INVESTIGATION ON THERMAL AND COMBUSTION PERFORMANCE OF KEROSENE-BIODIESEL BLENDS AND BIODIESEL EXTRACTED FROM USED COOKING OIL AS AN ALTERNATIVE FUEL TO KEROSENE STOVE

Charan Tut Thiep

A Thesis Submitted to the Department of Mechanical Engineering,

School of Mechanical, Chemical, and Materials Science and Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Thermal and Aerospace Engineering

Office of Graduate studies

Adama Science and Technology University

May, 2022

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DECLARATION

I hereby declare that this Master's Thesis entitled **"investigation on thermal and combustion performance of kerosene-biodiesel blends and biodiesel extracted from used cooking oil as an alternative fuel to kerosene stove"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Name of the student Signature Date

RECOMMEDATION OF THE ADVISOR/SUPERVISOR

I, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "**Investigation on thermal and combustion performance of kerosene-biodiesel blends and biodiesel extracted from used cooking oil as an alternative fuel to kerosene stove**" prepared under my/our guidance by **Charan Tut Thiep** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Thermal and Aerospace Engineering. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Advisor/supervisor	Signature	Date
Co-advisor/co-supervisor	Signature	Date

APPROVAL PAGE OF M.Sc. THESIS

I, the advisors of the thesis entitled "**Investigation on thermal and combustion performance of kerosene-biodiesel blends and biodiesel extracted from used cooking oil as an alternative fuel to kerosene stove**" and developed by **Charan Tut Thiep**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Major advisor/supervisor	Signature	Date
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Co-advisor/supervisor	Signature	Date

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the thesis by **Charan Tut Thiep** have read and evaluated the thesis entitled "**Investigation on thermal and combustion performance of kerosene-biodiesel blends and biodiesel extracted from used cooking oil as an alternative fuel to kerosene stove**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Thermal Engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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ACKNOWLEDGEMENT

I would like to thank Jesus my lord for giving me strength, patience, and guidance to complete this thesis.

I strongly indebted to my thesis advisor Dr. Gezahegn Habtamu in Adama Science and Technology University (ASTU) for his unreserved advice and skillful contribution to this thesis and his meticulous comments I received throughout my thesis work.

I strongly indebted to ASTU, chemical engineering department laboratory technical staffs. In addition, my special thanks to Chemical engineering head Ato Hunegnaw Baile for his cooperation during my thesis work and chemical engineering lab assists Mr. Bundi Roba and Mr. Burtukan H/mariam for their technical guidance and assistance.

All my families' members deserve special thanks in supporting my effort throughout of my life, and encouragement and moral support throughout the study period.

ABSTRACT

Different kinds of waste oils in Ethiopia are usually discarded after cooking potato chips, Sambusa etc. by street food venders and hotels. The environmental pollution due to disposed of waste oil in addition to direct use of biomass and charcoal in the country threats and motivated the researchers to find alternatives energy that overcomes the pollutants. Biodiesel is under alternative energy that can be obtained from waste oil, pure oil and animal fats. It is clean and renewable energy source compared to the common alternative fuels such as biogas and ethanol. In this work, sunflower waste oil was treated into biodiesel by transesterification using methanol as a reactant and potassium hydroxide as catalyst and its physicochemical properties were determined based on American Society for Testing Materials *D6751 procedure to check the grade of the extracted biodiesel. The yield which was obtained during the process was 91.86%. In addition, the energy and emission performance of wick/Butagas stove fired by pure kerosene, pure biodiesel and blend of kerosene and the biodiesel were investigated experimentally with Water Boiling Test, Controlled Cooking Test and Kitchen Performance Test protocols of cook stove. The studied considered blend of kerosene with biodiesel (percentage fraction in the range of 5 to 20). Mixture of 100 kerosene and zero percent biodiesel is termed B0 and 95% kerosene and 5% biodiesel is termed B5; the other blends are also named likewise. From the investigation, it was observed that 5% biodiesel, 10%biodiesel,15% biodiesel and 20% biodiesel can be used to fuel the wick/Butagas stove without any modification of the stove except B100. From experimental results, 5% biodiesel to 100% biodiesel results in lower emission soot and better energy performance than conventional kerosene. Among the experimental performance carried out using pure kerosene and 5% biodiesel the energy efficiency of the stove was found to be 38.7 and 39.9% for cold start, 40.0 and 41.5 for hot start and 26.4 and 28.1% for simmering tests of the water boiling test protocols. As seen from these typical results, the energy performance of pure biodiesel & kerosene blends was marginally better than pure kerosene.*

Keywords: *Biodiesel, kerosene and biodiesel blends, stove cooking test protocols, energy performances*

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ABBREVATIONS

ASTM	American Society for Testing Materials
BaO	Barium oxide
B100	100% biodiesel
B5	5% biodiesel
B10	10% biodiesel
B15	15% biodiesel
B20	20% biodiesel
CO	Carbon monoxide
CO_2	Carbon dioxide
GHG	Greenhouse gas
LHV	Lower heating value
HHV	Higher heating value
IFC/WB	International finance corporation/World Bank
UCO	Used cooking oil
WCO	Waste cooking oil
PSCO	Pure sunflower cooking oil
WSCO	Waste sunflower cooking oil
KOH	Potassium hydroxide
GC	Gas chromatography
FFA	Free fatty acid
WBT	Water boiling test
KPT	Kitchen performance test
CCT	Control cooking test
TAG	Triacylglycerol
R	Alkyl group

Nomenclature

$W_{s,i}$ = slag and impurities content in percent

W_1 = Weight of the oil before filtering in gram

W_2 = Weight of the oil after filtering in gram

W_w, C = weight of the moisture content in percent

W_3 = Weight of the oil before heating in gram

W_4 = Weight of the oil after filtering in gram

$\nu_{biodiesel}$ = Kinematic viscosity in mm2/sec

$\mu_{biodiesel}$ = Dynamic viscosityof biodiesel in g/mm-sec

ρ_{BD} = density of biodiesel in g/mm3

ρ_{Pk} = density of pure kerosene in g/mm3

M_{B5} = Mass of 5% biodiesel

M_{B10} = Mass of 10% biodiesel

M_{B15} = Mass of 15% biodiesel

M_{B20} = Mass of 20% biodiesel

M_{K95} = Mass of 95% pure kerosene

M_{K90} = Mass of 90% pure kerosene

M_{K85} = Mass of 85% pure kerosene

M_{K80} = Mass of 80% pure kerosene

X_{B5} = Mass fraction of 5% biodiesel

X_{B10} = Mass fraction of 10% biodiesel

X_{B15} = Mass fraction of 15% biodiesel

X_{B20} = Mass fraction of 20% biodiesel

X_{k95} = Mass fraction of 95% pure kerosene

X_{k90} = Mass fraction of 90% pure kerosene

X_{k85} = Mass fraction of 85% pure kerosene

X_{k80} = Mass fraction of 80% pure kerosene

HHV_{B5} = Higher heating value of 5% biodiesel in kj/kg

HHV_{B10} = Higher heating value of 10% biodiesel in kj/kg

HHV_{B15} = Higher heating value of 15% biodiesel in kj/kg

HHV_{B20} = Higher heating value of 20% biodiesel in kj/kg

LHV_{B5} = Higher heating value of 5% biodiesel in kj/kg

LHV_{B10} = Higher heating value of 10% biodiesel in kj/kg

LHV_{B15} = Higher heating value of 15% biodiesel in kj/kg

LHV_{B20} = Higher heating value of 20% biodiesel in kj/kg

Weight of water remaining after test (M_{hwr} in kg)

$\triangle t$ = Duration of phase in min

$\triangle t^T$ = Temp –adjusted time to boil pot in minutes

η_{th} =Thermal efficiency in %

M_{hwv} = Water vaporized in kg

R_b = Burning rate in kg/min

SFC = Specific fuel consumption in kg fuel/L water remaining

SC^T = Temp-corrected specific consumption in kg fuel used/kg water remaining

FP = Firepower in Watt

TDR = Turn-down ratio

M_p = Weight of empty pot

M_{stove} = Weight of the stove

T_b = Local boiling temperature

$\bar{a}_{ch}$ = chemical exergy in Kj/kg

W_{rev} = is the actual work of the fuel in kJ

AF = Air- fuel ratio

η_C = is the combustion efficiency in %

CHAPTER ONE

1. Introduction

1.1 Background and justification of the study

Ethiopia is located in the Horn of Africa with a population estimated at more than 93 million. The three most widely used fuels for preparation of food in the urban households are charcoal (91%), fuelwood (70%) and electricity (31%) (Gaia association, 2014). Major fuels for cooking and baking in rural areas, in the order of importance, are fuelwood, charcoal, and dung. Wood and charcoal are the most important energy source for household cooking, particularly in rural areas where alternative fuel sources are either unavailable or unaffordable. Accordingly, wood fuel resources are wasted and health problems associated with high indoor air pollution are common. The use of wood as the primary fuel source has also resulted in significant environmental degradation, leaving less than three percent of Ethiopia's land covered by forest Abadi and Shimels (2017). In additions, rural communities are generally low income, off-grid communities that depend on kerosene (and sometimes biomass) for lighting and only less than 2% of the total rural households in all the regions use kerosene for cooking Negussie (2015). Many of these households use wick-based kerosene lamps and less on kerosene wick-stoves, which are expensive to run and are extremely flammable. This burning of kerosene exposes mainly women and children to harmful particulate matter, causes eye strain for children who attempt to study at night, and decreases the ability of households to undertake livelihood development activities at night.

Figure 1. 1: a) Biomass stoves b) Charcoal stove c) electric stoves d) Sambusa, potato chips and Bonbolino e) Fish cooking in oil (Gambella tradition).

In several of the most populated African countries, including Uganda, Ethiopia, and Kenya, more than 60% of the population relies on kerosene as the primary lighting fuel and less on cooking (Nicholas et al., 2012). But nowadays kerosene stoves are very scarcely used for domestic cooking in Ethiopia. The use of kerosene stove in Ethiopia was discontinued due to high cost of kerosene. As substitute to kerosene used cooking oils disposed after frying potatochips, Sambusa, Bonbolino and fish cooking in Gambella is free and low cost and can be treated as a clean fuel. After using cooking sunflower oil for frying Potato chips, Sambusa, Bonbolino and Fish cooking the oil used is disposed into the environment by street vendors, hotels and restaurants. This causes environmental pollution. But waste oil can be treated and used as fuel for domestic cooking system such as kerosene stove and lighting as well as car engine.

