANOVA). Mean values of analyzed properties were compared using Duncan's' multiple range test at $p \leq 0.05$. Linear regression models were used to investigate the impact of leaching time, leaching water temperature and particle size on each of the dependent variables. Plots of main effects and interactions of factors were plotted variables.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Leaching Characteristics of Inorganic and Organic Matter from Cane Trash Briquettes samples

4.1.1 Elemental Concentration after Leaching

Table 4.1 displays the results of the final elemental composition of the original and leached cane trash**.**

Table 4.1: Results from the tests of original un-leached and leached cane trash samples

Wt.% dry Cane trash	**Original Unleached Cane Trash**		**Leached Cane Trash**		**Percentage change**	**Un-Leached biomass reported by Turn et al., (2003)**	**Leached Biomass reported by Turn et al.,(2003)**
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**			
C	46.27	0.39	49.73	0.31	+7.5%	45.13	47.42
H	6.20	0.09	5.99	0.11	-3.30%	5.71	6.06
O	41.53	0.48	42.84	0.28	+0.74%	41.69	41.54
N	0.43	0.03	0.26	0.02	-39.50%	0.48	0.35
S	0.06		0.02		-66.67%	0.22	0.04
Cl	0.02		ND		-100%	0.65	0.04

The figures show the dry biomass weight %. The leaching statistics of sugar cane trash fibers from Turn et al., (2003) were adopted and compared in Table 9 to compare the leaching impacts on the cane trash. The final study reveals that C, at 46.27%, has the highest concentration of all the elements in the original, undyed cane trash, with O coming in second at 41.53%. The original un-leached cane trash had H, N, S, and Cl concentrations of 6.20, 0.43, 0.06, and 0.02%, respectively. Similarly, Turn et al. (2003) found that H was 5.71%, N was 0.48%, and S was 0.22%. The original un-leached biomass of the reviewed literature had a higher Cl concentration at 0.65% (Turn et al., 2003), however the unleached cane trash in this investigation had a Cl level of only

0.04%. By washing the pollutants that were adhered to the cane trash surface (by washing away the contaminants attached to the cane trash surface, the mass per unit volume of C increases), such as components brought in during harvesting, the leaching technique considerably increased the C content in the biomass. Leached cane trash had a greater C content than un-leached cane trash (49.73% vs. 46.27%), which was in line with the findings of Yu et al. (whose C content increased from 43.50% to 44.90%) and Said's findings (Said et al. 2013). After leaching with water, a considerable reduction of Cl, S, and N took place. Cl was entirely washed away, and following leaching, there was no longer any identifiable Cl concentration in the cane trash. The investigation conducted by Yu et al. could not identify any Cl content either. S is frequently seen as a difficult element, much like Cl (occurring as sulfate). After leaching, the S level in the original, unprocessed cane trash reduced by 66.67% (from 0.06% to 0.02%), but the S removal in the reviewed study was almost 100%.

4.1.2 Elemental Analysis of Ash after Leaching

Table 4.2: Mass of Ash Related Elements in Sample, mg/g Dry Cane Trash

Wt.% dry Cane trash	**Original Unleached Cane Trash ash**		**Leached Cane Trash ash**		**Percentage change**	**Un-Leached biomass reported by Yu et al., (2014)**	**Leached Biomass reported by Yu et al.,(2014)**
Ca	16.08	1.09	18.64	0.93	15.90	1.16	0.94
K	19.18	0.95	7.08	0.40	75.24	7.27	3.04
Mg	0.54	0.06	0.30	0.06	44.00	1.28	0.60.
Na	ND	NA	ND	NA	NA	1.92	0.80
Si	16.64	3.21	15.93	1.89	4.20	17.90	23.18

According to Table 10, the main ash-related components found in the biomass samples were Ca, K, Mg, Na. In general, the leaching procedure demonstrated high effectiveness in removing components associated to ash. Ogden (Ogden et al. 2010) discovered comparable outcomes. After leaching, the K (7.08 mg/g) and Mg (0.38

mg/g) contents of the cane trash significantly decreased; the corresponding removal ratios were 75.24% and 44%. Additionally, at a reduction ratio of 4.3%, the Si in the leached cane trash slightly fell from 16.64 mg/g in the original, un-leached cane trash to 15.93 mg/g. Since clay minerals are the primary silicates, Si is the primary element in clays (Bostron et al 2012). The reduction of Si may be caused by the washing of dirt particles, especially clays, adhered to the cane trash surface. But the amount of calcium in the un-leached cane trash rose by 15.9% (from 16.08 to 18.64 mg/g). Due to the decreased levels of other inorganic elements, the calcium concentration marginally increased following the treatment. This is in line with the findings of Jinxia et al. (2021) who found that the hot water treatment had little effect since Si and Ca species in biomass often had limited water solubility. According to Bandara et al., (2020) washed samples had higher CaO, MgO, and Na2O contents. Washing can significantly reduce the amount of components, but adjusting the temperature and particle size has minimal impact. On the other hand, the removal of components is still on the rise as temperature is raised and particle size is decreased. It is important to note that the Ca in Yu et al., (2014)'s work demonstrated a greater drop upon leaching. The difference in Ca between the original un-leached cane trash and the biomass material utilized by Yu was 14.5 times higher, which is probably related to the different biomass kinds or growing conditions such water hardness and soil quality. Leaching pretreatment removed ash related elements that cause fouling, slagging and other operational problems in burners. Leaching also increased the higher heating value of the cane trash.

4.1.3 Leaching Effects on Organic Matter

Particularly for hot pulverized treatments, leaching removed a significant portion of the organic materials from the cane trash. Leaching removed a sizable amount of organic material, accounting for around 2.91% of the carbon in the sample of cane trash. The outcomes are in line with those published by Wu et al. (2011) for samples of mallee biomass made from various batches. Table 11 shows the pH, organic acid contents, and cation/anion ratio of the leachates produced by equilibrium water leaching of cane trash samples. The pH value of the leachate recovered from cane trash leaching in various leaching settings averages at 5.5 with a standard deviation of 0.04 as shown in Table 11, clearly indicating that the leachate is acidic. The findings imply that the organic matter leached from the cane trash samples contains at least a small amount of organic acids. As indicated in Table 11, an analysis employing ion chromatography reveals that the leachate samples contain organic acids such as acetate, formate, and oxalate. These acids make up 2.91% of the total organic carbon leached from cane trash.

Table 4.3: Properties of the leachates obtained from water washing of cane trash samples at equilibrium leaching conditions.

Property		Quantity In Leachate	
		Mean	Standard deviation
Concentrations of organic acid anions (% of TOC in leachate)	Ethanol	0.80	0.35
	Glycerol	0.17	0.11
	Acetate	0.03	0.02
	Propionic Acid	0.52	0.09
	Lactic Acid	0.15	0.46
	Glucose	0.51	0.15
	Formate	0.02	0.29
	Oxalate	0.71	0.06
	Total	2.91	
Cation/anion ratio	(Na+K+2Mg+2Ca)/(Cl+2S+3P)	3.3	0.89
pH		5.5	0.04

The pH value of the leachate recovered from cane trash leaching in various leaching settings averages at 5.5 with a standard deviation of 0.04 as shown in Table 11, clearly indicating that the leachate is acidic. The findings imply that the organic matter leached from the cane trash samples contains at least a small amount of organic acids. As indicated in Table 11, an analysis employing ion chromatography reveals that the leachate samples contain organic acids such as acetate, formate, and oxalate. These acids account for 2.91% of the total organic carbon leached from cane trash. Also listed in Table 11 is the cation/anion ratio of the leachate (Na^{+} K^{+} $2Mg^{+}$ 2Ca)/ (Cl^{+} 2S + 3P). The cation/anion ratio is 3.3 suggesting at least some of the AAEM species leached from the cane trash samples do not exist in the biomass samples as water soluble salts. In general, the results presented so far clearly demonstrate that under water leaching conditions, the organic acids leached from biomass samples remain in the leachates system and leached some of the acid- soluble (but water-insoluble) AAEM species (e.g., organically bound AAEM species via ion exchange). It is likely that water leaching of biomass overestimates the contents of the water soluble inorganic species in biomass samples. Therefore, a new method is needed for the correct quantification of these water-soluble inorganic species, eliminating the effect of the interactions between the leachate and the leaching biomass sample. Acids and sugars extracted from the cane trash might potentially be recovered and used in other downstream processes after leaching. Sugars and organic acids constituted the major fractions of the extracted organic matter and potentially serve as coproducts from the leaching system; however, further identification of organic extracts may be necessary to fully resolve deficiencies observed among anion balances for all feedstock.

4.1.4 Electrical Conductivity

Electrical conductivity (EC) provides an indication of the ion concentration in liquid samples. Removal of alkalis and other inorganic constituents from the cane trash is indicated by an increase in electrical conductivity of the leaching and milling water. Table 4.4 shows that the ions in the pulverized samples are more readily leached compared to the chopped samples for the excess leachate

Table 4.4: Electrical conductivity of excess leachate and expressed liquids from the laboratory cane trash investigation

	Leachate Type	Maximum			Minimum		
		Value	Run No.	Acronym	Value	Run No.	Acronym
Electrical Conductivity	Excess Leachate	3.7	23	H-L-P	0.64	11	C-S-C
	Expressed Liquid	5.48	11	C-S-C	3.09	23	H-L-P

However, the opposite can be said for the milling process (Expressed liquid). Although these results appear contradictory when comparing the variables (time, temperature and particle size) between the excess leachate and the expressed liquids, the results are logical when viewed from the perspective of the ions in the sample. During the leaching process, the more severe treatment (small particle size, hot water and long duration) mobilizes a greater fraction of the total water soluble ions from the material into the leach water. Thus, during milling, the concentration of water soluble ions in the cane trash is lower compared to the less severely treated samples (large particle size, cold water, short duration) and thus the EC of the excess leachate from the more severely treated samples is lower. The most obvious result of the EC analyses is the effect of particle size. Clearly from the data, particle size has the greatest effect on removing ions from the cane trash samples.

4.2 Physical and Combustion Properties of Leached Cane Trash Briquettes

Table 4.5 shows the summary of the values for physical and combustion properties obtained after the leaching process while Table 4.6 indicates their range.

Table 4.5: Physical and Combustion Properties

Variables Description	Original Unleached Cane Trash		Leached Cane Trash		Percentage change(increase or decrease)
	Mean	Standard Deviation	Mean	Standard Deviation	
HHV(MJ/kg)	16.85	1.21	17.99	1.45	6.94
Volatile Matter % dry basis)	73.80	1..23	76.75	2.64	3.80
Ash Content (g/g) dry basis	4.14	0.46	2.77	0.41	33.00
Fixed Carbon(% dry basis)	22.18	1.53	14.03	1.50	36.75
Mechanical durability (%)	89.5	2.11	96.52	2.01	7.02
Bulk density (Kg/m^3)	274	4.74	304.24	3.72	11.04
Moisture content (%)	61.7	3.14	54.51	5.09	7.17

Table 4.6: Maximum and Minimum Leaching Run Results

Variables	Maximum			Minimum		
	Value	Run Number	Acronym	Value	Run Number	Acronym
HHV(MJ/kg)	21.23	23	H-L-P	14.51	11	C-S-C
Volatile Matter (wt%)	82.29	23	H-L-P	74.11	11	C-S-C
Ash Content (wt%)	3.95	11	C-S-C	2.03	23	H-L-P
Fixed Carbon (wt%)	19.82	23	H-L-P	11.53	11	C-S-C
Mechanical Durability (%)	99.20	23	H-L-P	91.16	11	C-S-C
Bulk Density (kg/m^3)	312.01	23	H-L-P	297.381	12	H-M-C
Moisture Content (%)	66.4	9	W-M-C	45.50	23	H-L-P

4.2.1 Bulk Density

The density of loose cane debris, according to mill experiments, is between 50kg/m^3 and 65kg/m^3. The density of the compressed unleached waste ranged from 242 kg/m^3 to 306 kg/m^3. The mean and standard deviation of the unleached cane trash used in this investigation were 274kg/m^3 and 4.74 respectively. The mean density of the leached cane trash was 304.24 kg/m^3, with a standard deviation of 3.72, an increase of 30.24 kg/m^3 or 11.04%. Information from Table 4.6 shows that bulk density increases with the leaching severity. The bulk density was 312.01 kg/m^3 at H-L-P run 23, 100 ^{o}C, and

60 minute and at 1mm particle size. The density was lowest at 297.38kg/m^3 in run 12 as indicated in Table 4.6 and appendix B. The complete experimental results showing all the 27 run results is shown in Appendix C5 of the appendix.

Bulk density increased because leaching kinetics followed the shrinking particle model. In this scenario the particle becomes smaller after leaching. The reason being that some elements and organic matter (organic acids) were leached away (Behara and Parhi, 2016; Faraji et al., 2018). The particle size is the main parameter that influences the bulk density. The smaller the particle size the higher the bulk density.

It is expected that high bulk density will affect the fuel value index of biomass for energy generation, these results show a positive correlation as high density shows a higher mass in relation to volume and thereby they have a higher combustion yield. Table 4.7 shows the ANOVA statistical summary for the bulk density.