Thus, there is an urgent need to find alternatives renewable energy resources that are clean, sustainable, reliable, and economical feasible. Biodiesel is one of the solutions that have been considered to solve the problem of fossil fuel depletion and environmental degradation (Rahman et al., 2020, Kolakoti et al., 2020, Rajalingam et al 2016). Investigation of biodiesel (methyl ester) produced from vegetable oil, animal fats, waste cooking oils were carried out by many researchers. Palm biodiesel is predominantly used in Asia, while soybean is used in United State and canola biodiesel is dominant in Europe Hossain and Boyce (2009). However, the edible oil based biodiesel faced the high price of the feedstock and competition between food and fuel. Nevertheless, biodiesel can be produced from other feedstock such as non-edible oil, microalgae and animal tallow Abadi and Ayelew (2017). Biodiesel has different chemical composition from the petroleum diesel fuel and contains about 10% of oxygen by weight. Biodiesel has higher density, viscosity, and heating grades of diesel fuel. On top of that biodiesel does not contain any sulfur, aromatic hydrocarbons, metals and crude residues [1-28]. In addition, biofuel can be completely mixed with petroleum diesel and the blending of these two fuels allow any proportion. Biodiesel can be blended with diesel in existing compressed ignition engines without modifications to the engine (Rajalingam et al., 2016, Abdul et al., 2018). Biodiesel blended with diesel will bring many beneficial characteristics to the diesel engine as well as to the environment (Nobel et al., 2017, Radia et al., 2015).

Thus, this paper focus on the investigation of thermal and combustion performance of biodiesel extracted from used sunflower oil as an alternative fuel to kerosene that will bring back kerosene stove for domestic cooking which further diversify the cooking stove technologies, energy utilization and save Ethiopian environment from pollution due to deposal of used waste oil from cooking food. Besides, the detail characteristic properties of biodiesel, test efficiency of cooking stove, emission of CO and CO_2, and water boiling test (WBT) protocol of cooking stove will be evaluated in this study.

1.2 Statement of the problem

In rural areas, Ethiopian people cook's food using biomass and charcoal due to unavailability and high cost of electric power generation. While biomass and charcoal burning can contribute a lot to the environmental pollution in addition to waste oil which affect ecosystem and environment after disposing by cooking vendor's. Long back kerosene stove was also used and its use is now discounted due high cost and lack of kerosene. But the kerosene stove can be re-operated by biodiesel extract from waste oil disposed after frying potato chips, bread, fish, samosa etc. by street vendors, hotels and restaurants. To overcome those problem, biodiesel from waste sunflower oil is one of the alternative clean fuel which can discard the above problem issues. In addition, use of biodiesel extracted from waste oil has a twofold advantage: saving the environment from waste oil pollution and production of energy for cooking. But biodiesel is viscous and it might be challenging to use it in stoves that use wick for ignition and combustion of fuel with air that may result in problems like absorption of biodiesel by the wick for proper combustion without the need of external pressure. The current work focus on the investigation of the performance (thermal and combustion) of kerosene-biodiesel blends and biodiesel extracted from waste sunflower oil (disposed after cooking food) as an alternative fuel to kerosene stove in Ethiopian's householders and test the performance of kerosene stove with the biodiesel in pure form or blended with kerosene. The thermal performance was investigated in terms of thermodynamics efficiencies (the first law & second law) when the biodiesel is combusted in a wick kerosene stove under standard cooking stoves performance test protocols. The combustion performance was investigated in terms emission characteristics particularly CO and CO_2.

Research questions

1. Which process is used for waste oil conversion into biodiesel?
2. Which catalyst, KOH or NaOH will proceed faster during the process?
3. What are the characteristics of biodiesel extracted from used cooking oil?
4. What is the LHV and HHV of the biodiesel from extracted waste or used cooking oil?
5. Is the biodiesel extracted is safe to be used in kerosene stove as an alternative fuel in pure form or blend with kerosene?
6. What is the performance of kerosene stove (Butagas) fueled by pure biodiesel or biodiesel blend with kerosene?
7. What is the thermal efficiency (first law and second law of thermodynamics) during combustion of pure biodiesel or biodiesel blended with kerosene during combustion in Butagas stove?
8. What is the combustion gases characteristic of biodiesel during burning in Butagas stove?

1.3 Objectives of the study

1.3.1 General objective of the study

The general objective of this study is to extract methyl ester (biodiesel) from used cooking oil as an alternative fuel to kerosene and investigate the efficiency and emission characteristics during burning in Butagas stove in a laboratory scale.

1.3.2 Specific objectives of the study

The specific objectives of this study are

- To extract biodiesel from used sunflower oil using methanol and KOH catalyst;
- To characterize the physical and chemical properties of biodiesel extract such a s viscosity, flash point, fire point, LHV and HHV, Cetane number and chemical composition;
- To compare the extracted physical and chemical properties of biodiesel with international standard data;

- To study the combustion properties of pure biodiesel (B100) and its blend with kerosene such as 95% biodiesel & 5% kerosene or B5, and B10, B15 & B20particularly the emission of CO and CO_2 and
- To test the efficiency of Butagas stove fueled by pure biodiesel & its blend using standard protocol especially water boiling test (WBT), controlled cooking test (CCT) and kitchen performance test (KPT) protocols.

1.4 Significant of the study

The general significance of this study is to create and increase the alarm of using alternative (biodiesel) fuel at rural area in Ethiopia and also awaking them not to pollute the environment by disposing waste oil into environment. Then to reserve our future forest use, and to minimize the GHGs from fire woods, charcoal, etc. The specific significances of the study can be of the following:

- To reduce the householder unhealthy
- The biodiesel produced can be used as alternative fuel for running cooking devices used for householder activities.
- Conversion of used cooking oil into biodiesel saves the environment from pollution that may result by damping it in to the environment;
- The waste oil can be reused as alternative fuel for domestic energy used with biodiesel yield almost equal to the quantity of the used oil;
- The results determine the standard thermal and combustion performance of the wick-stove fueled by biodiesel and its blend and set the limiting criteria from combustion performance on the use of biodiesel for wick kerosene stove without any design modification.
- The used of biodiesel as an alternative fuel will reduce the emission of pollutants, including GHGs, thus providing both local and global environmental benefits compared to other fuel.
- Bringing the wick kerosene stove back in service using biodiesel extracted from used cooking oil as an alternative fuel for various activities of domestic energy utilization.

1.5 Scope and limitations of the study

1.5.1 Scope of the study

The scope of this project is to produce biodiesel from waste sunflower oil that might be damped to the environment after cooking fast foods such as potato chips; test its phyico-chemical properties & compare its properties with international diesel; test its thermal & combustion performance with wick stove and also to analyses the emission characteristic of CO and CO_2. Thermal efficiency of the stove/butagas fired by biodiesel extract and its blend with kerosene was studied with the main cook stove testing protocols namely, the water boiling test (WBT), the control cooking test (CCT) and the kitchen performance test (KPT).

1.5.2 Limitation of the study

The majors' limitation of this study are

1. From different waste cooking oil damped by street vendors' and hotels, only waste sunflower cooking oil was selected for investigation
2. Methanol as a reactant and KOH as a catalyst were selected from different reactant and catalyst used by other researchers.
3. Not all physicochemical properties were checked during the study
4. Stove utilization monitor protocol cook stove was not checked during study
5. O_2 & HC of fuels was not checked during this work

CHAPTER TWO

2. Literature review

2.1 Introduction

The feedstock coming from waste vegetable oils or commonly known as waste cooking oils is one of the alternative sources among other higher grade or refine oils (Rahman et al., 2020, Kolakoti et al., 2020, Rajalingam et al., 2016, Alejandro 2011, Amrik et al., 2018, Arjun et al., 2016, Howard et al., 2017, Thirumarimurugan et al., 2012, Man kee et al., 2010, Mapereka et al., 2017, Mirza et al., 2018, Mohammed et al., 2015). Waste cooking oils is easy to collect from other industries such as domestic usage and restaurants and also cheaper than other oil (refined oil). Hence, by using these oils as the raw materials, the cost of production of biodiesel can reduce. The advantages of using waste cooking oils to produce biodiesel are the low cost and prevention of environment pollution (Alejandro 2011, Benard A Udeh 2017, Salihu et al., 2021). These oils need to be treated before disposing to the environment to prevent pollution. Due to the high cost of disposal, many individuals dispose waste cooking oils directly to the environment especially in rural area. So that the use of waste cooking oils is an effective way to reduce the cost of biodiesel production. The kinematic viscosity of used cooking oil (UCO) is about 10 times greater, and is density is about 10% higher than that of mineral diesel Alejandro 2011. Many techniques have been developed to reduce the kinematic viscosity and specific gravity of the vegetable oils, which include pyrolysis, emulsification, leaning and transesterification (Alejandro 2011, Benard A Udeh 2017, Carlos et al., 2019, Dennis et al., 2010, Deepak et al., 2016). Among these techniques, transesterification is the more favorite. This is because of the fact that this method is relatively easy carried out at normal conditions, and give the best conversion efficiency and quality of the converted fuel (Arumugan et al., 2009).

2.2 Previous work done on production of biodiesel from waste cooking oils

Zhenget et al., 2009 analyzed the reaction kinetic of acid-catalyzed transesterification of waste frying oil. They found that at the methanol/oil molar ratio of 250:1 at 70 ℃ or in the range 74:1-250:1 at 80℃, the reaction was pseud-first-order reaction. High yield of 99±1% could be

achieved at both 70 and 80 °C temperature while stirring at rate of 400 rpm, using a feed molar ratio methanol: oil: acid of 1:245::3.8. A year later Yong et al., 2011 investigate a two-step catalyzed processes for synthesis of biodiesel by using waste cooking oil (WCO) from chines restaurants. In the first step, ferric sulfate-catalyzed methanolysis was carried out, while potassium catalysis was performed in the second step. The authors concluded that compare with one-step Sulphur acid catalysis the two-step catalyzed process provided a simpler and more economic method to produce biodiesel from WCO. In the further research work Itititipong et al., 2006 also used the two-step process to transesterify waste cooking oil, except that sulfuric acid was selected as acid catalyst and mixture of methanol and ethanol were used for transesterification in order to use the better solvent properties of ethanol and a more rapid equilibrium using methanol. More than 90% ester was obtained by using the two-stage method compared with yield of ~50% ester by using the single stage alkaline catalyst.

Lin et al., 2003 also used WCO to prepare biodiesel and then conducted a study in which the exhaust tail gas of biodiesel was compared when the engine was operated using different fuel types, including neat biodiesel, biodiesel/diesel blends, and normal diesel fuels. Among the collected data, the author found that B20 and B50 were the optimum fuel blends. Later Hossian and Boyce (2013) in their work compared optimum conditions of alkaline-catalyzed transesterification process for biodiesel production from pure sunflower cooking oil (PSCO) and waste sunflower cooking oil (WSCO) through transesterification process. The highest approximately 99.5% biodiesel yield acquired under optimum conditions of 1:6 volumetric oil-to-methanol ratio, 1% KOH catalyst at 40°C reaction temperature and 320 rpm stirring speed. Result of the test showed that the biodiesel production from PSCO and WSCO exhibited no considerable differences. Afterwards Bakir et al., 2012 present work on single step transesterification and two step transesterification, namely acid-base and base-base catalyzed transesterification process for production of biodiesel from chicken fried oil. For this purpose, hydrochloric acid and potassium hydroxide with methanol were used. The results disclosed that the two step base catalyzed transesterification was better compared to other methods. It resulted in higher yield and better fuel properties.

Patil et al., 2006 carried out comparative study on biodiesel production from waste cooking oil using sulfuric acid (two-step) and microwave-assisted transesterification (one-step). The two-

step transesterification process was used to produce biodiesel (alkyl ester) from high fee fatty acid (FFA) waste cooking oil. While microwave-assisted transesterification was done by using catalytic BaO and KOH in biodiesel production from waste cooking oil. The study shown that the microwave-heating method consumes less than 10% of the energy to achieved the same yield as conventional heating method. Further, fuel properties of biodiesel produced were compared with ASTM standards for biodiesel and regular diesel. In important study Ahmad J Al-kofahi, 2017, observed that from waste cooking oil CO emissions are increased with increase in engine load. Further it was found that volume of CO initially decreases but increase at full load indicating better burning conditions at higher temperature assisted by improved spraying qualities with uniform charge preparations of biodiesel. The emissions of unburn hydrocarbon for biodiesel exhaust due to lower than that of diesel fuel the increased gas temperature and higher cetane number of biodiesel could be responsible for this decrease. Higher temperature of burn gases in biodiesel fuel helps in preventing condensation of higher hydrocarbon reducing. While Edmilson et al., 2011. produced biodiesel from residual oils and also check the viability and degradation level of production process. Residual bovine, chicken and soybean oils were used for biodiesel production process. They used four transesterification methods, using acidic and basic catalysis and, gas chromatography with flame ionization detector (GC-FID). They concluded use of acidic catalysis at a lower temperature were the most efficient in the biodiesel production process. In the recent study Ahmad J Al-kofahi, 2017, prepared catalysts from raw chicken bones for transesterification reaction of waste cooking oil for biodiesel production. The study revealed that heterogeneous catalyst calcined at 900℃ exhibited good catalytic activity in the transesterification of WCO, providing maximum biodiesel yield of 89.33% at 5.0 g catalyst loading 15:1 methanol to oil molar ratio at temperature of 65℃ in reaction time of 4 hours.

2.2.1 Catalysts in transesterification

Transesterification also known as alcoholysis (Busca 2009, Avhad et al., 2015), is a multistep reversible reaction in which tri-glyceride are converted to di-glyceride and then to mono-glyceride which gets converted to biodiesel (Moreira et al., 2010, Goa et al., 2011) and glycerol (by-product) as in equation 2.1 to 2.3. This is a chemical process in which carboxylic acid ester is converted into carboxylic acid esters as shown by equation 2.1 up to 2.3.

Tri-glyceride + R'OH ⇌ Di-glyceride + $RCOOR_1$ ----------(2.1)

Di-glyceride + R'OH ⇌ Mono-glyceride + RCOOR' ----------(2.2)

Mono-glyceride + R'OH ⇌ Glycerol + $RCOOR_1$ ----------(2.3)

Traditionally, biodiesel processing is comprised of two processes esterification and transesterification Deepak et al., 2010. The conventional esterification use methanol with homogeneous acid catalyst such as sulfuric acid to convert free fatty acids (FFAs) into esters. Conventional transesterification uses a homogeneous base catalyst such as sodium/potassium methoxide along with methanol to convert to the triglycerides into biodiesel and glycerol.

Thus, typically there are two kinds of catalysts which are used in any biodiesel process (Carlos et al., 2019, Deepak et al., 2010).

1. Homogeneous catalysts (Rashid et al., 2008, Qian et al., 2008, Hassan and Vinjamur, 2014) which function in the same phase (liquid, gaseous, etc.) as the reactants. Typical, they are dissolved in a solvent with the substrates.
2. Heterogeneous catalysts (Ramos et al., 2008, Arzamendi et al., 2008) occur in a different phase then the reactants. Most heterogeneous catalysts are solids that act on substrates in a liquid or gaseous reaction mixture. Diverse mechanisms for reaction on surface are known, depending on how the adsorption takes place. The total surface area of solid has an important effect on the reaction rate, the smaller the catalyst particle size, the larger the surface area for a given mass particle.

2.2.1.1 Base catalyst

The most widely used catalysts for transesterification reaction are basic catalysts. Bas-catalyzed transesterification proceeds faster and they are less corrosive but can be used only when free fatty acid content is less than 2% (Sharma and Singh 2007). Any strong base capable of deprotonating the alcohol will serve as suitable catalyst such as NaOH, KOH, NaOME, etc. (Oguzhan, 2011, Ruzaimah et al., 2011, Mi et al., 2011, Siddharth et al., 2011, Zahir et al., 2011). The presence of water causes undesirable hydrolysis of base so reaction must be carried out in dry atmosphere. Homogeneous base catalysts such as carbonates (Arzamendi et al., 2008), alkaline metal hydroxide (Rashid et al., 2008) and alkoxide are most commonly used.

Alkoxide does not form soap from triglyceride saponification due to presence of hydroxide ion which act as an impurity in alkoxide (Sivasamy et al., 2009). While using alkaline catalyst, the free fatty acid content should not increase 0.5% by weight. Otherwise soap formation will take place which harmers the production of biodiesel. Various authors reported that 90% yield is obtained by using potassium hydroxide and boiler ashes in the methanolysis and ethanolysis of coconut and palm oil (Ejikame, 2008). Akaline catalyst NaOH was found to perform better than NaOMe. However, to obtain higher yield the concentration of NaOMe is slightly higher as compared to NaOH. Singh et al., (2006) studied about alkaline catalysts (NaOH, KOH, KOMe and NaOMe) and found that better yield is obtained by potassium based catalyst as compared to sodium based catalyst. Whereas methoxide based catalyst produces higher yield compared to hydroxide based catalyst (Singh et al., 2006). Base catalysts are mostly used because reaction takes place at low temperature and pressure that is 60°C and 20 psi and obtain high yield about 98%. However, there are some shortcomings it requires high energy, to separate the catalyst from the media after transesterification pro-reaction treatment is required, difficult to recover glycerol after the reaction moreover it form soap with free fatty acids.

2.2.1.2 Acid catalyst

The acid catalyzed transesterification does not gain much popularity because of its very slow rate than the alkali catalyzed reaction (Sharma and Singh 2007). Its performance does not get affected by the presence of free fatty acid and it can catalyze simultaneously both esterification and transesterification. Acid catalyst can produce biodiesel from low cost feedstock having high free fatty acid (FFA). However, acid catalyzed reactions have lower moisture sensitivity as well as non-appearance of soap formation. Acid catalysts are used where oil has higher FFAs (Sivasamy et al., 2009). Acid catalyzed reaction is of two stages processes, in the first stage esterification takes place in the presence of acid catalyst while in the second stage reaction takes place in the presence of base catalyst (Sivakumar et al., 2011, Ritesh et al., 2011, Romain et al., 2011). The acid catalyst mostly used are sulfuric acid, organic sulfonic acid, hydrochloric acid as catalyst for transesterification of rice brain oil between temperature range of 60-80°C (Zullaikah et al., 2005).

2.2.1.3 Heterogeneous catalyst

It is difficult to separate homogeneous catalyst from the reaction mixture so heterogeneous catalysts are developed. They are advantageous because they do not form soap through saponification of triglyceride and eliminate corrosion problem and reaction requires high temperature and pressure (Arzmendi et al., 2008, Zhen et al., 2014, Guldhe et al., 2017, Al-sakkari et al., 2017). However, there are some limitations like, they have poor performance compared to homogeneous catalyst, and due to less surface contact catalyst does not participate effectively in the reaction so catalyst must be in porous state (Kiss et al., 2008). The surface of heterogeneous catalyst must be hydrophobic in nature so that it absorbs triglyceride and to avoid adsorption of polar by product like water and glycerol on surface. Solid catalysts which are mostly used are alkaline earth alkoxide, solid organic bases, basic metal oxide (Arrieta et al., 2005). Acid zeolites, basic zeolite (Shu et al., 2007, Chai et al., 2007), hetropoly acid (Cao et al., 2008), sulfated zirconia and mixed metal oxides, insoluble/immobilized metal salts and hydroxides, basic metal oxide (Oguzhan, 2011), ion exchange resins and immobilized sulfonic acid, hydotalcite, double metal cyanide complexes (Lee et al., 2014).

2.3 Previous work done on kerosene as a fuel in cooking stove

Depending on how the fuel is burned in kerosene cook stoves, they can be broadly categorized into two types; wick stove, which rely on capillary transfer of fuel, and the efficient and hotter burning pressure stoves in which the fuel is vaporized after being forced through vapor-jet nozzles Obet Nenyi Otoo, 2018. In the more popular wick-type kerosene cook stoves, a provision is made for holding some fuel (kerosene) at the base, and there are air inlet holes on the outer circumferences to permit the up draught of air by natural convection to support combustion. Once ignited, the conversion of chemical energy to heat occurs in a well-articulated wick-and-burner system which helps to produce flame. The combustion efficiencies of kerosene cook-stoves, which are in range of 35-55% are significantly higher than those of solid biomass cook-stoves (7-47%) Oliver et al., 2021.

Kapilan et al., 2018 studies that, biodiesel can be used as a substitute for kerosene in wick stove without any modification in its design. Only a small amount of ethanol is needed for start-up. They give the thermal efficiency of the kerosene and biodiesel in wick/butagas stove

as 51.82% and 52.39% respectively. They also investigated, the fuel consumption rate of kerosene in wick/Butagas stove is higher than that of biodiesel. And concluded that, the kerosene results in higher emission soot than biodiesel.

Adamu and Adame (2020) developed a simple bio-oil stove to experimentally evaluate the combustion performance of bio-oil extracted from Jatropha seed after mixing it with kerosene in four different proportions. They mixed kerosene to the bio-oil for reducing the viscosity of the oil. They did not process the bio-oil into biodiesel. They designed bio-stove since the oil is viscous and cannot be used in wick stoves directly. They reported the performance of this bio-oil stove using water boiling point test (cold and hot-start high power test). They determined the thermal efficiency, specific fuel consumption, and fire power of the bio-oil stove when fired with the blended fuels in the cold-start high power phase.

2.4 Previous work done on cooking stove performance test protocol

The three most popular test protocols in use for evaluation of cook-stove's performance are the water boiling test (WBT), the controlled cooking test (CCT), and the kitchen performance test (KPT). While WBT is a laboratory-based test intended to provide reliable information on cooking-stove's technical performance, the CCT and KPT are field-based tests that assess cook-stove's performance under controlled conditions that simulate actual cooking conditions and measure the impact of stove interventions household fuel consumption, respectively Obet Nenyi, 2018. Five common types of biomass cook stoves were investigated by (MacCarty et al., 2003) to quantify their relative emission of greenhouse gases (Obet Nenyi, 2018, Oliver et al., 2021). The WBT was used, and it was shown that specific energy consumption and emission from incomplete combustion were substantially reduced improved biomass stoves compared to the thee-stone fires. The WBT was also used by Jetter and Kariher 2019 in characterizing the performance of 14 solid fuel household cook-stoves and fuel combinations (including 10 stoves and four fuels). The time to boil, thermal efficiencies, specific fuel consumption, and CO, CO_2, hydrocarbon and particulate emissions were evaluated under high- and low-power, cold and hot-start conditions Oliver et al., 2021. Some of the cook-stoves were shown to have improved fuel efficiency and lower pollutant emissions compared with the traditional 3-stone fire, and short times to boil, higher fuel efficiencies, and low pollutant

emissions were obtained for the cook-stoves with smaller mass components exposed to the heat of fuel combustion.