Table 4.7: ANOVA Statistical summary for bulk density

Response Variable	Independent Variable	P-Value	F-Value	T-Value	R_sqr(Adj)	R_sqr(Pred)
Bulk Density	Particle size	0.000	50.34	-7.09	64.65	54.74
	Temperature	0.749	0.11	0.32		
	Time	0.746	0.11	-0.33		

The Regression model for the bulk density is indicated in equation 2.

$$BULK\ DENSITY = 308.70 + 0.0044TEMP - 0.0086TIME - 0.820Ps \ldots\ldots\ldots\ldots\ldots 4.1$$

Table 4.7 for the ANOVA results for the bulk density indicates that temperature and time had no meaningful significance for their p-values were > 0.05. However, it was noted that the smaller the particle sizes, the higher the density of cane trash briquettes. Density of briquettes with particle size of 1.0 mm recorded highest value of 312.01kg/m^3. This result is in agreement with Maninder et al (2012) who reported that the finer the particle sizes of briquette materials the higher the ease of compaction. This is because there is less inter-particle spaces and intra-particle voids for smaller particles compared to large particles.

4.2.2 Mechanical Durability

The unleached cane trash samples recorded a mean of 89.50% and a standard deviation of 2.11 for mechanical durability as indicated in Table 4.5. The leached cane trash briquette samples had a mean of 96.52% and standard deviation of 2.01 for mechanical durability. This was an increase of 7.02%. Mechanical durability of cane trash briquettes increased with the leaching severity. Run 23 with more severe conditions (H-L-P) recorded the highest mechanical durability of 99.20% while run 11 with less severe conditions (C-S-C) had the lowest percentage for mechanical durability of 91.16% as indicated in Table 4.6. Table 4.8 shows the ANOVA analysis summary for mechanical durability.

The mechanical durability increased because leaching had reduced the cane trash particle sizes by washing away inorganic and organic matter. Smaller particle sizes increased the bulk density of the briquettes; the increase in the bulk density eventually enhanced the mechanical durability by enabling the briquettes to be compact perfectly densified.

Table 4.8: ANOVA Statistical summary for mechanical durability

Response Variable	**Independent Variable**	**P-Value**	**F-Value**	**T-Value**	**R_sqr(Adj)**	**R_sqr(Pred)**
Mechanical durability	Particle size	0.000	62.29	-7.89	78.48%	73.53%
	Temperature	0.001	16.09	4.01		
	Time	0.000	19.43	4.41		

The 3 experimental factors, temperature, particle size, and time were statistically significant to a confidence level of 95%. The p-values for all the experimental factors is less than 0.05. as indicated in Table 4.8.

Equation 4.2 shows the statistical fitting for the behavior of the Mechanical Durability measured experimentally.

$$MD = 95.281 + 0.02312TEMP + 0.0485TIME - 0.3852Ps \ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

The high the mechanical durability index of briquettes indicates high hardness of briquettes and the ability to withstand handling stresses especially in packaging and transportation. The briquettes with low mechanical durability should be handled with care to reduce the possibility of disintegration during packaging and long distance transportation (Sotannde et al. 2010; Obi et al., 2013). These factors (Temperature, Particle Size and Time) affects the severity of the leaching process. Leaching reduced the particle size by washing away inorganic and organic matter causing shrinking of the particles. Smaller particle sizes enhanced the bulk density which enhanced the mechanical durability by allowing optimal densification conditions.

4.2.3 Higher Heating Value

The Higher Heating Value (HHV) of the unleached cane trash reached a mean of 16.85 MJ/kg, with a standard deviation of 1.21 from the triplicate tests (Table 4.5). The HHV of leached cane trash slightly increased by 6.94% to 17.99 MJ/kg after leaching. Chin et al. (2015) reported an inversely linear relationship between ash content and HHV. Similar results were also found by Jenkins et al. (1998) and Obernberger et al. (2004). The biomass HHV is considered to be strongly related to organic compounds (Yu et al., 2004). The ash content reduction results in a relatively higher content of organic matter such as lignocellulose and volatile matter and consequently increasing the HHV. The biomass heating value represents the calorific release during combustion. Improving HHV obviously enhances the energy potential of cane trash as a biomass solid fuel. The ANOVA statistical summary for HHV is as indicated in Table 4.9. Figure 4.1 shows the comparison of HHV for the leached and unleached cane trash briquette samples.

Table 4.9: ANOVA Statistical summary for HHV

Response Variable	**Independent Variable**	**P-Value**	**F-Value**	**T-Value**	**R_sqr(Adj)**	**R_sqr(Pred)**
HHV	Particle size	0.000	86.71	-9.31	81.82	77.09
	Temperature	0.003	14.45	3.80		
	Time	0.000	18.84	4.34		

The equation that models the behavior of the leached cane trash briquette (HHV) based on the independent variables is shown in the Equation 4.3.

$$HHV = 17.480 + 0.01448TEMP + 0.03158TIME - 0.3005Ps \text{ ....4.3}$$

Results from ANOVA statistical analysis for the HHV shows that the 3 experimental factors, temperature, particle size, and time were statistically significant to a confidence level of 95%; with p-values <0.05. The adjusted R^2 and the predicted R^2 were 81.82% and 77.09% respectively as shown in table 15; proofing the dependability of this experimental model.

The heating value of the leached cane trash briquettes was generally higher than that for the un-leached samples by 6.58%. The increase of the heating value of leached cane trash briquettes is associated with the excess extraction of ash hence yielding lower dilution by ash.

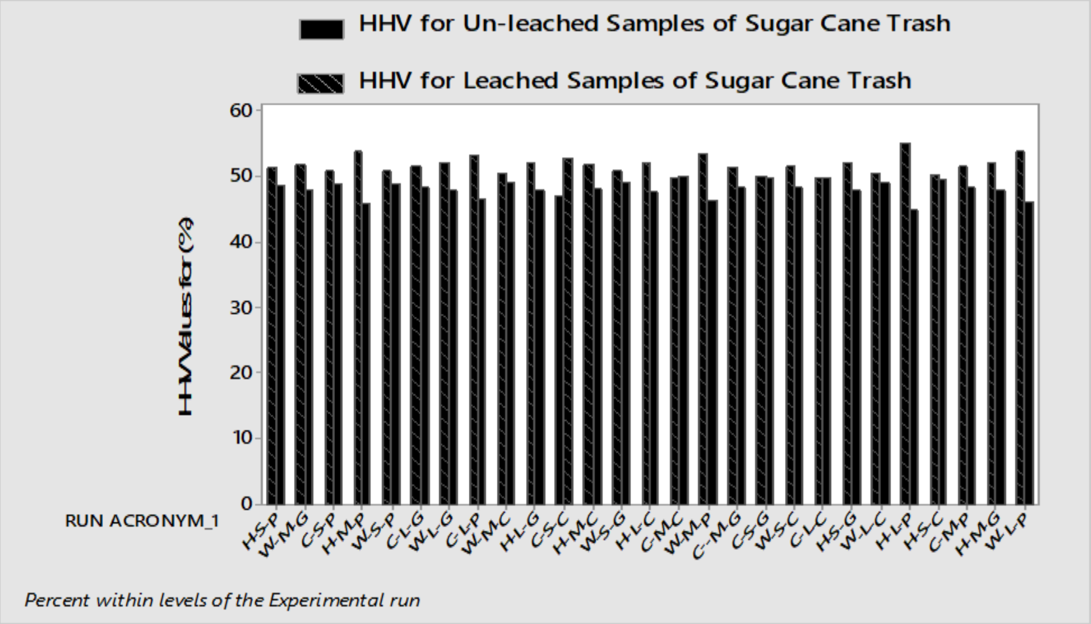


Figure 4.1: Comparison of HHV for the leached and un-leached cane trash briquettes

There were higher values of heating values for the most severe treatment runs. For example, run 23, H-L-P with 21.23 MJ/kg compared to the least severe treatment runs such as run 11, C-S-C with 14.51 MJ/kg). The reason behind it being the reduction of ash. Ash content decreases with increasing treatment severity, from 3.95% in unleached pulverized samples to about 2.66% in the H-L-P samples. This observation is directly attributable to the removal of inorganic components of the ash from the cane trash, primarily K, Mg, S and C1. The reduction in ash content produces an increase in HHV of the processed biomass fuels compared to the untreated biomass fuels. The results reported in this investigation are promising indicator of the nature of treated cane trash fuel.

4.2.4 Moisture Content

According to the proximate analysis, the Moisture Content (MC) of the un-leached cane trash was 61.7%, which is consistent with the dry surrounding environment during storage. The moisture contents of feed stocks after leaching were in the range from 45.50% to 66.4%% with a mean of 54.51 and standard deviation of 0.51 on a wet basis as indicated in Tables 4.5. Table 4.10 shows the experimental results for moisture content in all 27 runs.

Table 4.10: Moisture content Leaching Run Results

		Time [A] in minutes		
Particle Size [C] in mm	**Temperature[B] in ºC**	**20**	**40**	**60**
1	25	0.516	0.51	0.514
1	50	0.507	0.499	0.459
1	100	0.487	0.48	0.455
5	25	0.567	0.563	0.55
5	50	0.564	0.543	0.541
5	100	0.535	0.518	0.517
10	25	0.572	0.585	0.609
10	50	0.578	0.664	0.593
10	100	0.585	0.616	0.593

Data recorded with mean and standard deviation. MC =0.5451±0.0509 fraction dry basis

The high moisture in leached biomass would make most of these materials unsuitable for thermochemical conversion without prior dewatering and possibly drying. A high moisture content of biomass normally wastes more energy during combustion, because the moisture consumes heat for evaporation during the early stage (Yu et al.; 2014). Fuel blending, hydrothermal and supercritical processing, biochemical conversion, and other processes can be employed to overcome difficulties with high moisture content (Demirbas, 2007). But for more conventional combustion and gasification applications water-leaching pretreatments initially produce high moisture feedstock in need of further mechanical dewatering or drying constituting the subject of related research. The ANOVA statistical summary for MC is as indicated in Table 4.11.

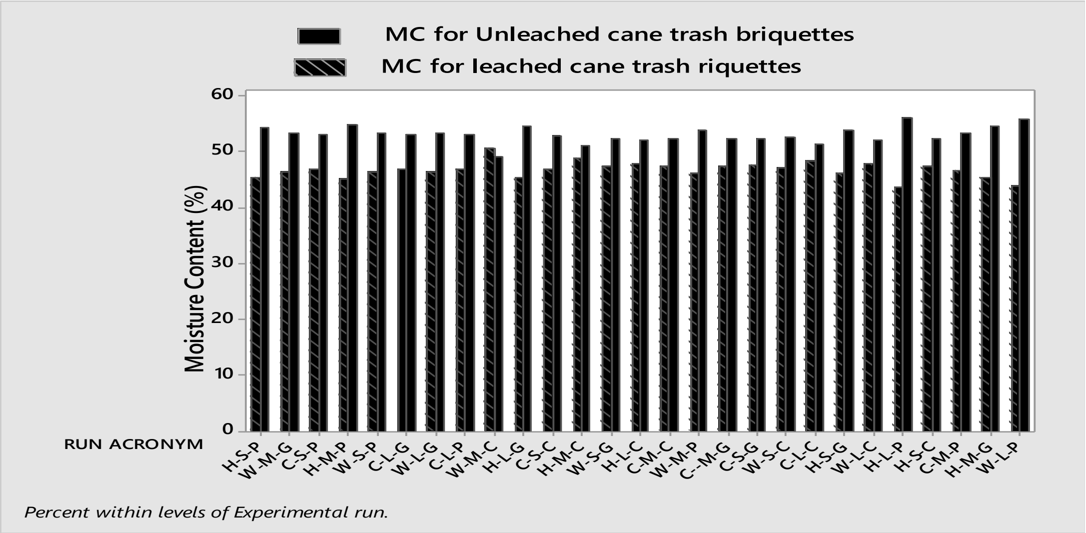
Table 4.11: ANOVA Statistical summary for MC

Response Variable	**Independent Variable**	**P-Value**	**F-Value**	**T-Value**	**R_sqr(Adj)**	**R_sqr(Pred)**
Moisture content	Particle size	0.000	111.96	10.58	81.56%	77.69%
	Temperature	0.031	5.28	-2.30		
	Time	0.039	0.77	-0.88		

The equation that models the behavior of the leached cane trash briquette moisture content based on the leached cane trash briquette independent variables considered is shown in Equation 4.4

$$MC = 0.5084 - 0.00305TEMP - 0.000222TIME + 0.01191Ps \text{ ....4.4}$$

From Table 4.11 it’s clear that the particle size had a significant impact on moisture content during pressing and dewatering. This variable was statistically significant at 95% confidence level. Time and temperature did not have much impact on the moisture content changes. However, Figure 4.2 shows that the pulverized samples, in most cases, were reduced to near or below 50% after a single pressing. On average, the 9 pulverized samples were reduced by 20.28% compared to 2.70% for the chopped samples as indicated in Table 4.12. Greater reduction in moisture content under the identical milling conditions indicates greater moisture removal efficiency for the smaller particle size.



Percent within levels of Experimental run.