2.4.1 Water boiling test (WBT)

Water boiling test (WBT) is a laboratory test that involves the investigation of the cooking stoves in a controlled environment in order to evaluate or reveal their technical performance. This method focuses on simulation of cooking practice by water boiling hence does not present the actual cooking conditions. WBT is vital at the time of the design of the cook stoves (Smith et al., 2007). Although WBTs were initially designed as laboratory tests, it is important to note that they can as well as be carried out in the field particularly for huge cook stoves that cannot be transported to laboratory. The process testing involves three main stages i.e:

Cold-start-high power phase: This stage involves raising the temperature of water from ambient temperature to boiling point from cold start. This simulates rapid cooking tasks like making tea, boiling milk, etc. (Smith et al., 2007).

Hot-start-high power phase: This stage involves raising the temperature of water from ambient temperature to boiling point when the stove is already hot.

Low power simmering phase: This phase involves maintaining the boiling water at simmering temperatures i.e. about 2-3 degrees below the boiling point of water. This simulates slow cooking tasks like cooking rice, beans or hard grains (Smith et al., 2007).

The key parameters that can be investigated by WBT include; **thermal efficiency**, **combustion efficiency, fuel burning rate and time to boil**. These parameters measure the technical performance of stoves and vary from one stove to the other. These tests must be carried under the same conditions in order to obtain meaningful results.

2.4.2 Control cooking test (CCT)

The control cooking test (CCT) is a laboratory or a field test that evaluate the performance of the cooking stoves using a standardized local cooking task (s). This method reveals behavior of the stove under ideal cooking conditions in a locality/project area. CCT test efficiency of the cook stoves.

The summary of the control cooking test (CCT) process is enumerated below:

- The first step involves identification of the appropriate cooking task based on the cooking practices within the project area. In addition, it is also important to identify the prevailing local conditions and cooking behaviors. This can be achieved through consultation with community or through a survey.
- The next step is to describe in detail the procedures to be employed during the test while taking into consideration the identified cooking task, local conditions as well as cooking practices.
- Last but not least, the test is performed in accordance with the set out procedures and results documented and evaluated. Note that local cooks may be employed to carry out the cooking tasks hence providing realistic results regarding the project area.

The key indicators that can be measured from this technique are the **fuel consumption** and the **speed of cooking (time of cooking)**. Considering that this procedure simulates the actual cooking, it is therefore capable of providing reliable results as compared to the WBT with regard to predicting actual performance and fuel consumption in the fuel. However, it may not predict the outcomes of uncontrolled usage of the cook stoves in actual practice.

2.4.3 Kitchen performance test (KPT)

Of the three tests, kitchen performance test (KPT) is the most complex. KPT is the field test that evaluate the performance of the stove as well as the effectiveness and impact of the stoves in real cooking settings. The process of KPT involves both qualitative survey and quantitative measurements. Two kinds of qualitative surveys are carried out i.e. pre-treatment survey which is designed to assess the situation of households before dissemination of stoves and post-treatment surveys which are designed to assess the impact of the stoves in the households. KPT is useful in determining the **fuel consumption**, **gauging user satisfaction** and assessing the **impact** and **effectiveness** of the cook stove interventions. But in this study, only fuel consumption parameter will be evaluated.

2.5 Combustion of fuels

Combustion is a chemical reaction between substances, usually including oxygen and usually accompanied by the generation of heat and light of flame Yunus Cengel, 2006. Kerosene, when burned in appliances, emits many potentially health-damaging pollutants.

$$\text{Fuel} + a\,(O_2 + 3.76\,N_x) \longrightarrow b\,CO_2 + c\,H_2O + a\,(3.76\,N_x) \qquad (2.4)$$

Due to that case, combustion of fuel blends can improve the combustion process itself and in other instances it may allow for combustion of some available fuels that cannot burn separately (Asfar and Hamed, 1998; Shyam et al., 1987; Cookson et al., 1987; Chicurel,1993) . Blending of fuels is not restricted on combustion. Other study is reported for pyrolysis and liquefaction of fuel blends, which show remarkable improvements (Kim et al., 1999; Akash et al., 1994, 1992).

Souza et al., (2009) have conducted a study on biodiesel (methyl ester from waste vegetable oil) in a water-cooled tube furnace comparing it to diesel. It was found that biodiesel burn much better than diesel fuel with high heat transfer in most parts of the furnace tube. It was concluded that some fuels can have higher heat transfer rates than diesel, which results in higher furnace performance. In another study Saario et al., (2005) have studied combustion behavior of heavy fuel oil in a cylindrical furnace. It was reported that how turbulent plays important in achieving good combustion results. Galan et al., (2009) studied the reaction kinetics of triacetin without adding any catalyst. The results were promising to find a solution to generated by-products of glycerin from biodiesel industry. Abu-Quidais (2002) reported the effect of heat transfer and emission on the combustion of shale oil in a water-cooled furnace. Such combustion unit has the capability of allowing other types of non-petroleum fuels to be investigated such as shale oil, vegetable oil etc. (Akash, 2012; Akash and Jaber, 2003; Schwab et al., 1987; Daguat and Cathonnet, 2006; Akash and Mhsen, 1999; Akash, 2006).

Zhang and Van Gerpen (2001) investigated the use of blends of methyl ester of soybean oil and diesel in turbo-charged, four cylinder, direct injection diesel engine modified with bowl in piston and medium swirl type. They found that the blends gave a shorter ignition delay and similar combustion characteristics as a diesel. Radwan et al., 2009 investigated the effect of ignition delay period of jojoba methyl ester by conducting experiments in a shock tube test rig by varying the factors like equivalence ratio, ignition temperature and ignition pressure. They reported that the ignition delay for jojoba methyl ester was lower while the ignition temperature and ignition pressure were higher. In the same year, Yusup et al., 2007 studied the in-cylinder characteristics of a six-cylinder, direct injection, 306 kw diesel engine using ester of methyl tallowate as fuel. Peak rate of heat release for the blend of diesel tallowate had found to be lower than diesel. The combustion of waste cooking oil had compared by Yu et al., 2009 with

diesel as fuel in a direct injection diesel engine. Tashtoush et al., 2003 investigated the combustion performance of ethyl ester of waste vegetable oil. Nazar et al., 2007 found that the duration of combustion is higher for straight vegetable oil when compared to methyl ester of vegetable oil. Sinha and Agarwal (2005) investigated the combustion characteristics of rice bran oil in transport diesel engines. Combustion of sunflower oil had investigated by Usta et al., 2005. Lif and Holmberg (2006) reported that combustion efficiency is improved when water is emulsified with diesel. Saikishan et al., 2007 attempted to find the cetane number based on the properties of biodiesel by using simulation techniques. In either work, they analyzed the influence various fuel properties namely density, viscosity, flash and fire points on the cetane number of a biodiesel and its various blends. The kinetics of rapeseed oil methyl ester (RME) has studied by Daguat et al., 2004 in a jet-stirred reactor for the first time. James et al., 2008 had reported that biodiesel could alter the fuel injection and ignition processes whether neat or in blend form. In other studies, (Andrews and Mkapi, 1996; Kammen, 1995; Stumpf and Muhlbauer, 2002) studied that the chemical structure of plant or vegetable oils is different from that of kerosene; thus, they have distinct physical and chemical properties and have different combustion characteristics. For example, the flash and viscosity of plant oils are very much higher than that of kerosene. Previous studies on utilization of plant oils as cooking fuel found out that plant oils cannot be used in wick stoves (Stumpf and Muhlbuaer, 2002). Due to their high viscosity, the flow velocity of plant oils in those wick stoves is very low; hence, the wick cannot maintain the oil supply and the flame extinguished consequently. Even if the thermal efficiency of wick stove is very low when compared with the high-pressure stoves, the wick/butagas stove will be operated by biodiesel due to the high cost of pressure stove in developing countries householder like Ethiopia.

2.5.1 Emission of biodiesel

Since biodiesel is free from sulfur hence less sulfate emissions and particulate reduction is reported in the exhaust Prem et al., 2010. Due to near absence of sulfur in biodiesel, it helps reduce the problem of acid rain due to transportation fuels. The lack of aromatic hydrocarbon (benzene, toluene etc.) in biodiesel reduces unregulated emission as well like ketone., benzene etc. Breathing particulate has been found to be hazard for human health, especially in term of respiratory system problem. PM consist of elemental carbon (~31%), sulfate and moisture (~14%), unburnt fuel (~7%), unburnt lubricating oil (~40%) and remaining may be metals and

others substances. Biodiesel is oxygenated fuel (hence more complete combustion) and causes lesser particulate formation and emission. Smoke opacity is a direct measure of smoke and soot. Various studies show that smoke opacity of biodiesel is generally lower Prem et al., 2010. Several experimental investigations are performed on 4-stroke diesel engines with vegetable oil methyl ester and found that hydrocarbon emission are much lower in case of biodiesel compared to diesel Prem et al., 2010. This is also due to oxygenated nature of biodiesel, where more oxygen is available for burning and reducing hydrocarbon emission in the exhaust Bital, 2015. CO is a toxic combustion product resulting from incomplete combustion of hydrocarbons. In presence of sufficient oxygen, CO is converted into CO_2. Biodiesel is an oxygenated fuel and lead to more complete combustion, hence CO emissions reduce in the exhaust. Alton et al., 2001, reported that CO emission for biodiesel is marginally higher in comparison to diesel, while Scholl et al., 1983 reported the reverse i.e. CO emission for soybean methyl ester (SME) is slightly lower than diesel. Kalligerous et al., 2003 also reported lower CO emissions for sunflower oil.

The NO_x forms by oxidation of atmospheric nitrogen at sufficiently high temperatures. NO_x formation is highly dependent on temperature and availability of oxygen. There are several reported results Prem et al., 2010 of slight increase in NOx emission for biodiesel. It is quite obvious, that with biodiesel, due to improved combustion, the temperature in the combustion chamber can be expected to be higher and higher amount of oxygen is also present, leading to formation of higher quantity of NO_x in biodiesel-fueled engines. However, biodiesel's lower sulfur content allows the use of NO_x control technologies that cannot be otherwise used with conventional diesel. Hence biodiesel's fuel NO_x emissions can be effectively managed and eliminated by engine optimization Prem et al., 2010. WHO provides interim target for some pollutants Nicholas et al., 2012, while researchers are trying to reduce these pollutants by searching an alternative fuel. Bellows are some pollutants which are released after fuels burning Nicholas et al., 2012.

2.5.1.1 Particulate matter (PM)

There is a strong and consistent body of evidence indicating that exposure to fine particulate matter (PM) increases the risk of respiratory and cardiovascular disease, cancer, and mortality (Krewski et al., 2005; Samet and krewski 2007; Tsai et al., 2012). Fine PM originates from

both natural and anthropogenic sources and is emitted as a product of incomplete combustion. The median aerodynamic diameter of particles emitted from combustion is typically well below 2.5 μm ($PM_{2.5}$), the particle size below which the majority of PM deposits in the deep lung. The WHO has established $PM_{2.5}$ guideline concentrations for all nonoccupational environments (indoors and outdoors) of 10 $\mu g/m^3$ (animal) and 25 $\mu g/m^3$ (24 h) (WHO 2006). However, acknowledging the difficulty of achieving the animal guideline concentration in low- and middle-income countries, 3 interim target for achieving the guideline values were provided-5, 25 and 35 μg $PM_{2.5}/m^3$. Combustion sources are known also to emit ultrafine particles (UFP), which have aerodynamic diameter<0.1 μm. There is some evidence from laboratory-based studies to suggest that UFP exhibit higher toxicity per unit mas than larger particles in the respirable size range (e.g., $MP_{2.5}$) (Peters et al., 1997). Due to their small diameters, ultrafine particles typically contribute little mass to traditional-based PM measurements but may constitute the predominant contributor to particle count and surface area. Surface chemistry and composition may be determinant of toxicity, but their importance's is still uncertain (Stanek et al., 2011). Compared to respirable particles, UFP more easily evade lung-clearance mechanism and enter the lung interstitium and vascular space. The toxicological mechanism is not well characterized and epidemiological evidence that distinguishes the risk of UFP from other respirable particles is limited. No UFP guideline levels currently exist.

2.5.1.2 Carbon monoxide (CO)

Carbon monoxide (CO) is a colorless and odorless gas generated by the incomplete combustion of the hydrocarbon fuels. When inhaled, CO bind to hemoglobin in red blood cells to form carboxyhemoglobin, reducing oxygen-carrying capacity of the blood and increasing the risk of chronic and acute adverse health effect in adults, children, and fetuses. The effect of acute exposure includes dizziness, muscle cramping, loss of consciousness, and, in extreme cases, death. Low-level chronic exposure has been associated with neurodevelopmental effect (Dix-cooper et al., 2012; Garland and pearce 1967; Hiramatsu et al., 1996; Long 1997) and cardiovascular diseases (Yang et al., 1998). WHO guideline levels reflect air concentrations at which a normal adult would not exceed 2% carboxyhemoglobin. Several time-weighted average guideline levels were established to protect against both chronic and acute adverse

effect of CO: 100 mg/m (averaging time, 15 minutes), 10mg/m (8 h), and 7 mg/m (24 h) (WHO 2010).

2.5.1.3 Polycyclic aromatic hydrocarbon (PAH)

Polycyclic aromatic hydrocarbon (PAH) are in class of multiringed compound present in indoor environments in both the gas and particle phases. PAH are present as constituents of some hydrocarbon fuels, including kerosene, and also generated as a product of incomplete combustion. Benzo[a]pyrene (BaP) is commonly used as an indicator of the toxic potency of PAH considered a Class 1 carcinogen (IARC 2010), although more than a dozen PAH compounds have been associated with cancer and other adverse health outcomes. There is emerging evidence in animal models that phenanthrene, which is present in petroleum-based fuels, is a potent immunosuppressant in animals and possibly in human (Nadeau et al., 2010). However, noncancer risks are not currently considered in WHO guidelines for these compounds. Specific PAH and their relative proportions vary by source. Using Bap as an indicator. WHO has established a unit risk for lung cancer as 8.7×10^{-5} per ng Bap/m^3. WHO also provides a separate guideline for naphthalene ($C_{10}H_8$), a two-ring compound and the simplest PAH, which partitions almost entirely in the gas phase. Naphthalene is considered by IARC to be a Class 2 carcinogen (possibly carcinogenic to humans), with sufficient evident of carcinogenicity from animal studies but lacking evidence from human populations (IARC 2002). A guideline level 0.01 levels (0.001 mg/m^3) in the absence of emission sources.

2.5.1.4 Sulfur dioxide

Sulfur dioxide (SO_2) is generated from the sulfur content of fuels during combustion. The majority of sulfur emitted indoors exist as SO_2, but is later converted to secondary sulfur-containing compounds in the atmosphere (e.g., sulfate). Acute effects attributed to SO_2 exposure include changes in pulmonary function and respiratory symptoms, while chronic exposures al level<20 μg/m^3 have been associated with increases in all-age mortality and childhood respiratory disease. WHO established a precaution 24-h indoor guideline level of 20 μg/m^3, with interim target levels at 50 and 125 μg/m^3 (WHO 2010). To protect against acute adverse effects, a 10-mm guideline level was set at 500 μm/m^3.

2.5.1.5 Nitrogen oxides (NO_x)

Nitrogen oxide (NO) and nitrogen dioxide (NO_2) are formed in reactions between atmospheric nitrogen and oxygen during combustion process, particularly at higher combustion temperatures. There is strong evidence linking NO_2 with adverse respiratory health effects in adults and children. These effects include inflammation, asthma, and reduced immune defenses that lead to exacerbation of, or susceptibility to, existing or new respiratory infections. WHO 1-h and annual guideline levels for NO_2 are 200 $\mu g/m^3$ and 40 $\mu g/m^3$, respectively (WHO 2006).

2.6 Previous work done on first-and-second laws efficiency

Energetic efficiency, or first-law efficiency Paul Viktor Gilli, 1996, is defined as the ratio of energy transferred to the ultimate purpose of the system divided by the actual energy input to the system (not counting "free", e.g. ambient, heat). When the theoretical maximum value of the energetic efficiency is greater than 100%, it is called the coefficient of performance (COP); otherwise, it is called efficiency and is denoted by **η.**

Heat pumps have COP values that usually are much greater than 100%; furnaces have an efficiency of less than 100%. This is true at least if the energy input of the fuel is measure by the gross calorific value or higher heating value (HHV). If the net calorific value or lower heating value (LHV)-excluding the heat of condensation of the water vapor in the flue gas-is used, and if the flue gas is cooled down to a temperature where sufficient condensation occurs, efficiencies of 100% or even slightly higher are possible in a condensing boiler under favorable circumstances.

Obviously, it is not satisfactory that efficiencies can be above 100%. Therefore, the second-law efficiency Paul Viktor Gilli, 1996, or exergetic efficiency, **is** defined; its maximum (ideal) value for a process is 100%. Second –law analysis can be based on the entropy or the exergy (available energy) concept. Currently, the exergy concept is often preferred because it is a positive concept: High temperature means high exergy but low entropy. And the division of energy into exergy (b) and anergy (a) part is, in principle, easy to handle.

To apply the exergy concept (Thring, 1994; Cambel et al., 1980; ASME 1987, 1988, 1992; Kotas et al., 1987; Moran and Sciubba, 1994), a distinction must be made between closed

systems (internal energy, **u**) and open systems (enthalpy, **h**). Technical applications usually use open systems.

AS far as heat (**q**) is concerned, exergy (**b**) and enthalpy (**h**) are coupled by a quality factor, the carnot factor ν_c, depending on absolute working temperature **T** and ambient temperature T_o. This follows from the definition of entropy (**s**), or rather its differential (**ds**) Paul Viktor Gilli, 1996:

$$ds = (1/T)dq = (1/T)dh \quad (2.5)$$

$$db = dh - Tds = dh - (To/T)dq = (1 - To/T)dh = \nu c dh \quad (2.6)$$

$$\nu c = db/dh = |1 - To/T| = |(T - To/T| \quad (2.7)$$

Thus, the aim of this project is to develop the biodiesel as alternative fuel to kerosene in wick/Butargas stove for household application, this is because the problem arises due to:

- Unclean burning of kerosene which must affect human health
- Continuous increase of the fuel cost
- Global warming from the fuel waste after combustion

In this case, the household stove is chosen because;

- It is the more favorite issue in poor countries
- It is small size and it is good for laboratory testing
- Can be handled easily and also available

2.7 Research work in Ethiopia Review

The government of Ethiopia considers biofuel as an opportunity for enhancing food security and meeting the growing energy demand in the country, thereby saving scarce foreign exchange Abadi and Ayelew, 2017. Due to the favorable air condition and suitable soil type for biodiesel development, different types of plant species which can be used for producing bio-diesel grow in the country. Jatropha, which is very important feed-stock for biodiesel grows in many parts of the country and used as a hedge and medical plant Abadi and Ayelew,

2017. The same document shows that, in Amahara region there are about 11 million wild and planted jatropha plants. It has a various name depending on the locations it grows. In some areas it is called "Ayderkie", which means Draught Resistant, and in some place it is called "Yedinber Shimagilie", which means Border Mediator since it is widely used as hedge. Another plant which grows in many parts of the country and important feed-stock for producing biodiesel is castor oil. Imported palm tree seedlings are planted in 100ha area in Gambella regional state for producing oil and soap around Tepi area Abadi and Ayelew, 2017. Ethiopia is endowed with natural resource suitable for bio-diesel development and at national level, an estimate area of 25-million-hectare suitable land is available for development of biodiesel Abadi and Ayelew, 2017. The biodiesel development activity by currently operational developers indicates that more than 100,000 ha of land are currently under biodiesel's crop cultivation; while more than 300,000 ha of potential land are expected to be additionally utilized Negussie Zeray, 2015.

2.8 Summary of the literature review

From literature review it is clearly show that the production of biodiesel as alternative for household application have evolved over the years. The catalysts for transesterification process reviewed are typically homogeneous (basic catalyst, acidic catalyst) and heterogeneous catalyst. Kerosene stoves based on fuel burning, performance test protocols, fuels combustion and efficiency based on the first-and-second are also reviewed. But only most performance test protocol (i.e. water boiling test (WBT), control cooking test (CCT) and kitchen performance test (KPT)) was involved long ago. The main conclusions observed in literature are:

- Waste oil can be converted into biodiesel using methanol, ethanol and other chemical and catalyst (typically, homogeneous and heterogeneous).
- Water boiling Test (WBT), controlled cooking test (CCT) and kitchen performance test (KPT) protocols are the most common test protocols of stoves.
- Neither lab scale or industrial scale Waste oil –to –biodiesel converting or treatment and characterization plants does not exist in Ethiopia.
- The most common cooking oil used by street vendors in Ethiopia are palm and sunflower oils.

- The most pollutants which are observed in combustion are particulates matter (PM), carbon monoxide (CO), polycyclic aromatic hydrocarbon (PAH), sulfur dioxide (SO_2) and nitrogen oxide (NO_x).
- The efficiency of the system can be identified by knowing the energy output and input of the system, and the available energy used to do the work.