Figure 4.2: Change in moisture content resulting from pressing the cane trash biomass material

Table 4.12: Moisture reduction levels between pulverized and chopped cane trash samples after pressing/milling

Sample Type	Mean	Standard Deviation	Difference From Original Unleached Samples	Percentage Difference
Original unleached samples	0.617	0.0314		
9 Pulverized Samples	0.49189	0.02314	0.12511	20.28
9 Chopped Samples	0.5994	0.02794	0.0176	2.70

Particle size reduction requires more power that would end up offsetting these gains. Both unit operations should be evaluated within the context of the larger stoves system which is beyond the scope of this investigation. The remaining variables were considered but no patterns were observed. Neither leaching time nor water temperature had an appreciable effect on the ability to remove moisture by milling. Initially the leached cane trash had more moisture content compared to the unleached cane trash. This requires drying and dewatering, but the benefits exceeds the involved costs. The costs are deemed offset by the pro-longed boiler life due to reduced corrosion (Loo and Koppejan, 2008).

4.2.5 Ash Content

Both unleached and leached cane trash showed a relatively low ash content, at 4.14% and 2.77%, respectively as shown in Table 4.5. The percentage of ash removed after leaching was 33%, which is largely due to the removal of a great number of ash particles, as well as some alkaline metals such as K and partial Cl and S contents in the biomass (Liu et al., 2011). Reviewed literature showed relatively higher ash contents 8.28% for the unleached biomass compared to 6.27% after washing. Generally, the ash content is inversely related to the biomass combustion efficiency. High ash content in biomass decreases the heating value and generates ash-related problems such as precipitation on the inner surface of the burner when applying biomass as a solid fuel (Chin et al., 2015). The ash content of the treated and untreated cane trash briquette samples at various treatment levels is graphically presented in Figure 4.3.

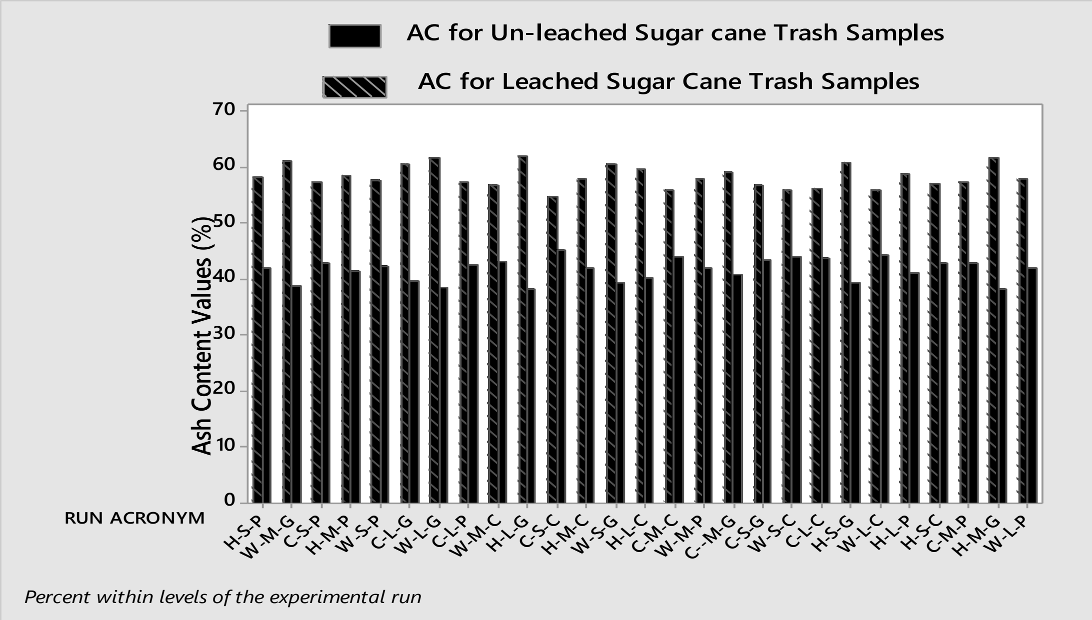


Figure 4.3: Differences in Ash Content among the leached and un-leached cane trash briquette samples under their respective treatment conditions.

The values in Table 4.5 are in dry mass basis for instance there was 4.14 grams of ash per 15grams of unleached cane trash. After leaching, there was 2.77 grams of ash per 15 grams of leached cane trash.

Table 4.13: ANOVA statistical summary for Ash content

Response Variable	Independent Variable	P-Value	F-Value	T-Value	R_sqr(Adj)	R_sqr(Pred)
Ash content	Particle size	0.000	167.30	12.93	87.86	85.64
	Temperature	0.003	16.49	-4.06		
	Leaching time	0.012	7.42	-2.72		

Regression Equation for ash content.

$AC = 2.9966 - 0.003600TEMP - 0.00461TIME + 0.09710Ps$..............4.5

All the 3 experimental factors of the leaching time, leaching water temperature and particle size had significant effect on the cane trash briquette ash content at 5% level of significance. With all of their p-values being less than 0.05. The adjusted R2 and the predicted R2 were 87.86% and 85.64% respectively as indicated in Table 4.13. This is a proof that this experimental model is dependable for providing more precise view of correlation.

Ash content decreases with increasing treatment severity, from 4.14% in untreated pulverized cane trash to about 2.03% in (H-L-P) treatment. This reduction in ash content is directly attributable to the removal of inorganic components of the ash from the cane trash, primarily K, Mg, S and C1. The reduction in ash content produces an increase in higher heating value (HHV) of the processed fuels compared to the untreated cane trash.

4.2.6 Volatile matter

The volatile matters of leached and unleached cane trash were 76.75% and 73.80% as indicated in Table 4.5. Biomass with a higher content of volatile matter typically has a relatively lower ash content (Wu et al 2019). High content of volatile matter accelerates the combustion process and generates more energy at a given temperature (Chin et al., 2015). Therefore, the leached cane trash with a slightly higher volatile matter than unleached cane trash performed better in generating heat. The volatile matter slightly increased by 3.8% from 73.80% in unleached cane trash to 76.753% in leached cane trash. Significant increases in volatile matter were found in unleached biomass from the reviewed literature, increasing from 74.00% to 80.30% after leaching. Increases in volatile matter will enhance the energy per unit of dry mass, conveying the benefits of the leaching process (Tonn et al., 2012). The volatile matter increased because ash content had been reduced by washing away ash related elements. This is also due to the reduction of other constituent inorganic and organic matter which were removed and could be detected in the leachate. Table 4.14 shows the ANOVA statistical summary for Volatile matter and Appendix C6 in the Appendix shows the 27 experimental runs for the volatile matter.

Table 4.14: ANOVA statistical summary for Volatile matter

Response Variable	Independent Variable	P-Value	F-Value	T-Value	R_sqr(Adj)	R_sqr(Pred)
Volatile matter	Particle size	0.000	74.70	-8.64	80.92	75.96
	Temperature	0.003	27.27	5.22		
	Time	0.000	11.30	3.36		

The equation that models the behavior of the leached cane trash briquette volatile matter is shown in Equation 4.6

$$VM = 75.532 + 0.03722TEMP + 0.0458TIME - 0.5217Ps \ldots\ldots\ldots\ldots\ldots.. 4.6$$

All the 3 independent variables leaching water temperature, particle size and leaching time were highly statistically significant to a confidence level of 95% with p-value<0.05 as tabulated in Table 4.14.

4.2.7 Fixed Carbon

Fixed carbon (FC) of unleached cane trash had a mean of 22.18% and standard deviation of 1.53 as indicated in Table 4.5. The FC for the leached cane trash had a mean of 14.03 and standard of 1.50. This is a decrease of 36.75%. The results show that leaching reduced the amount of FC in the cane trash. This result agreed with a previous study by Hadders and Olsson (1997) who showed that fixed carbon in switchgrass decreased and the content of volatile matter increased as harvest was delayed to later months. The reason for the decrease being natural leaching by weather in the farm. A study by Adler et al. (2006) reported similar results for switchgrass harvested in fall and spring. Additionally, switchgrass harvested in later months in the fall had a lower ash and higher reactivity compared to earlier months in the summer. Fixed carbon reduced because the volatile materials had been removed. Fixed carbon in the biomass is the solid carbon in the biomass that remains after volatile materials are driven off.

$FC = 100 - (\%MC + \%VM + Ash)$…………………………..4.7

The mass loss over this is the “Volatile Matter”. This includes carbon “C” and also H, N, O; it is the component that devolatilizes. Fixed carbon from proximate analysis is a different value than total elemental carbon in ultimate analysis. The total carbon “C” includes some organic carbon that escapes as volatile matter emissions during combustion. Fixed carbon is a calculated percentage of material that was lost during the testing of moisture, volatile matter and ash. For this briquettes a lower fixed carbon is good because you have more that can volatilize. Appendix C7 shows the leaching experiment results for FC in the 27 runs. The ANOVA analysis summary for the FC in leached cane trash is shown in Table 4.15.

Table 4.15: ANOVA statistical summary for Fixed Carbon

Response Variable	**Independent Variable**	**P-Value**	**F-Value**	**T-Value**	**R_sqr(Adj)**	**R_sqr(Pred)**
Fixed Carbon	Particle size	0.000	83.02	9.11	**77.46%**	**72.44%**
	Temperature	0.028	6.01	-2.45		
	Time	0.022	3.31	-1.82		

The model equation for fixed carbon based on the independent variables considered is shown in Equation 4.8.

$$FC = 13.457 - 0.01077TEMP - 0.01528TIME + 0.3393Ps \ldots\ldots\ldots\ldots\ldots\ldots 4.8$$

All the 3 independent variables were highly statistically significant at 95% confidence level with p-value <0.05. The adjusted R^2 of the model was equal to 77.46%, while the predicted R^2 was 72.447% as indicated in Table 4.15. This showed that the statistical model is reliable. Figure 23 indicates the differences in the FC of leached and unleached cane trash samples.

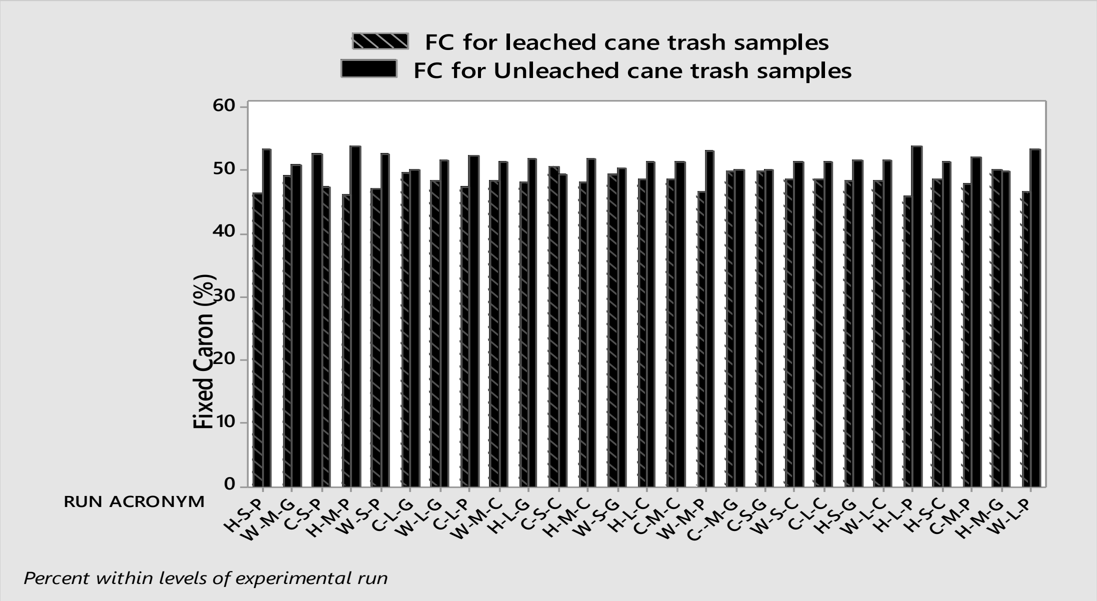


Figure 4.4: Differences in the levels of fixed carbon between the leached and unleached cane trash briquettes samples.

Fixed carbon decreased with increasing leaching severity. The energy value of the biomass is largely dependent on its volatile matter, fixed carbon and ash content. Biomass with high volatile matter, high carbon and low ash content is preferable for energy conversion. Fixed carbon of any material gives an estimate of the heating value of the fuel and acts as the main heat generator during combustion.

4.2.8 Evaluation of Physical and Combustion Properties of Leached Cane Trash Briquettes

The effects of the independent experimental variables on the dependent variables was investigated. Figures 4.5 to 4.10 illustrates the effects of leaching time, temperature, and particle sizes on the selected physical and combustion properties of leached cane trash.

4.2.9 Effects of leaching time on selected physical and combustion properties of cane trash briquettes

Figure 4.5 indicates the changes that occur to the cane trash bulk density and mechanical durability as leaching process is done relative to time taken to perform the leaching. The curves present a clear observation of the effect that the experimental variable time has on briquettes bulk density and mechanical durability. Though, leaching time had less significant effect to the bulk density and mechanical durability, there was an equally positive effect in which bulk density and mechanical durability increases with a longer leaching time. The highest bulk density values were determined in run number 23 and the lowest in run number 12. This observation shows that bulk density increases with the leaching severity. Similarly, the maximum mechanical durability values occurred at run number 23, the most severe treatment. Figure 4.6 shows the effects of leaching time to VM, HHV, AC, MC and FC.

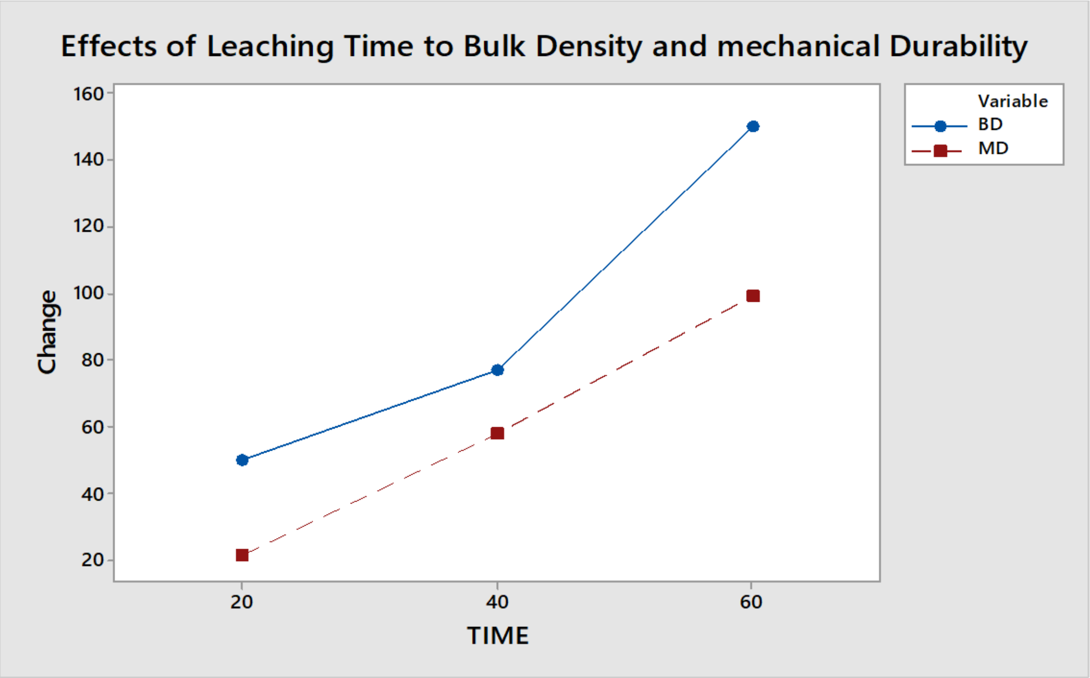


Figure 4.5: Effects of leaching time to bulk density and mechanical durability

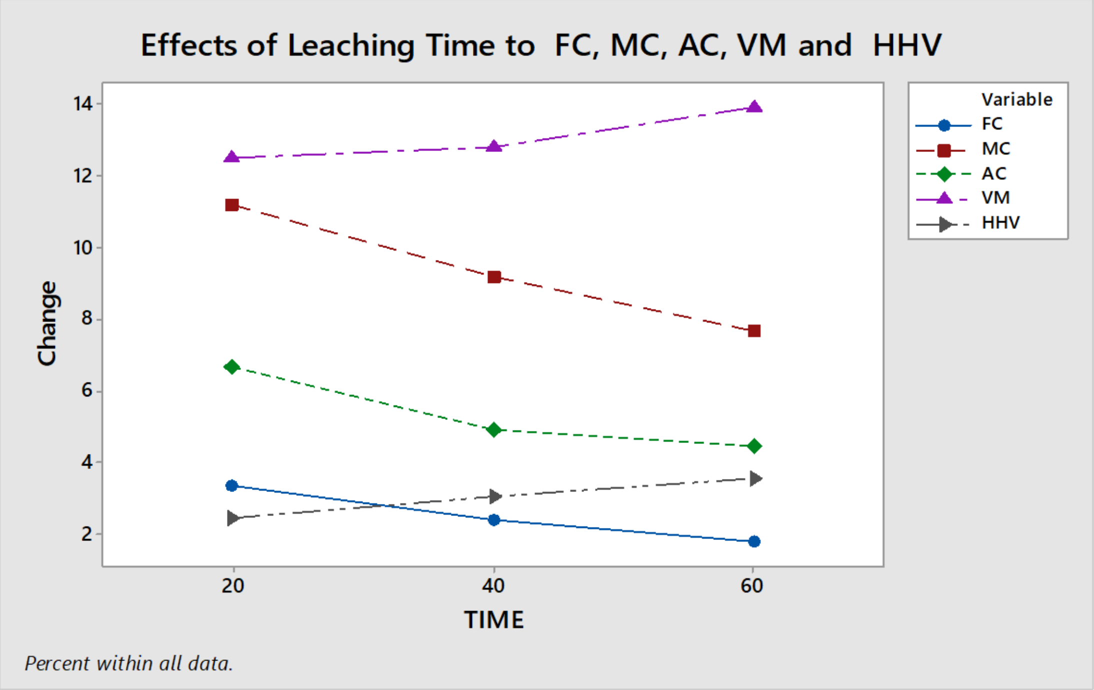


Figure 4.6: Effects of leaching time to VM, HHV, AC, MC and FC

The increase in the leaching time has a positive effect to all the dependent variable except for the ash content and fixed carbon. As leaching time increases the HHV, MC and VM increases. On the other hand, this has a negative effect to the ash content and the Fixed carbon whose trend is observed to go down. The increase in time allows for more removal of organic and inorganic matter that inhibit proper combustion. This is the reason for the subsequent increase in HHV and VM. Leaching reduces ash content because most of the materials in the ash are washed away, thus ash content reduces. There were lower values of AC at H-L-P (run 23) and highest at C-S-C (run 11) a clear show that ash content reduces with leaching severity.

4.2.10 Effects of leaching temperature on selected physical and combustion properties of cane trash briquettes

Figure 4.7 shows the trends exhibited by bulk density and mechanical durability when the leaching temperature is varied.

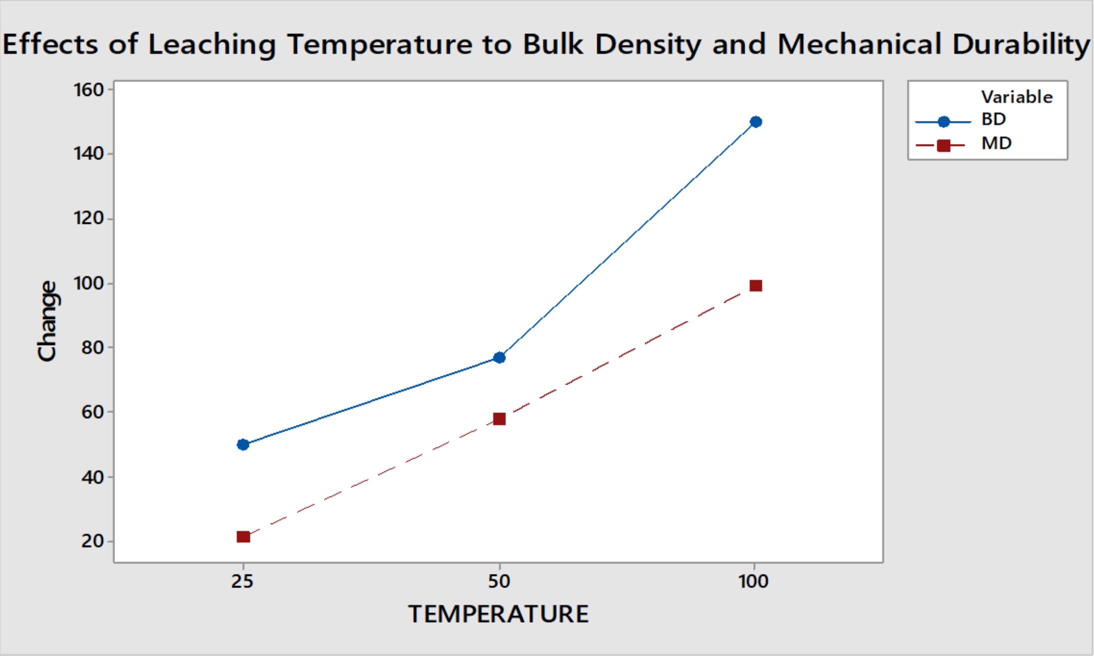


Figure 4.7: Effects of leaching temperature to Bulk density and Mechanical durability

It is evident from this observation that leaching temperature rise has the effect of increasing briquettes bulk density and the Mechanical durability. Higher temperatures remove more moisture in the cane trash and creates favorable compaction conditions. Yank et al. (2016) noted that high temperature and pressure are widely agreed to enhance binding mechanisms but require important energy input. Grover and

Mishra (1996) advised that the preheating temperature should not exceed 300 °C to prevent biomass materials decomposition. The study concluded that densification at temperature of 80 °C could produce briquettes with high density and mechanical durability required to meet quality certification standards. As part of the process parameters in briquetting of pine needles, Mandal et al. (2019) used a temperature range of 60–150 °C. Results from the study showed that a temperature of 150°C was found to be optimum to produce briquette.

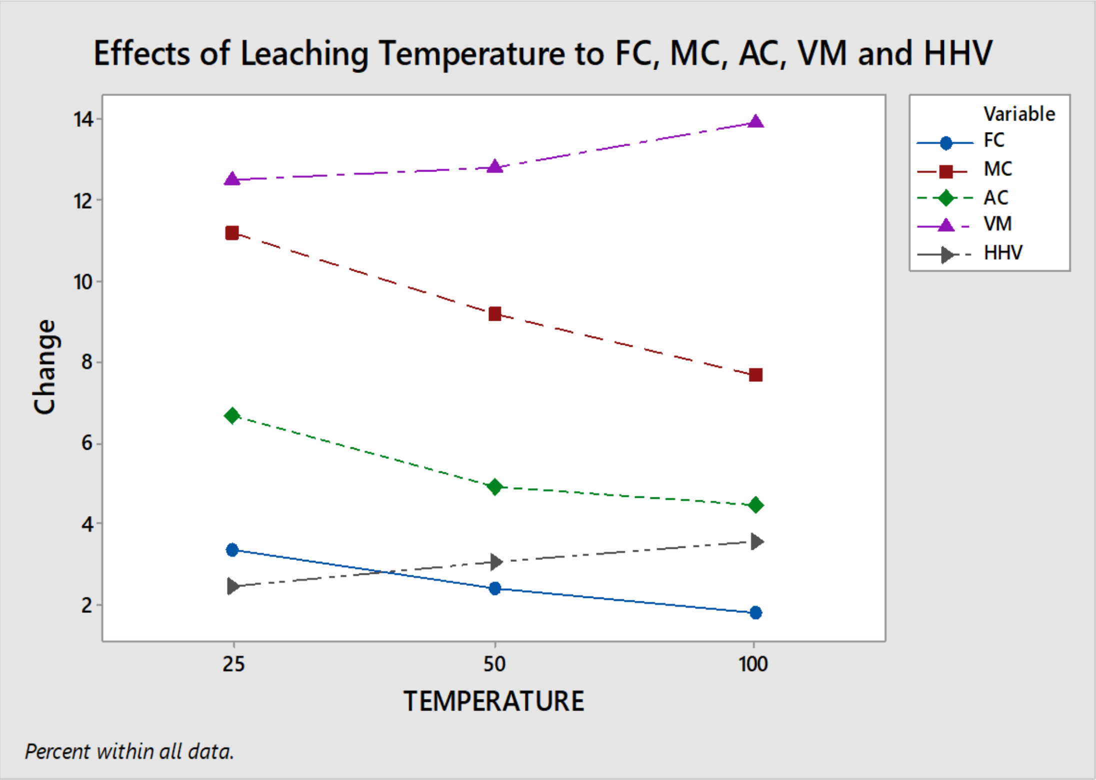


Figure 4.8: Effects of leaching temperature to VM, HHV, AC, MC and FC

Optimum temperature value within the range of 65 °C to 100 °C for feedstock preheating was proposed by Kaliyan and Morey (2009) but added that temperatures higher than 100 °C and up to 300 °C can be used if desired. Figure 4.8 has graphical presentation of the effects of leaching temperature to VM, HHV, AC, MC and FC. Leaching temperature rise has the effect of increasing the VM and HHV. but leaching temperature rise has the effect of decreasing the MC, AC and FC. Increased temperatures allow for severe leaching process as more organic and inorganic matter is dissolved. The more the removal of the unwanted organic and inorganics in thee biomass the higher the HHV and VM. Inversely, the removal of more material from the biomass lowers the AC and FC of the material.

4.2.11 Effects of Particle size on selected physical and combustion properties of cane trash briquettes

The effects of particle size to Bulk density and mechanical durability are indicated in Figure 4.9.