2.9 Research distance

As mentioned above, most researchers rise on the production of biodiesel from waste oils feedstock as alternative to conventional diesel for CI engine and less on the issues of household applications especially for cooking. Particularly there was no thermodynamic and combustion performance study of biodiesel in pure or blend with kerosene to use it as alternative fuel for kerosene stove (Butagas) in Ethiopian context. The aim of this research is to investigate by asking a basic question "what would be the experimental thermal and combustion performance of waste sunflower oil converted to biodiesel as an alternative fuel to wick/Butagas stove without any design modification?"

CHAPTER THREE

3. Material and methods

3.1 Sample and materials

The used sunflower oil was collected from the street breads and chips sellers, wick/Butagas stove was purchased from shop in Adama city market and the conventional kerosene for blending was obtained from Adama city main shell (around Adama Post Office). The other materials (such as KOH, methanol, funnel, flask, chiller, flue gas analyzer etc.) was taken and used in Chemical Engineering laboratory within the Adama Science and Technology University (ASTU) campus.

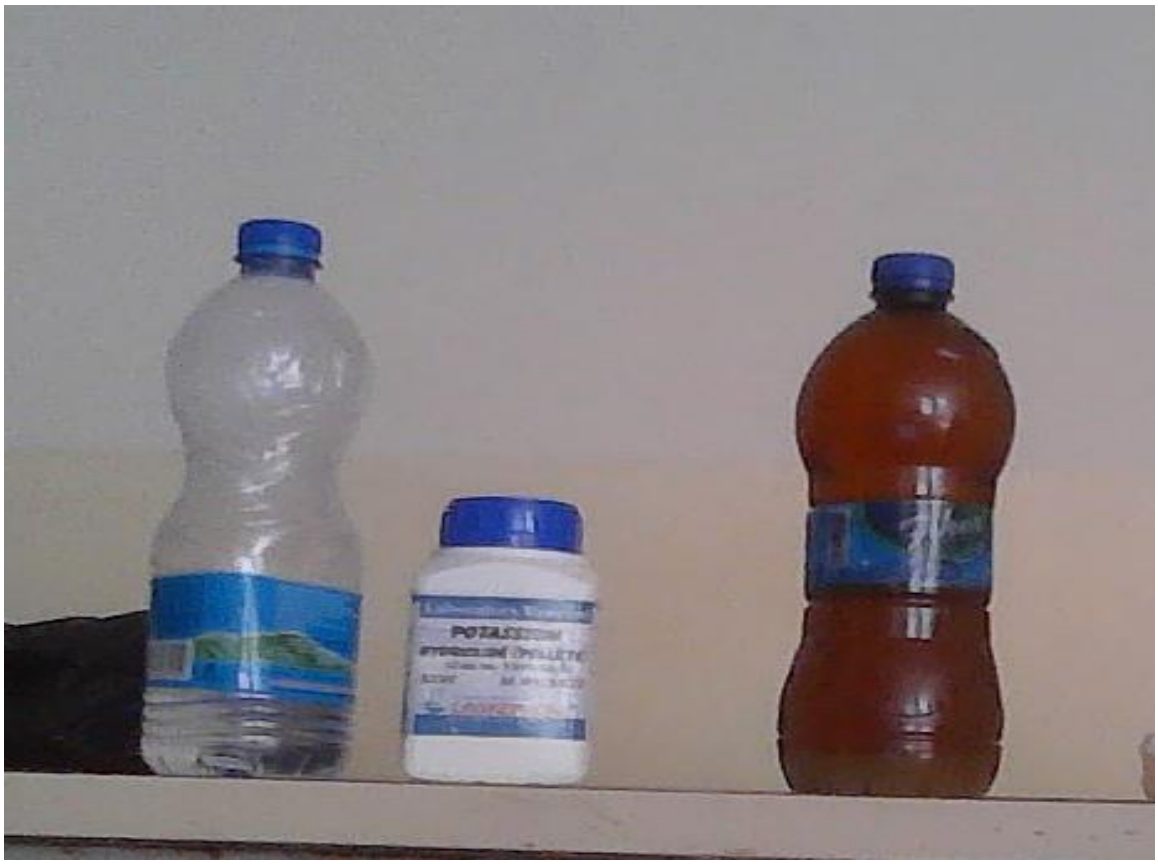


Figure 3.1: Project materials and sample in laboratory

3.2 Data collection

In the field tour, information from the breads and chips sellers for the disposal of waste cooking oil was collected by interviewing and observing them in the street. And the project data which gave the solutions for refined waste oil was collected using an experiments in laboratory.

3.3 Methodology

The methods and analysis which was carried out during biodiesel production were of the following:

3.3.1 Filtering

Initially, waste or used sunflower cooking oil was filtered using white cloth filter to remove slag and impurities in a separate container as shown in Figure 3.2.

Figure 3.2: Filtering of waste cooking oil to removes slag and impurities

3.3.2 Heating

The used cooking oil (UCO) was heated up to 55℃ for 30 minutes in magnetic stirrer to avoid impurities and moisture content as shown in Figure 3.3.

Figure 3.3: Heating of the waste oil to avoid moisture

3.3.3 Mixing solution

Before transesterification process, potassium hydroxide was first mixed with methanol together in one container before adding to the waste cooking oil (WCO). After adding the murky, this was then heated to about 55℃ for 60 minutes.

3.3.4 Transesterification

Transesterification process and any methanol evaporation the resultant biodiesel was left lie for at least 24 hours. Separations were used to separate the top (methyl ester) and bottom (glycerol) layers of the biodiesel. The top layer was mainly composed of free fatty acid methyl esters or (biodiesel). The bottom deposit was mostly of glycerol, salts, soap, other impurities and excess methanol as it is a very polar compound that is it partitions more with polar glycerol as opposed to the non-polar methyl esters.

3.3.5 Washing

The top methyl ester layer was separated and removed from every production sample. Once separated from the glycerin the biodiesel was purified by washing gently with warm water to remove residual catalyst or soaps, dried, and send to other process like drying. This is mutually the end of the production process which resulted in a clear amber-yellow liquid with a viscosity similar to petro diesel.

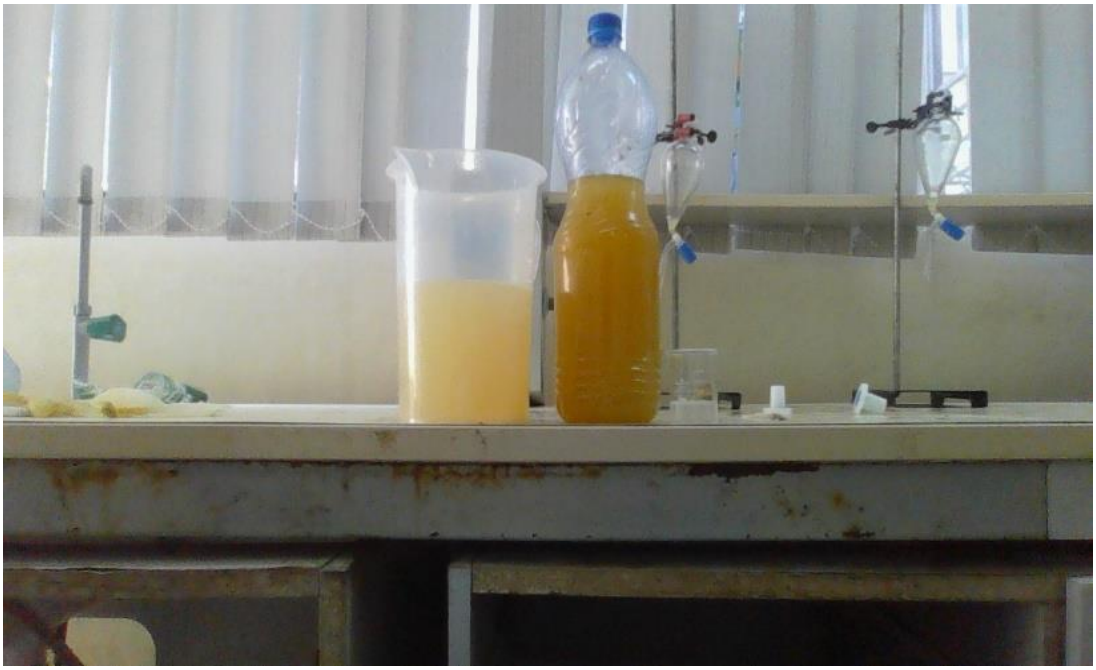


Figure 3.4: Amber-yellow biodiesel after washing

The general flowchart of the treatment of waste sunflower cooking oil and its conversion process into biofuel is indicated in the form of flow chart (Figure3.5).