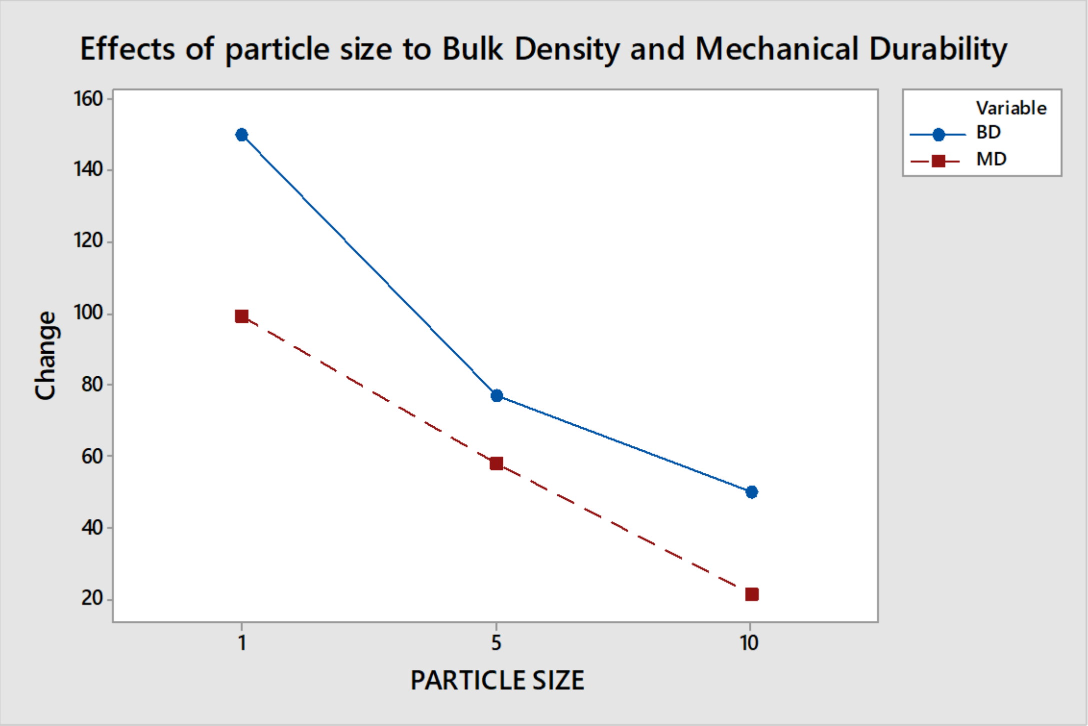


Figure 4.9: Effects of particle size to Bulk density and mechanical durability

The increase in particle size shows an inverse effect. In this case, as a result of a large particle size, a lower density of the briquettes occurs. Smaller particle sizes increase the bulk density of briquettes because they are easy to compact and do not have larger inter particle spaces. Similarly, smaller particles size of the cane trash briquette causes a higher mechanical durability. The briquette is more durable due to optimal compaction conditions.

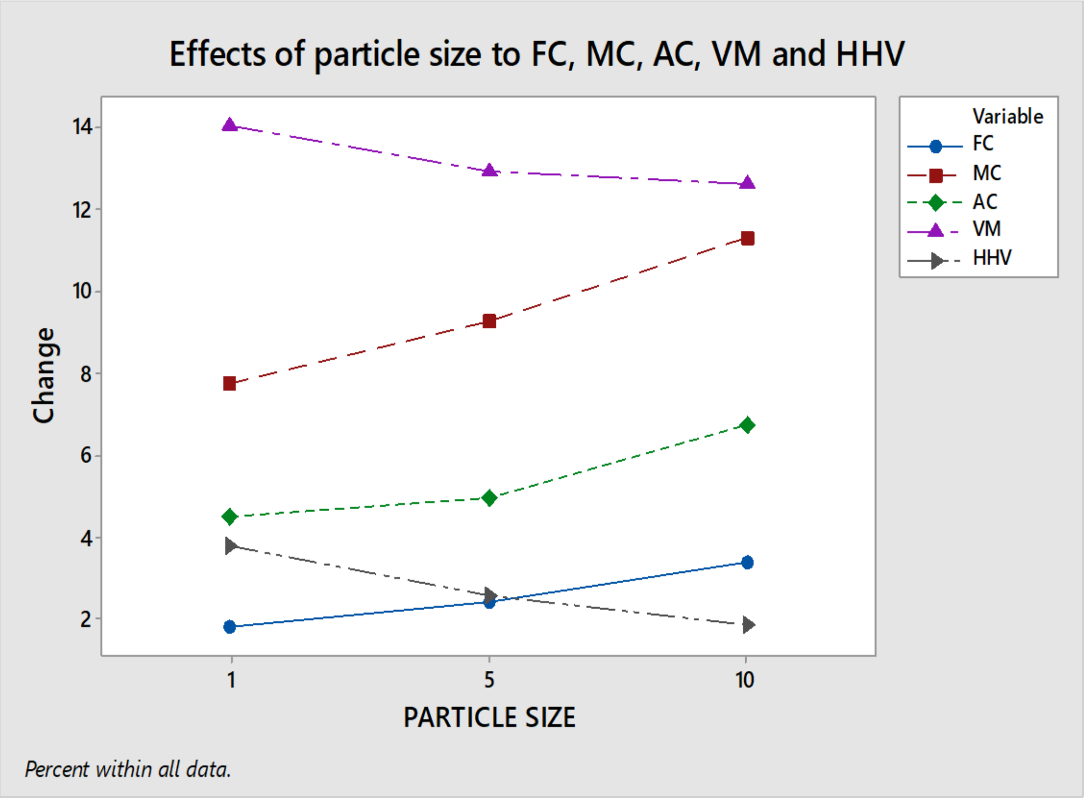


Figure 4.10: Effects of particle size to VM, HHV, AC, MC and FC

From Figure 4.10 above, its observed that the volatile matter increased with reducing particle size. The experimental results show a consistent increase in volatile matter with decreasing particle size. The reduction of particle size correspondingly reduced the ash content and the fixed carbon, suggesting that leaching also changed the mass fraction and composition of organic compounds in the leached solids for the cane trash. For moisture content, the increase in particle size shows a positive effect, in this case, as a result of a large particle size, more amount of the moisture content is recorded. This is because larger particles allow more inter particles spaces to lock up moisture. It also requires more power to press the leaching water out in larger particles trash samples before drying than in smaller particle trash samples. The increase in particle size had appositive trend to the FC. In this case, as a result of a large particle size, a higher amount of fixed carbon was recorded. This is because large particles reduce the severity of the leaching process. The severe the leaching the lesser the ash and fixed carbon. The particle size had the most effect to the heating value of the treated cane trash briquettes. The mean HHV was highest (at 21.23 MJ/kg) for the smaller particle sizes and low (14.51 MJ/kg) for large particle sizes. Thus the particle size had the influence of increasing the HHV of the cane trash briquettes.

4.2.12 Analysis of the Gaseous and Particulate Emissions from Leached Cane Trash Briquettes

Table 4.16 shows the results of the gaseous and particulate emissions from unleached and leached cane trash briquettes while Table 4.17 indicates their range.

Table 4.16: Summary of the gaseous and particulate emissions from unleached and leached cane trash briquettes

Variable	Original Unleached Cane Trash		Leached Cane Trash		Percentage change (decrease or increase)
	Mean	Standard Deviation	Mean	Standard Deviation	
CO [ppm]	1484.00	4.01	698.81	7.35	(-)52.91
NO[ppm]	199.80	7.90	147.00	4.43	(-)26.43
SO2[ppm]	0.80	0.10	0.62	0.12	(-)22.50
Nox[ppm]	205.90	8.20	175.80	6.00	(-)14.62
Tgas Temperatures[K]	549.30	2.60	604.00	3.33	(+)9.96
TSP[mg/Nm3]	62.20	0.30	35.38	5.37	(-)41.51
Efficiency (%)	52.00	5.60	60.42	6.49	(+)8.42

Table 4.17: Maximum and Minimum Leaching Run Results

Variables	Maximum			Minimum		
	Value	Run Number	Acronym	Value	Run Number	Acronym
CO [ppm]	709.67	11	C-S-C	685.74	8	H-L-P
NO [ppm]	155.14	11	C-S-C	141.07	8	H-L-P
SO_2 [ppm]	0.84	11	C-S-C	0.35	8	H-L-P
Nox [ppm]	188.30	11	C-S-C	161.09	8	H-L-P
Tgas [K]	609.30	8	H-L-P	599.26	11	C-S-C
TSP [mg/Nm^3]	47.02	11	C-S-C	27.00	8	H-L-P
Efficiency (%)	72.83	8	H-L-P	45.17	11	C-S-C

The emission values were recorded in triplicates per treatment and used in linear regression model without aggregation. However, Appendix C8 shows results of the mean emissions value per treatment, Table 4.18 is indicating the descriptive statistics of gaseous and particulate emissions from leached cane trash briquettes and Table 4.19 displays the Statistical Analysis Summary for gaseous and particulate emissions. Further,

Table 4.18: Descriptive statistics of gaseous and particulate emissions from leached cane trash briquettes

Variable	CO	NO	SO2	NOx	Tgas	TSP	Eff.
Mean	698.813	147.00	0.625	175.80	604.00	35.38	60.42
Standard Deviation	7.346	4.43	0.104	6.00	3.33	5.37	6.49

Table 4.19: Statistical Analysis Summary for gaseous and particulate emissions

Response Variable	Independent Variable	P-Value	F-Value	R_sqr (adjust)	R_sqr (Pred)
Carbon Monoxide	Particle Size	0.000	47.31	83.17	76.41
	Leaching Temperature	0.000	17.99		
	Leaching Time	0.168	1.96		
Nitrous oxide (NO)	Particle Size	0.000	113.42	91.95	88.71
	Leaching Temperature	0.000	27.30		
	Leaching Time	0.001	10.75		
Sulfur-dioxide (SO2)	Particle Size	0.014	5.34	18.41	0
	Leaching Temperature	0.817	0.20		
	Leaching Time	0.684	0.39		
Oxides of nitrogen (NOx)	Particle Size	0.000	174.4	94.16	91.81
	Leaching Temperature	0.000	17.40		
	Leaching Time	0.000	20.76		
Tgas	Particle Size	0.000	283.24	96.25	94.74
	Leaching Temperature	0.000	39.23		
	Leaching Time	0.000	14.04		
Total Suspended Particles (TPS)	Particle Size	0.000	144.43	93.57	90.99
	Leaching Temperature	0.000	24.60		
	Leaching Time	0.000	23.29		
Efficiency	Particle Size	0.000	89.29	90.88	87.22
	Leaching Temperature	0.000	18.30		
	Leaching Time	0.000	24.97		

4.2.13 Carbon Monoxides

The 2 experimental factors, temperature and particle size, were statistically significant to a confidence level of 95%. The p-values for the 2 experimental factors was less than 0.05. Leaching time was not statistically significant to 95% confidence level for its p-value is more than 0.05, p-value = 0.168. The adjusted R^2 of the model was equal to 83.17%. While the predicted R^2 was 76.41%. as indicated in Table 4.19.

The equation that models the behavior of CO emissions based on the leached cane trash briquette independent variables considered is shown by Equation 4.9.

$$CO = 696.89 - 0.84TIME40 - 2.71TIME60 - 4.82TEMP50 - 8.38TEMP100 + 7.92Ps5 + 13.58Ps10 \text{---}4.9$$

CO is a sign of inefficient combustion. The following four reasons may contribute to incomplete combustion in a solid fuel combustion system: b) insufficient oxygen flow; in forced draught stoves/burners, the combustion fan and induced draught fan may not be of the proper size; in natural draught stoves/burners, improper chimney setup; or the chimney is not warm enough for a positive draught; (a) poor stoves/burner design, which results in a low temperature in the combustion chamber; (c). Poor oxygen and fuel mixing is a common problem with solid fuel; nevertheless, diffusers can effectively mix air and fuel in a liquid or gaseous fuel. ;(d) The fuel's moisture content; a larger moisture content could have a major impact on combustion (B.M Jenkins et al 1998). Leached and unleached briquettes produced very different CO emissions when burned. Whereas, at the chosen level of significance (= 0.05), there was no discernible difference between the various treatment samples. These findings show that the leached briquettes produce around 50% less CO than the unleached briquettes, and none of the previously stated causes appear to have caused incomplete combustion. The cause of this decrease in CO in leached briquettes is attributed to the increase in the volatile matter that could burn up completely without much emissions.

4.2.14 Nitrous Oxide

The 3 experimental factors, leaching water temperature, leaching time and particle size, were highly statistically significant to a confidence level of 95%. The p-values for all the three experimental factors was <0.05. The adjusted R^2 of the model was equal to 91.95%, while the predicted R^2 was 88.71%. as tabulated in Table 4.19. The equation that models the behavior of NO emissions based on the leached cane trash briquette independent variables considered is shown by Equation 4.10.

$$NO = 146.997 - 1.984TIME40 - 2.640TIME60 - 2.657TEMP50 - 4.344TEMP100 + 4.342Ps + 8.927Ps10 \quad \ldots 4.10$$

Leaching process had a greater effect of washing away nitrogen from the cane trash. This is the reason for the marked reduction in nitrous oxides between the leached and unleached samples. Washing away of nitrous oxides was proportional to the severity of the leaching process.