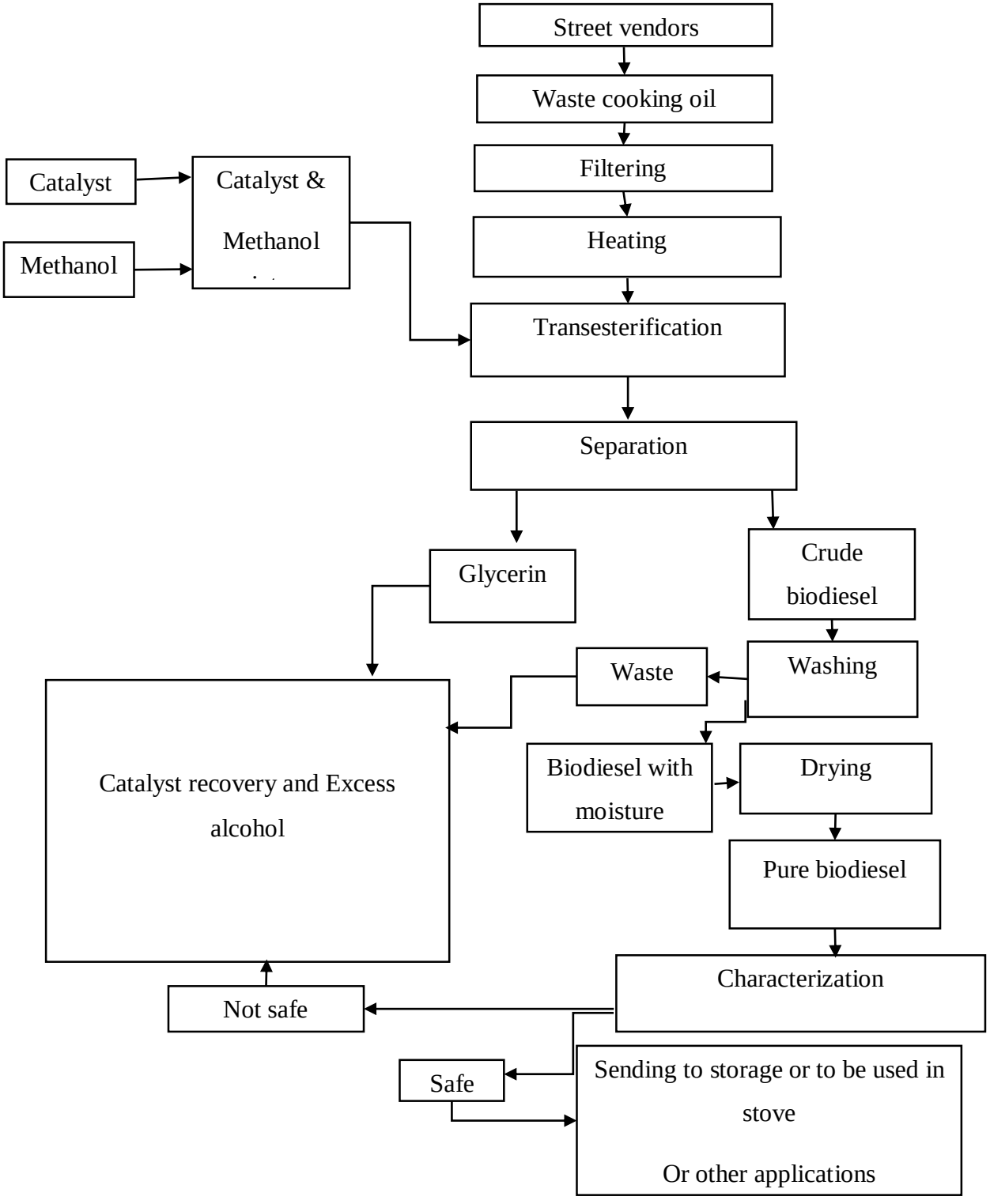


Figure 3.5: General flow chart of the biodiesel process

3.3.6 Determination of the biodiesel properties

The last step for biodiesel is the determination of the properties. When the biodiesel yield is obtained it will not be directly send to the storage because the properties gives its safety to use it. The properties of the biodiesel which was determined are density, viscosity, acid value, cetan index, flash and fire point. LHV or HHV was also estimated using correlation equations.

3.3.7 Estimation of energy performances in the stove

The fuel which was consumed during the boiling of some amount of water, cooking some amount of rice and averaging the fuel used/or consumed per day were measured while calculating the performances of the wick/butargas stove. In this point, the amount of fuel consumed, energy input and energy output was estimated while calculating the thermal and combustion efficiencies of the stove.

3.3.8 Software

The software which was used in this statistical analysis was Microsoft excel.

CHAPTER FOUR

4. Analysis of biodiesel as alternative fuel in stove

4.1 Introduction

Cooking of fast food such as potato chips need large amount of oil because it requires the full immersion of food at temperature greater than 180℃. This causes large amount of waste cooking sunflower oil to be generated from fried food and discarded into the environment. Due to the high cooking temperatures generated in the oil, changes in its chemical and physical composition which affect both the food and oil quality. Waste cooking oil can often be obtained for free or already treated for a small price. One disadvantage of using waste oil is it must be treated to remove impurities like free fatty acid (FFA) before conversion to biodiesel is possible.

4.2 Pretreatments of the oil

Removal of unwanted impurities such as (slag/food content (%), moisture content (%), Free fatty acid (%FFA)) from the main constituent to make it suitable for further processing i.e. carry out the reaction. The free fatty acid (%FFA), color and gums content of oil governs the requirement of pretreatment for a particular oil. For virgin and refined oils there is no to minimal requirement of pretreatment. For other oils like used cooking oil (USC)/waste cooking oil (WCO) pretreatment is necessity.

4.2.1 Slag and Impurities content of the oil ($W_{s,i}C$)

To determine the slag and impurities content of the oil, weight of the oil is recorded before filtering (W_1) and after filtering (W_2). The slag and impurities content can be evaluated as;

$$W_{s,i\,C} = \frac{W_1 - W_2}{W_1} \times 100\% \qquad (4.1)$$

Where $W_{s,i}$ = slag and impurities content,

W_1 = Weight of the oil before filtering (958.5 ml)

W_2 = Weight of the oil after filtering (944.7 ml)

4.2.2 Moisture content (humidity) of the waste oil ($W_w C$)

To determine the water content of the waste cooking oil, weight of the oil is recorded before heating (W_3) and after heating (W_4) of the waste cooking oil up to 60℃ for 30 to 60 minutes in magnetic stirrer. The weight of water content of the waste cooking oil can be computed as;

$$W_{w,C} = \frac{W_3 - W_4}{W_3} \times 100\% \qquad (4.2)$$

Where W_w, C = weight of the moisture content

W_3 = Weight of the oil before heating ($W_3 = W_2 = 944.7$ grams)

W_4 = Weight of the oil after filtering (936.3 grams)

4.2.3 Transesterification

400 ml of waste sunflower cooking oil was transferred to 500 ml flask four times and heated to 52 ℃ in magnetic stirrer temperature control. The molar ratio of the waste cooking oil to the methanol was 1:4. A solution containing 4.0 gram of potassium hydroxide and 100 ml of methanol were added individually and vigorously stirred using a magnetic stirrer, and reactions were allowed for 60 minutes. Except for temperature, time and catalyst concentration of methanol, and the waste sunflower oil volume remained constant. Evaporator where the working fluid coming from chiller machine is attached to the flask for methanol recovery since the methanol can evaporate before poured into waste oil flask. The sample were removed and poured into separating two 100 ml funnels, and other in the flask and kept overnight to settle for separation, then the biodiesel in the upper layers was decanted from the glyceride and kept for next step. Figure 4.1 shown the experimental set up used for transesterification process.

Figure 4.1: Reactor setup with chiller used for the transesterification of waste oil

4.2.4 Separation of the mixture

The homogenous mixture produced by the reaction was left for 24 hours for physical separation. Glycerin precipitated at the bottom of the container funnel due to its high density and the biodiesel on the top due to its low density. Figure 4.2 shown the separation of the mixture

a b

Figure 4.2: Separation of the mixture (or a) ongoing separation and b) separated mixture)

4.2.5 Washing of the biodiesel

After physical separation, the methyl ester (biodiesel) still contains some glycerin and little methanol. Washing the product by using warm water (55°C) distilled water to get the rest glycerin out by saponification with water, also wash can ride the rest of methanol and catalyst out of diesel fuel due to the water is good solvent for methanol. The washing was repeated (three time) until the clean water was obtained as shown in Figure 4.3.

Figure 4.3: Washing of the biodiesel

4.2.6 Drying of the biodiesel

Due to washing the water content is arisen in the biodiesel fuel product which affect the diesel tank where this water becomes handicap for completing the perfect combustion of biodiesel fuel. The biodiesel was heated up to 58℃ for 45 minutes. Therefore, the water content and the rest of methanol will be removed. At this step, the biodiesel fuel is ready for chemical, mechanical testing such as combustion efficiency, pour point, cloud point, density, cetane number, shear stress and viscosity to be evaluated whether if it can be candidate to an alternative fuel. The heating of the fuel is shown in the Figure 4.4.

Figure 4.4: Heating of the biodiesel fuel

4.2.7 Yield of the biodiesel

The yield of biodiesel (%wt.) after pretreatment stage, relative to the volume of waste cooking sunflower oil poured into the reactor was calculated from the methyl ester and waste oil volume. Every 400 ml of waste sunflower oil gives 370 ml biodiesel product before washing and drying. And every 370 ml of biodiesel product gives 367.45 ml after washing and drying. Figure 4.5 and 4.6 shows the yield of biodiesel before washing and drying, and after washing and drying.

Therefore, the yield of biodiesel can be evaluated before washing and drying, and after washing and drying as follow:

$$\text{Biodiesel yield (before washing \& drying) (\%)} = \frac{\text{Volume of methyl ester}}{\text{Volume of waste oil}} \times 100\% \qquad (4.3)$$

$$= \frac{V_{ester1}}{V_{oil}} \times 100\% \quad (4.4)$$

Where V_{ester1} = volume of methyl ester before washing and drying

V_{oil} = volume of waste oil

Figure 4.5: Biodiesel product before washing and drying

$$\text{Biodiesel yield (after washing and drying) (\%)} = \frac{V_{ester2}}{V_{oil}} \times 100\% \quad (4.5)$$

Where V_{ester2} = volume of methyl ester after washing and drying

V_{oil} = volume of waste oil

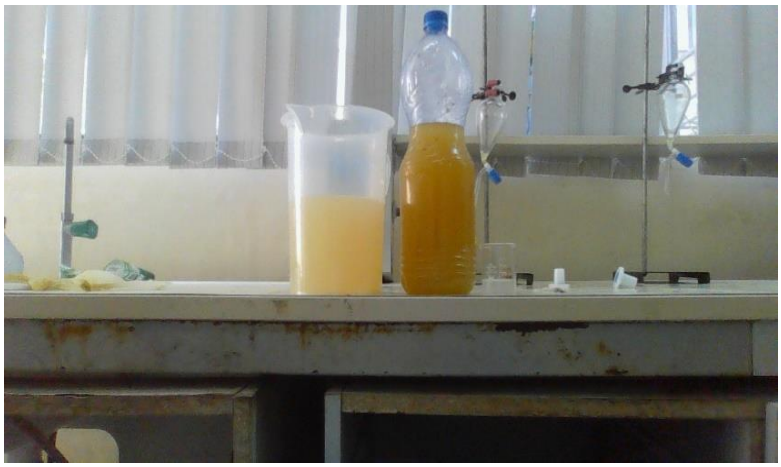


Figure 4.6: Biodiesel product after washing and drying

4.3 Characterization of biodiesel

Properties of the biodiesel are the physical properties obtained during the biodiesel tests. The safety of the biodiesel is identified by its properties. The biodiesel can be determined using the international standard ASTM method. These properties determine the safety of the biodiesel fuel to be used either in I.C engine or in household stove application. The following are the properties of the biodiesel which will be determined:

4.3.1 Density

This is defined as the ratio of the mass of the fuel to the volume of the fuel at a reference temperature of 15℃ Rahman et al., 2020. Density is measured by an instrument called hydrometer. The knowledge of density is useful for quantity calculations and assessing ignition delay. The unit of density is kg/m^3. Mathematically, the density can be calculated as:

$$\text{Density} = \frac{\text{Mass of the fuel}}{\text{Volum of the fuel}} \quad (4.6)$$

In this study, the density of the pure biodiesel was obtained using correlation experiment (iteration) in laboratory.

Table 4.1: Experimental estimated density

Volume of biodiesel (ml)	**Mass of glass (M_{glass}) + Mass of biodiesel (M_{bio}) (g)**	**M_{glass} (g)**	**M_{bio} (g)**	**Density (g/ml)**
20.000	71.810	55.070	16.740	0.837
30.000	80.600	55.070	25.530	0.851
40.000	88.940	55.070	33.870	0.847
50.000	97.610	55.070	42.540	0.851
60.000	106.050	55.070	50.980	0.850
average density (g/ml)				0.846

The average density of pure biodiesel in this experiment becomes 0.846 g/ml.