4.2.15 Sulfur-dioxide

The equation that models the behavior of SO_2 emissions based on the leached cane trash briquette independent variables considered is shown by Equation 4.11.

$$SO2 = 0.5583 + 0.0029TIME40 - 0.0324TIME60 - 0.0015TEMP50 + 0.0239TEMP100 + 0.0608Ps5 + 0.1451Ps10 \quad \ldots 4.11$$

SO_2 depends on the presence of fuel bound sulfur. Sulfur is considerably low compared to coal. Hence, SO_2 emissions are much lower than the detectable range of 1 ppm most of the time during combustion. however, at high temperatures the SO_x spiked irregularly. This spiking irregularly is attributed to the production of thermal SO_x (oxides of sulfur) such as SO_3 as reported by Evans and Roesler (2011)

4.2.16 Oxides of Nitrogen

The equation that models the behavior of NOx emissions based on the leached cane trash briquette independent variables considered is shown by Equation 4.12.

$$NOx = 174.560 - 3.488TIME40 - 4.796TIME60 - 1.794TEMP50 - 4.509TEMP100 + 6.888Ps5 + 14.369Ps10 \ldots\ldots 4.12$$

Reviewed literature suggests that NOx (oxides of nitrogen) depend on two factors (W. Fan et al 2010); (a) fuel bound nitrogen content; and (b) thermal NOx produced when the combustion temperature exceeds 1200 °C. The combustion temperature did not exceed 1200 °C as the briquettes were combusted in a domestic wood stove. Therefore, NOx emissions should be proportional to the fuel bound nitrogen content.

4.2.17 Flue Gas Temperature

The equation that models the behavior of flue gas temperatures based on the leached cane trash briquette independent variables considered is shown by Equation 4.13.

$$Tgas = 605.780 + 0.832TIME40 + 1.610TIME60 + 1.08TEMP50 + 2.676TEMP100 - 4.241Ps5 - 7.193Ps10 \ldots\ldots 4.13$$

The reason for the increase in the flue gas temperature is a result of increased ash deformation temperatures. The removal of chlorine and sulfur improved the fuel combustion properties by raising the ash fusion temperature.

4.2.18 Total Suspended Particles

The equation that models the behavior of TSP emissions based on the leached cane trash briquette independent variables considered is shown by Equation 4.14.

$$TSP = 34.933 - 3.098TIME40 - 4.231TIME6O - 2.171TEMP50 - 4.501TEMP100 + 4.493Ps5 + 10.854Ps10 \ldots\ldots 4.14$$

Particle emissions decreased with the increased treatment severity. The particle emissions were the highest for un-leached chopped cane trash briquettes, at 72.8 ± 0.5 mg/Nm^3 reducing to 47.02 ± 1.4 mg/Nm3 for the leached material. Over 80% of the potassium and chlorine was leached out of the feedstock. This leaching decreased in inorganics significantly reducing the particulate matter. There was a significant difference between total suspended particulates (TSP) from the un-leached and leached feedstock at alpha = 0.05 (level of significance). Similarly, the TSP reduced to 41.51% between un-leached to leached feedstock. Particulate matter had a strong relationship with potassium and chlorine content of the fuel. The fuel property of the cane trash significantly improved during leaching. Hence, there was a significant difference between the TSP from leached and unleached feedstock.

4.2.19 Efficiency

The equation that models the behavior of efficiency based on the leached cane trash briquette independent variables considered is shown by Equation 4.15.

$$Eff = 59.954 + 4.886TIME40 + 6.187TIME60 + 3.439TEMP50 + 5.530TEMP100 - 6.296Ps5 - 12.336Ps10 \ldots\ldots 4.15$$

There were significant differences in efficiency between the leached and un-leached cane trash briquettes. The leached cane trash briquettes had an average efficiency of 60.42±6.49% compared to about 51% of the unleached cane trash briquettes. The increase in efficiency is caused by the increase in the ash deformation temperatures due to the removal of inhibiting elements such as chlorine and sulfur. The low levels of chlorine terminated the activity of free radical chain reactions that leads to ash fusion at lower temperatures.

4.3 Effects of Independent Variables on Gaseous and Particulates Emissions from Leached Cane Trash Briquettes

The effect of leaching time, leaching temperature and particle size on selected gaseous and particulate emissions was determined. Figures 4.11 to 4.16 indicates the variation of selected emissions at changing conditions of time, temperature and particle size.

4.3.1 Effects of leaching time to gaseous and particulates emissions

TSP decreases with a longer leaching time. This is because more undesirable organics and inorganics have been leached away. On the other hand, Tgas temperatures increase with a longer leaching time. Figure 4.11 shows the effects of leaching time to TSP, Tgas and Efficiency.

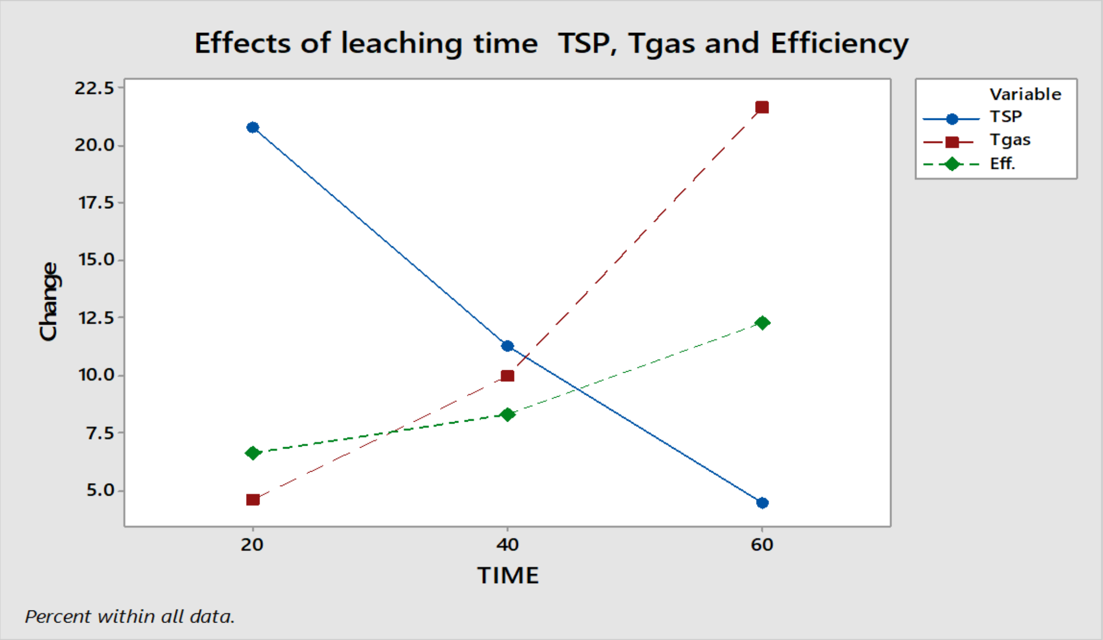


Figure 4.11: Effects of leaching time to TSP, Tgas and Efficiency

More leaching time removes enough alkali and alkaline compounds that hinder combustion. Thus the more the undesirable elements are removed the better the fuel hence leading to higher Tgas values being recorded. Tgas increased with the leaching severity just as TSP reduced with the leaching severity. Leaching time hand an overall effect of reducing the SO2, NOx and CO as shown in the Figure 31. long leaching time provides sufficient removal of inorganic and organics compounds that are responsible for these pollutants. The longer the leaching time the more the removal of these gaseous pollutants. Figure 4.12 shows the effects of leaching time to CO, NOx, SO2 and NO.

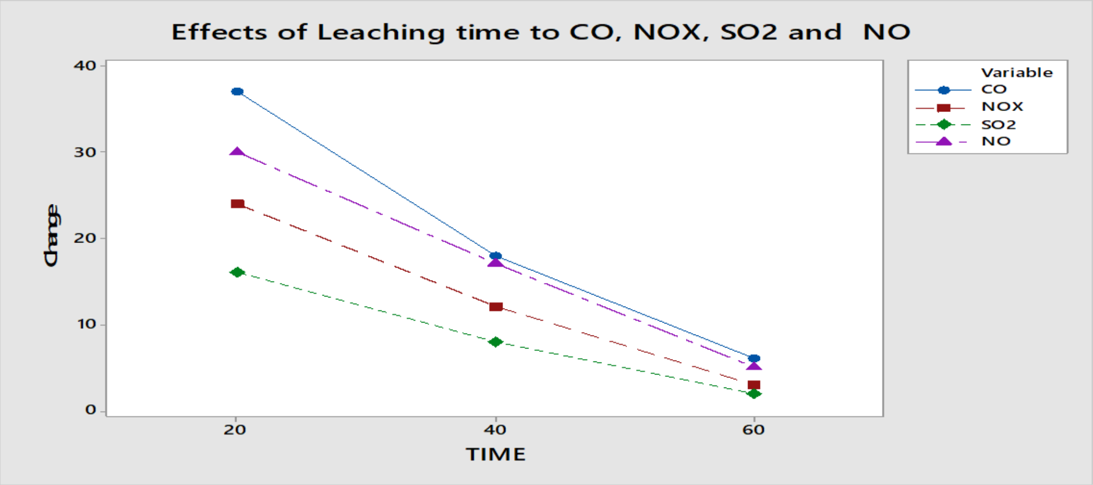


Figure 4.12: Effects of leaching time to CO, NOx, SO_2 and NO

4.3.2 Effects of leaching temperature to gaseous and particulates emissions

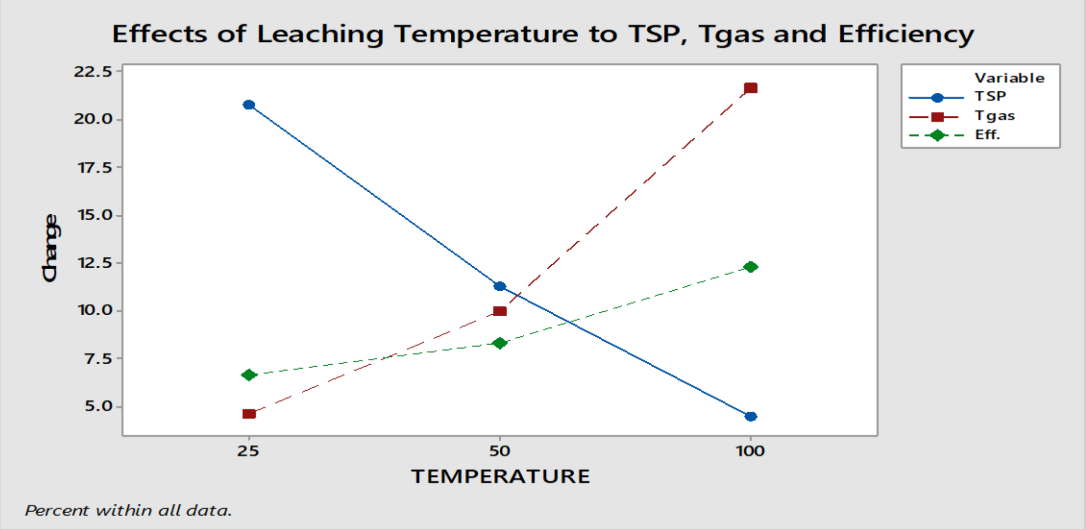


Figure 4.13: Effects of leaching temperature to TSP, Tgas and Efficiency

Figure 4.13 shows that leaching temperature rise has the effect increasing Tgas temperatures and combustion efficiency. But it reduces the quantities of TSP produced in biomass combustion. Figure 4.14 indicates the effects of leaching temperature to CO, NOx, SO2 and NO.

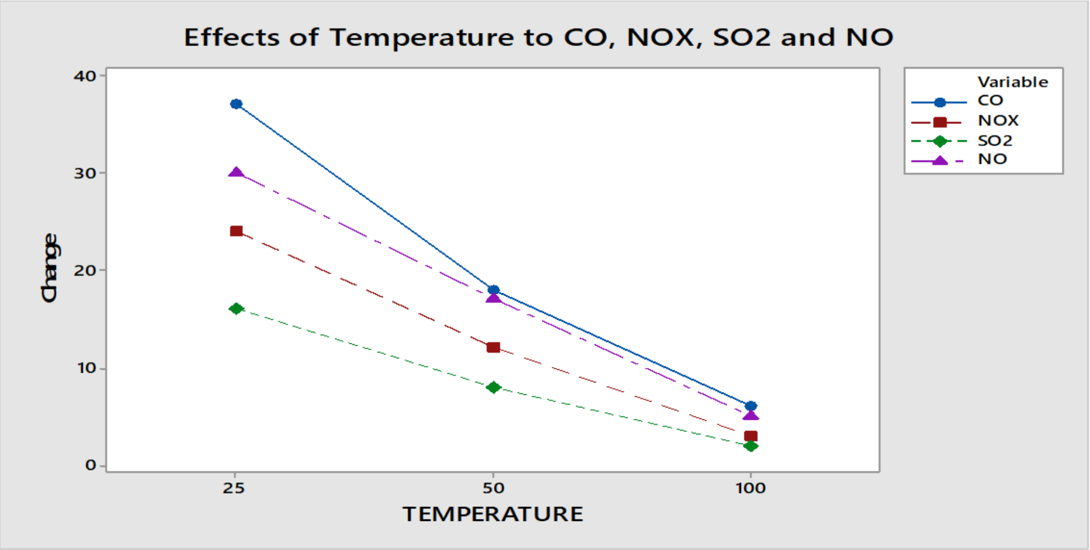


Figure 4.14: Effects of leaching temperature to CO, NOx, SO_2 and NO

Leaching temperature rise has the effect of decreasing NOx, CO and NO. Compounds that would have generated these gases are washed away more with increased temperatures. Hence a biomass leached at increased temperatures has lower gaseous emissions of NOx, CO and NO. SO2 depends on the presence of fuel bound sulfur. Sulfur is considerably low in biomass. Figure 4.15 shows the effects of particle size to TSP, Tgas and Efficiency.

4.3.3 Effects of particle size to gaseous and particulates emissions

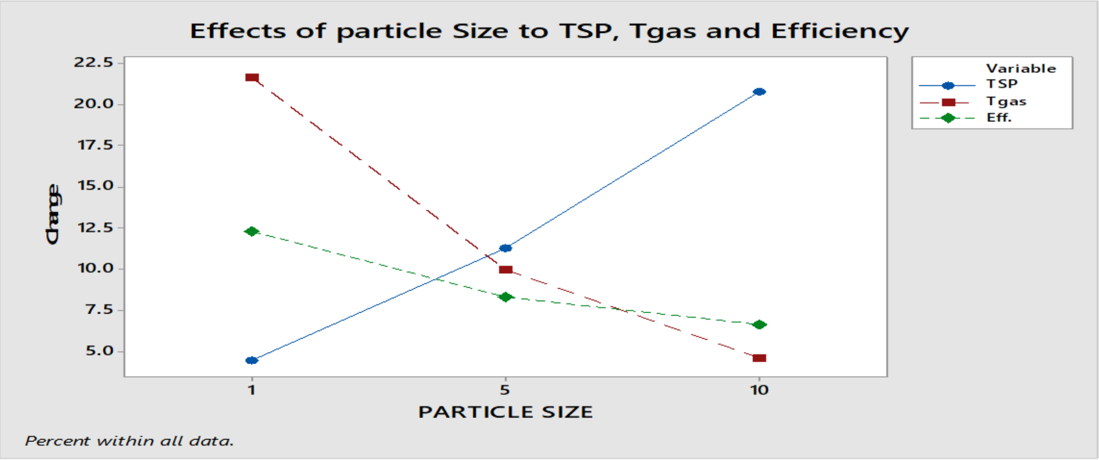


Figure 4.15 Effects of particle size to TSP, Tgas and Efficiency

Particles size has the effect of increasing the TSP of the cane trash fuel. The larger the particle size the more the TSP is emitted to the atmosphere. This is because there was no effective leaching to remove substantial pollutants in samples with large particle sizes. Contrary the increase in particle size shows an inverse effect for efficiency and Tgas recorded. In this case, as a result of a large particle size, a lower efficiency of the briquettes combustion occurs. Similarly, the increase in particle size shows a negative effect for the flue gas temperature as it is observed that particle size increase lowers the amount of the Tgas temperature.

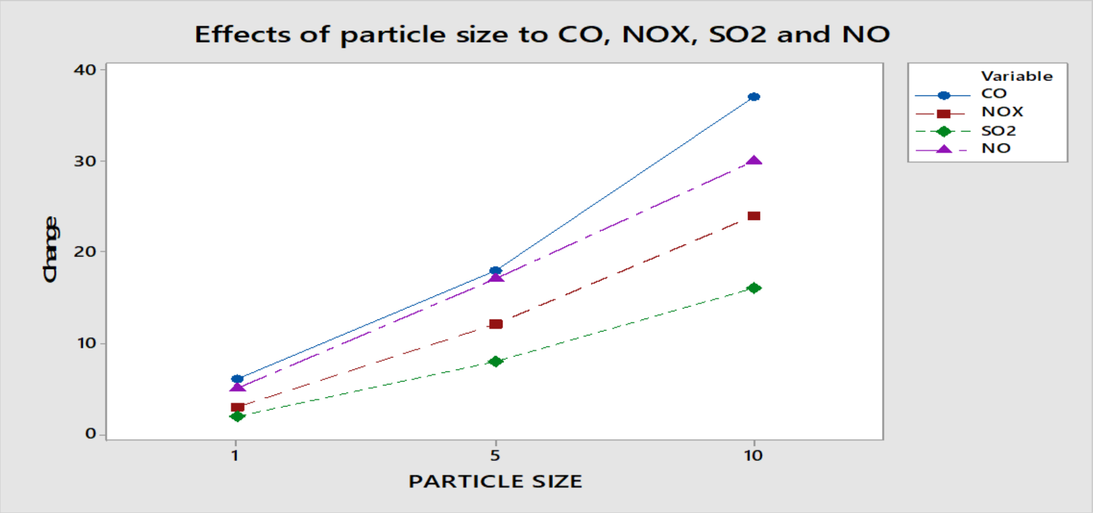


Figure 4.16: Effects of particle size to CO, NOx, SO_2 and NO

Figure 4.16 clearly shows the effects the particle size to the selected gaseous emissions. It is observed that the increase in particle size shows a positive effect for CO, NOx and NO where the increase in particle sizes results in the increase of these pollutants. Particle size increase shows slightly positive effect foe SO_2. It is observed that as a result of a large particle size, more amount of the SO_2 is recorded. It is worth noting that the smaller the particle size , the severe the leaching process and therefore the lesser the pollutants. Large particle sizes do not give severe leaching results; thus some unwanted elements are not completely removed from the biomass hence enhancing pollution.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of this study was to determine the physical and combustion characteristics of leached cane trash briquettes in Drolet Pyropak Stove. Based on the findings, the following conclusion were drawn.

1) Although the leaching process has comparable effects of increasing carbon and volatile matter and lowering ash, Cl, S, and N compounds in this study and from the works done previously by other academics, differences between the proximate analysis and ultimate analysis may be seen. Leaching as a pretreatment method is very effective in removing inorganic ash forming compounds. The effect of particle size is more influential on the leaching rate. The temperature shows substantial impact on the leaching capacity. Hence small particles can leach faster while high leaching temperatures can leach more. Thus reducing large particles can reduce the size of the leaching bath, while heating the leaching water can enhance the quality of the leached cane trash. Leaching temperature of 50 ^{o}C for 60 minutes with 1 mm particle size is recommended for leaching cane trash. Even though the best pretreatment efficiency was obtained with smaller particle size and high temperature washing combinations, for large scale industrial purpose this will not be an economical solution. Because the effect of temperature on small particle size is small compared to large particle sizes, the medium temperature and small particle size recommended based on the leaching behavior is acceptable. For the recommended leaching temperature and particle size, around 33% of ash can be eliminated within the 60 minutes leaching time.

2) Leaching consistently improved the cane trash briquette fuel characteristics. In every instance, the ash content was dramatically decreased. The elimination of ash boosted the heating values of the treated cane trash.
3) Through improved densification during briquetting and enhanced heating values, leaching treatments boosted energy density by 6.94%
4) Leaching enhanced characteristics such fixed carbon, volatile matter, bulk density, and mechanical durability.
5) Leached cane trash briquettes produce about half as much carbon monoxide CO (698.813 ppm) as an unleached briquette (1484 ppm).

5.2 Recommendations

1) Hot water washing of cane trash is an effective pretreatment method to remove ash related elements.
2) Washing at 50^{o}c with 1mm particle size for 60 minutes is recommended as the optimal leaching condition for cane trash.
3) Ash melting tendency could be expected to reduce after the leaching treatment.
4) This study allows for the determination of the options and economic conditions that can be used in industry in order to remove ash related compounds from cane trash before application.

The following recommendations for further study were made:

1) Since organic acids and sugars make up the majority of the extracted organic materials and may act as coproducts of the leaching mechanism, further research into organic extracts is required.
2) It is well known that organic material that is dissolved in biomass can be acidic. This may result in an overestimation of water-soluble AAEM species during

sequential leaching for chemical fractionation when biomass is leached in batches. It is necessary to develop a better method for measuring the amount of water-soluble AAEM species in biomass.

3) Examine and evaluate the biomass ash's microstructure both before and after leaching under burner temperatures. Therefore, it is necessary to directly examine and comprehend sedimentation or agglomeration.

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APPENDICES

Appendix A: Treatments Done to Raw Cane Trash

Table: A1 Cane trash treatments

Run	Acronym	Description	Temp	Duration	Particle Size
1.	H-L-P	Hot soak, long duration, pulverized cane Trash	100	60mins	1mm
2.	H-M-P	Hot soak, Medium duration, pulverized cane Trash	100	30mins	1mm
3.	H-S-P	Hot soak, short duration, pulverized cane Trash	100	5mins	1mm
4.	H-L-C	Hot soak, long duration chopped can Trash	100^0c	60mins	10mm
5.	H-M-C	Hot soak, medium duration chopped can Trash	100^0c	30mins	10mm
6.	H-S-C	Hot soak, short duration chopped can Trash	100^0c	5mins	10mm
7.	W-L-P	warm soak, long duration pulverized cane Trash	50^0c	60mins	1mm
8.	W-M-P	warm soak, medium duration, pulverized cane Trash	50^0c	30mins	1mm
9.	W-S-P	warm soak, short duration, pulverized cane Trash	50^0c	5mins	1mm
10.	W-L-C	warm soak, long duration chopped can Trash	50^0c	60mins	10mm
11.	W-M-C	warm soak, medium duration chopped cane Trash	50^0c	30mins	10mm
12.	W-S-C	warm soak, short duration chopped cane Trash	50^0c	5mins	10mm
13.	C-L-P	Cold soak, long duration pulverized cane Trash	25^0c	60mins	1mm
14.	C-M-P	Cold soak, medium duration, pulverized cane Trash	25	30mins	1mm
15.	C-S-P	Cold soak, short duration, pulverized cane Trash	25^0c	5mins	1mm
16.	C-L-C	Cold soak, long duration chopped can Trash	25^0c	60mins	10mm
17.	C-M-C	Cold soak, medium duration chopped cane Trash	25^0c	30mins	10mm
18.	C-S-C	Cold soak, short duration chopped cane Trash	25^0c	5mins	10 mm

Run	Acronym	Description	Temp	Duration	Particle Size
19.	H-L-G	Hot soak, long duration grinded can Trash	100^{0}c	60mins	5mm
20.	H-M-G	Hot soak, medium duration grinded can Trash	100^{0}c	30mins	5mm
21.	H-S-G	Hot soak, short duration grinded can Trash	100^{0}c	5mins	5mm
22.	W-L-G	Warm soak, long duration grinded cane Trash	50^{0}c	60mins	5mm
23.	W-M-G	warm soak, medium duration, grinded cane Trash	50^{0}c	30mins	5mm
24.	W-S-G	warm soak, short duration, grinded cane Trash	50^{0}c	5mins	5mm
25.	C-L-G	Cold soak, long duration grinded Trash	25^{0}c	60mins	5mm
26.	C-M-G	Cold soak, medium duration grinded cane Trash	25^{0}c	30mins	5mm
27.	C-S-G	Cold soak, short duration grinded cane Trash	25^{0}c	5mins	5mm

Appendix B: Leaching Results for Physical and Combustion Properties

Table B1: Results of physical and Combustion Properties from the 27 Runs

Run Number	Run Acronym	Fixed Carbon	Moisture Content	Bulk Density	Volatile Matter	HHV	Ash Content	Mechanical Durability
1	H-S-P	11.76	0.487	307.80	81.58	18.27	2.75	98.00
2	W-M-G	14.33	0.543	303.69	75.75	18.16	2.87	97.13
3	C-S-P	14.99	0.516	306.13	75.81	18.01	2.85	96.52
4	H-M-P	11.56	0.480	311.29	82.18	20.31	2.70	99.07
5	W-S-P	12.11	0.507	306.51	76.98	18.04	2.79	96.96
6	C-L-G	14.73	0.550	303.62	75.76	17.85	2.95	97.03
7	W-L-G	13.96	0.541	304.50	76.41	18.23	2.81	97.40
8	C-L-P	12.22	0.514	307.31	78.01	19.85	2.84	97.72
9	W-M-C	15.22	0.664	298.42	74.89	16.80	3.64	96.10
10	H-L-G	13.81	0.517	298.36	79.25	18.30	2.20	97.70
11	C-S-C	16.55	0.572	302.12	74.11	14.51	3.95	91.16
12	H-M-C	15.02	0.616	297.38	75.32	17.60	3.47	96.23
13	W-S-G	14.61	0.564	304.30	74.55	17.40	2.08	97.00
14	H-L-C	15.28	0.593	302.04	75.63	17.80	3.23	96.24
15	C-M-C	15.32	0.585	302.53	74.34	16.24	3.76	93.22
16	W-M-P	11.87	0.499	308.30	79.43	20.07	2.77	98.59
17	C--M-G	14.87	0.563	304.15	74.88	17.81	3.10	96.00
18	C-S-G	14.87	0.567	304.46	74.29	16.86	3.44	95.40
19	W-S-C	15.26	0.578	302.70	74.21	17.40	3.77	91.16
20	C-L-C	15.31	0.609	299.34	74.34	16.31	3.72	95.77
21	H-S-G	13.92	0.535	303.46	75.74	18.20	2.91	97.36
22	W-L-C	15.13	0.593	300.69	75.02	16.80	3.57	96.23
23	H-L-P	11.53	0.455	312.01	82.29	21.23	2.03	99.20
24	H-S-C	15.24	0.585	302.70	74.32	16.55	3.59	95.11
25	C-M-P	12.43	0.510	306.81	77.64	18.52	2.15	97.21
26	H-M-G	14.99	0.518	304.59	78.20	18.26	2.80	97.56
27	W-L-P	11.84	0.459	309.23	81.35	20.24	2.76	98.84

Appendix C: Leaching Experimental Results

Table C1: Leaching of K relative to the experimental variables

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ºC**	**20**	**40**	**60**
1	25	6.94	6.96	7.22
1	50	7.12	7.44	7.48
1	100	7.4	7.64	8.15
5	25	6.62	6.56	6.92
5	50	6.42	6.56	7.01
5	100	6.51	6.65	7.01
10	25	6.16	6.67	6.84
10	50	6.26	6.74	6.96
10	100	6.64	7.04	7.04

Data recorded with mean and standard deviation. K=7.08±0.40 mg/g

Table C2: Leaching of Ca relative to experimental variables

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ºC**	**20**	**40**	**60**
1	25	18.67	19.42	19.62
1	50	19.41	20.2	20.35
1	100	19.79	20.38	20.39
5	25	17.69	17.85	18.45
5	50	17.71	18.45	18.55
5	100	18.30	19.09	18.84
10	25	15.93	16.90	17.62
10	50	17.56	18.24	17.94
10	100	17.85	18.30	19.23

Data recorded with mean and standard deviation. Ca=18.648±0.96 mg/g

Table C3: Leaching of Mg relative to experimental variables

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ºC**	**20**	**40**	**60**
1	25	0.41	0.44	0.44
1	50	0.43	0.45	0.46
1	100	0.44	0.47	0.48
5	25	0.36	0.38	0.4
5	50	0.38	0.4	0.41
5	100	0.39	0.41	0.38
10	25	0.30	0.33	0.34
10	50	0.34	0.35	0.39
10	100	0.35	0.41	0.42

Data recorded with mean and standard deviation. Mg=0.38±0.06 mg/g

Table C4: Leaching of Si relative to experimental variables

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ºC**	**20**	**40**	**60**
1	25	15.56	17.02	17.14
1	50	15.77	17.11	17.9
1	100	17.28	18.08	19.89
5	25	12.95	14.53	15.5
5	50	14.11	15.29	15.97
5	100	14.77	16.47	16.56
10	25	11.91	12.9	13.65
10	50	12.85	14.13	14.9
10	100	13.65	15.24	15.87

Data recorded with mean and standard deviation. Si=15.93±1.89 mg/g

Table C5: Bulk Density Leaching Run Results

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ºC**	**20**	**40**	**60**
1	25	306.13	306.81	307.31
1	50	306.51	308.3	309.23
1	100	307.8	311.29	312.01
5	25	304.46	304.15	303.62
5	50	304.3	303.69	304.5
5	100	303.46	298.36	304.59
10	25	302.12	302.53	299.34
10	50	297.38	298.42	300.69
10	100	302.04	302.70	302.70

Data recorded with mean and standard deviation. BD =304±3.72 wt. % dry basis

Table C6: Volatile Matter Leaching Run Results

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ºC**	**20**	**40**	**60**
1	25	75.81	77.64	78.01
1	50	76.98	79.43	81.35
1	100	81.58	82.18	82.29
5	25	74.29	74.88	75.76
5	50	74.55	75.75	76.41
5	100	75.74	78.2	79.25
10	25	74.11	74.34	74.34
10	50	74.21	74.89	75.02
10	100	74.32	75.32	75.63

Data recorded with mean and standard deviation. VM =76.75±2.64 wt. % dry basis

Table C7: Fixed Carbon Leaching Runs Results

		Time [A] in minutes		
Particle Size [C] In mm	**Temperature[B] In ^{o}C**	**20**	**40**	**60**
1	25	13.86	12.43	12.22
1	50	12.11	11.87	11.84
1	100	11.76	11.56	11.53
5	25	14.87	14.87	14.73
5	50	14.61	14.33	13.96
5	100	13.92	14.99	13.81
10	25	16.55	15.32	15.31
10	50	15.26	15.22	15.13
10	100	15.24	15.02	15.28

Data recorded with mean and standard deviation. FC =14.030±1.5 wt. % dry basis

Table C8: Recorded mean emissions for the leached cane trash briquette samples.

Run	**Treatment**	**CO (ppm)**	**SO2 (ppm)**	**NOx (ppm)**	**TSP(Mg/Nm^3)**	**Eff %**	**Tgas Temp (K)**	**NO (Nitrous Oxide) (ppm)**
1.	H-S-C	695.89	0.6738	185.4851	43.89	50.03	600.54	152.9
2.	C-M-G	700.07	0.6206	177.6048	37.44	59.63	602.21	151.76
3.	W-L-G	698.43	0.606	176.0855	32.72	62.72	604.56	146.56
4.	H-L-G	695.89	0.7333	171.865	31.47	63.02	606.83	143.28
5.	H-M-G	697.53	0.5849	172.5575	32.01	62.9	605.61	143.37
6.	C-S-P	703.23	0.5849	176.2007	33.34	60.33	606.01	145.37
7.	W-S-G	700.16	0.6335	179.7051	36.92	58.77	602.74	147.19
8.	C-M-P	700.13	0.5711	171.4347	31.15	63.07	607.02	143.41
9.	H-L-C	700.85	0.7283	181.1615	34.33	60.72	602.79	148.16
10.	C-M-C	708.41	0.6238	186.3722	43.56	54.39	599.58	154.09
11.	C-S-C	707.19	0.7235	185.9516	44.17	49.56	599.26	153.11
12.	W-S-P	692.41	0.6054	171.5083	33.12	65.32	607.03	144.13
13.	W-M-C	706.27	0.6818	182.7141	39.71	57.18	600.17	151.39
14.	H-S-G	697.77	0.6449	177.788	33.73	59.17	604.42	146.49
15.	H-M-P	686.17	0.8168	166.9647	27.32	70.49	609.01	141.23
16.	W-M-G	699.31	0.6129	176.0971	33.00	62.19	603.19	146.67
17.	C-L-C	707.17	0.6336	181.5013	40.19	56.00	600.39	154.07
18.	C-L-P	693.34	0.56462	170.9809	30.21	63.67	607.05	143.21
19.	H-L-P	685.74	0.3499	161.0917	27.00	72.83	609.3	141.07
20.	W-L-P	687.11	0.4859	170.9368	30.09	68.58	608.11	142.71
21.	C-S-G	704.21	0.4839	181.0354	38.23	53.14	600.11	153.31
22.	C-S-C	709.67	0.8407	188.2987	47.02	45.17	599.88	155.14
23.	H-M-C	704.19	0.7179	182.537	38.19	58.41	601.61	149.17
24.	W-M-P	687.22	0.5058	168.2325	30.16	66.31	608.09	142.83
25.	C-L-G	699.63	0.6303	176.5322	37.31	61.51	602.79	148.55
26.	W-L-C	704.34	0.6855	182.5794	39.02	57.23	601.67	150.41
27.	H-S-P	686.37	0.51885	169.9298	30.00	69.11	609.01	144.14

Appendix D: Experimental Apparatus

Figure. D1: Jeffco Cutter Grinder (Jeffress Bros. Ltd, Queensland Australia) used for particle size reduction of cane trash samples.

Figure D2: Heating bath, heater and pump used to maintain temperature during "Hot" laboratory scale experiments

Figure D3: Leaching tank

Figure D4: hydraulic press

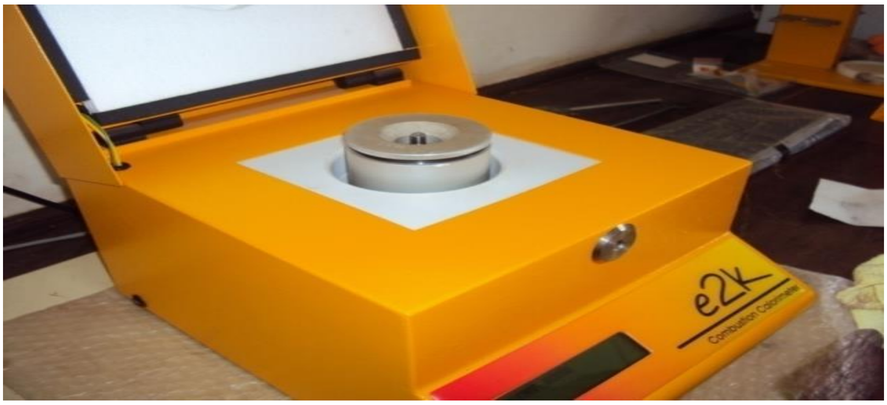


Figure D5: Bomb Calorimeter

Figure D6: Muffle furnace

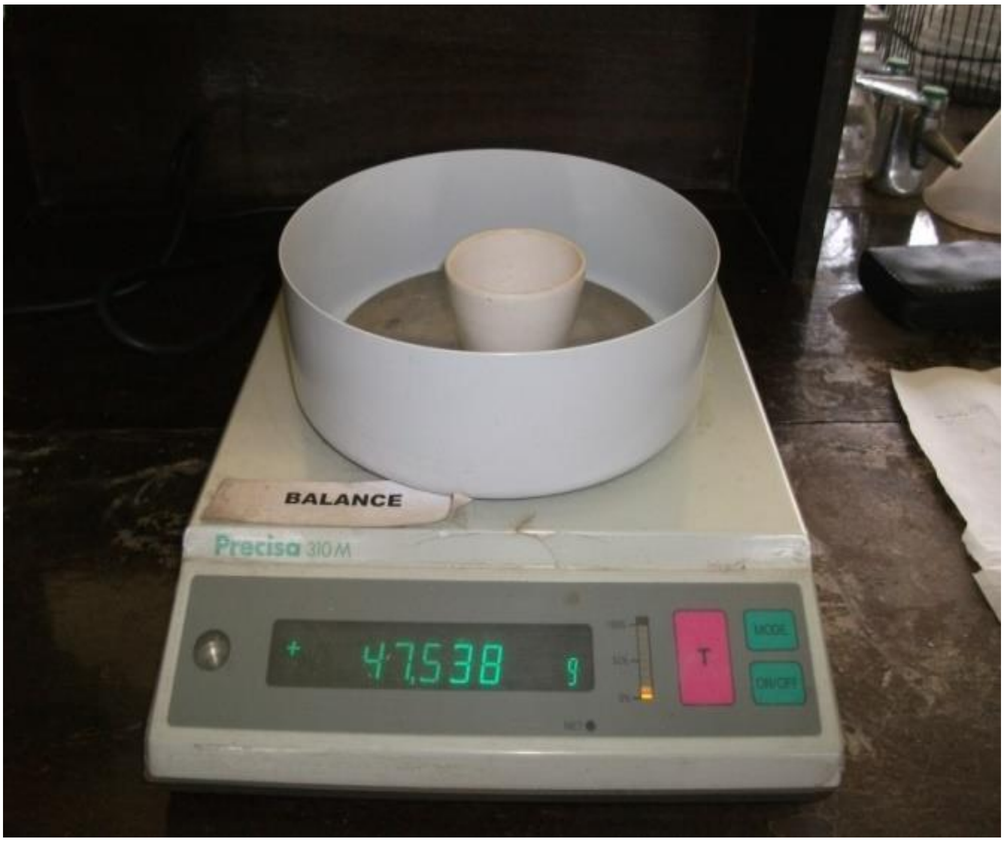
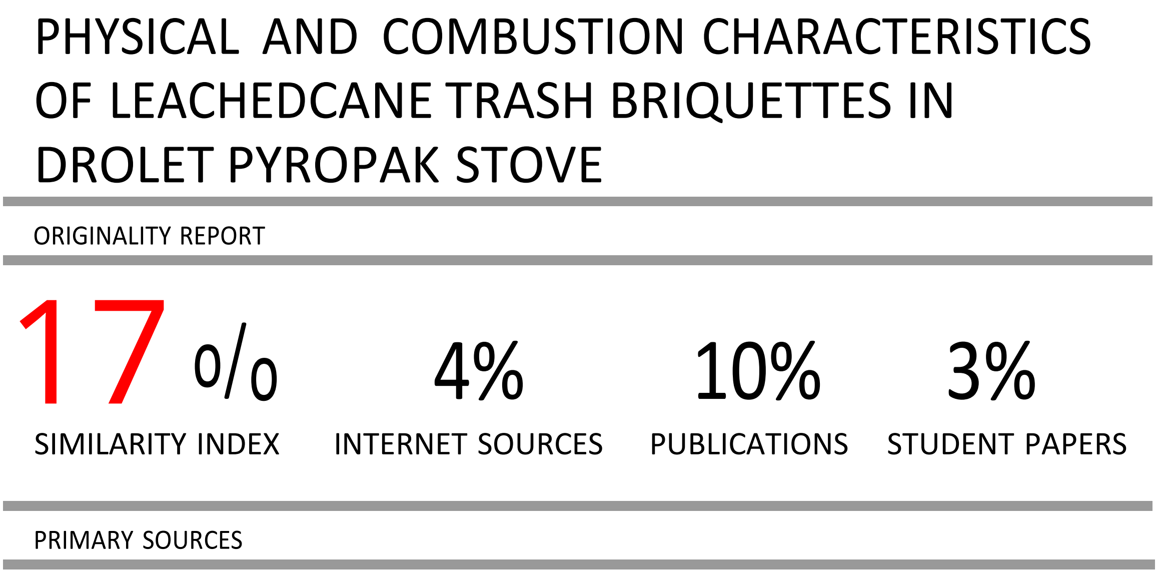


Figure D7: Digital Scale

Figure D8: Combustion analysis system set up

Appendix E: Antiplagiarism Certificate



PHYSICAL AND COMBUSTION CHARACTERISTICS OF LEACHEDCANE TRASH BRIQUETTES IN DROLET PYROPAK STOVE

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