4.3.2 Viscosity

The viscosity of liquid fuels is their property to resist the relative movement tendency of their composing layers due to intermolecular attraction forces (viscosity is the reverse of fluidity). Viscosity is one of the most important properties of biodiesel. Viscosity influences the ease of

starting the engine, the spray quality, the size of the particles (drops), the penetration of the injected jet and the quality of the fuel-air mixture combustion (Alptekin and Canaki, 2009). The viscosity at 40 ℃ was determined using Viscometer at Materials Science and Engineering in Adama Science and Technology University campus. Fuel viscosity has both an upper and lower limit. The fuel with a too low viscosity provides a very fine spray, the drops having a very low mass and speed. This lead to insufficient penetration and the formation of black smoke specific to combustion in the absence of oxygen (near the injector) Rajalingam et al., 2016. A too viscous biodiesel leads to the information of too big drops, which will penetrate to the wall opposite to injector. During this experiment, the viscosity which was obtained is dynamic viscosity in centipoise (cp).

Table 4.2: Experimental viscosity tests

	Test 1 (centipoise)	**Test 2 (centipoise)**	**Test 3 (centipoise)**
	32	29	27
Average dynamic viscosity (cp)	29.333		

During this experiment, the measuring time to start was 10 seconds and waiting time for result show was 5 seconds. The dynamic viscosity of experimental biodiesel becomes $\mu_{biodiesl}$ = 0.29333 poise. Then, the kinematic viscosity can be obtained by the ratio of dynamic viscosity to the density of the biodiesel.

Dynamic viscosity ($\mu_{biodiesl}$) = 0.29333 poise = 0.29333 g/cm-sec = 0.0029333 g/mm-second
Density of biodiesel ($\rho_{biodiesel}$) = 0.847 g/ml = 0.847 g/cm^3 = 0.000847 g/mm^3

$$Kinematic\ viscosity\ (vbiodiesel) = \frac{\mu_{biodiesl}}{\rho_{biodiesel}} \quad (4.7)$$

$$= \frac{0.0029333\ \text{g/mm}-\text{second}}{0.000847\ \text{g/mm3}} = 3.463\ \text{mm}^2/\text{sec}$$

4.3.3 Acid value

The acid value (AV), also called neutralization number or acid number is the mass of potassium hydroxide (KOH) in milligrams that is required to neutralize the acid constituents in one gram of sample. The acid value determination is used to quantify the presence of acid moieties in a biodiesel sample. In a typical procedure, a known amount of sample dissolved in organic

solvent is titrated with a solution of potassium hydroxide with known concentration and with phenolphthalein as an indicator. The acidic compounds that could possibly be found in biodiesel are:

1) Residual mineral acids from the production process
2) Residual free fatty acid from the hydrolysis process or the post-hydrolysis process of the ester and
3) Oxidation byproduct in the form of other organic acids (Berthiaume and Tremblay, 2006).

This parameter is a direct measure of the content of the free fatty acids, thus the creativeness of the fuel, of filter clogging and the presence of water in the biodiesel. A too high amount of free glycerin can cause functioning problems at reduced temperatures and fuel filter clogging. This parameter can also be measure the freshness of the biodiesel. Fuel that has oxidized after long-term storage will probably have a higher acid value. Mathematically, the acid value was calculated as:

$$\mathrm{AV} = \frac{\text{volume of KOH} \times \text{normality of KOH} \times \text{Eq. weightof KOH}}{\text{Weight of sample}} \qquad (4.7)$$

Weight of sample = 1 ml

Equivalent weight of KOH = 56.1 g/mol

Volume of 0.01N KOH used = 0.8 ml, by substituting the values we have

$$\mathrm{AV} = \frac{0.01 \times 0.8 \text{ ml} \times 56.1 \text{ g/mol}}{1 \text{ ml}} = 0.44$$

4.3.4 Cetane number (CN)

The physical and chemical properties of fuel play very important role in delay period. The cetane number (CN) of the fuel is one such important parameter which is responsible for the ignition delay period. Cetane number of a fuel is defined as the percentage by volume of normal cetane in a mixture of normal cetane and α-methyl naphthalene which has the same ignition characteristics (ignition delay) as the test fuel, when combustion is carried out in a standard engine under specified operating condition. A fuel of higher cetane number gives lower delay

period and provides smooth engine operation. Biodiesel has a higher cetane number than petro-diesel because of its higher oxygen content.

$$\text{Cetane number} = 454.74 - 1641.416D + 774.74D^2 - 0.554B + 97.803(LogB)^2 \quad (4.8)$$

Where; D is density ($\rho = 0.846$ g/cm^3) and B is the corrected mid boiling point in ℃ (B =332.5 ℃) from international standard of biodiesel.

By substituting the values into equation (4.8), the Cetane number (CN) was found to be 58.

4.3.5 Flash point

Flash point is the minimum temperature at which a liquid gives off vapor within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid. The flash point is normally an indication of susceptibility to ignition. The flash point is determined by heating the liquid test equipment and measuring the temperature at which a flash will be obtained when a small flame is introduced in the vapor zone above the surface of the liquid. A standard closed container is used to determine the closed-cup flash point and a standard open-surface dish for the open-cup flash point temperature, as specified by the America Society for Testing and Materials (ASTM). These are referenced in OSHA's 1910.106 standard. This property was measured by using heat capacity measurement tester by following ASTM D93 under ASTM D6751 standard where the result was 132 ℃.

4.3.6 Fire point

Fire point of a fuel is the lowest temperature at which the vapor of fuel can continue to burn for at least five seconds after the ignition has started. It means; the term fire point describes that it is the lowest temperature for a substance to hold the combustion for a small time period after the ignition by an open flame. Usually, the fire point of a substance is about 10℃ higher than the flash point of the same substance. We can measure the fire point of a substance using the "open cup apparatus". In this study fire point was measured using heat capacity measurement. The result which was obtained is 146 ℃.

4.3.7 Calorific value

The calorific value of a fuel is the thermal energy released per unit quantity of fuel when the fuel is burned completely and the products of combustion are cooled back to initial temperature of the combustible mixture. It measures the energy content in a fuel. This is an important

property of the biodiesel that determines the suitability of the material as an alternative to diesel fuels. In this study, this parameter is obtained using correlation equation. The higher heating value (HHV) and lower heating value (LHV) of biodiesel are 40.2 MJ/Kg and 37.5 Mj/kg (P. Schinas et al., 2008). (Zhang et al., 2000) the higher heating value (HHV) and lower heating value (LHV) of kerosene are 46.2 Mj/kg and 43.3 Mj/kg respectively.

Table 4.3: Correlation equations to obtains HHV and LHV of blend fuels (Joseph M., 2014)

$MB5 = VB5 * \rho pD$	$XB5 = MB5/(MB5 + Mk95)$	$MK95 = VK95 * \rho pk$
$MB10 = VB10 * \rho pD$	$XB10 = MB10/(MB10 + MK90)$	$MK90 = VK90 * \rho pk$
$MB15 = VB15 * \rho pD$	$XB15 = MB15/(MB15 + MK85)$	$Mk85 = VK85 * \rho pk$
$MB20 = VB20 * \rho pD$	$XB20 = MB20/(MB20 + MK80)$	$Mk80 = VK80 * \rho PK$
$Xk95 = Mk95/(MB5 + Mk95)$		$Xk90 = Mk90/(MB10 + MK90)$
$Xk85 = Mk85/(MB15 + MK85)$		$Xk80 = Mk80/(MB20 + MK80)$
$HHVB5 = XB5 * HHVBD + XK95 * HHVpK$ $HHVB10 = XB10 * HHVBD + XK90 * HHVpK,$		
$HHVB15 = XB15 * HHVBD + XK85 * HHVpK$		
$HHVB20 = XB20 * HHVBD + XK80 * HHVpK$		
$LHVB5 = XB5 * LHVBD + XK95 * LHVpK, LHVB10 = XB10 * LHVBD + XK90 * LHVpK,$		
$LHVB15 = XB15 * LHVBD + Xk85 * LHVpK$		$LHVB20 = XB20 * LHVBD + XK80 * LHVpK$

Table 4.4: HHV and LHV of each fuel biodiesel-kerosene blend

Fuel	Volume (ml)	mass (g)	mass fraction (%)	HHV (Mj/kg)	LHV (Mj/kg)
B5	20	16.92	0.053	45.882	42.9926
B10	40	33.84	0.105	45.57	42.691
B15	60	50.76	0.1573	45.3	42.4
B20	80	67.68	0.209	44.94	42.0835
K95	380	304	0.947	45.882	42.9926
K90	360	288	0.895	45.57	42.691
K85	340	272	0.843	45.3	42.4
K80	320	256	0.7909	44.94	42.0835
Density of pure biodiesel = 0.846 g/ml		Density of pure kerosene = 0.8 g/ml			

4.4 Production cost of biodiesel

The production cost of biodiesel is the sum of the costs of all the resources, which was consumed during the process of generation of a product. These costs are necessary to convert raw input (waste oil, methanol and catalyst) into finished output (biodiesel).

They are mainly divided into three (3) categories;

1. **Direct material cost**: - This is the cost of the materials which become part of the finished product (biodiesel). Examples; raw materials (like waste oil, methanol and catalyst), tooling's (like laboratory instruments, characterization), consumables, etc.
2. **Direct labor cost**: - Direct labor cost is wages that are incurred in order to generate finished goods (biodiesel). Example; employee salaries (laboratory assistant).
3. **Factory (laboratory) over heat cost**: - These are costs, which includes by providing support to the production. Examples; electricity consumption, material handling, land rent, etc.

In this study, the production cost was just considered as laboratory expense and the materials (waste oil) cost. Therefore; the production cost can be calculated as;

$$\text{Production cost} = (\text{Lab expense} + \text{material cost}) \quad (4.9)$$

Where;

The laboratory expense was 800 Birr and material cost was 975 Birr and hence, the production cost of biodiesel becomes 1775 Birr.

4.5 Fuels blends

The biodiesel and kerosene blends are prepared on volume basis. A mixture of kerosene and neat waste cooking oil or waste cooking oil methyl ester have been tried in proportions of B5, B10, B15 and B20. The total volume of the fuel is 400 ml in which the volume of biodiesel is subtracted from 400 ml. The fuel blends are shown in figure 4.7.

Figure 4.7: Fuel blends in volume basis

4.6 Analysis of wick cook stoves performance

If liquid and/ or gaseous fuels are used, the procedure is simplified because there is neither char nor ash to be measured. Moreover, many liquid and gaseous stoves are small enough to directly measure on a scale, so that fuel consumption can be very straightforward. However, if the stoves are too larger to put on the scale, then fuel consumption may be difficult to assess. Similarly, if the gas is from a piped source (as with gas stoves in the United State (US) version 3.0, then a flow meter may be needed to measure the quantity of fuel consumed. In addition, the tester must know the calorific value of the fuel. For fossils, this can vary depending on exact mix of distillates that are used. Some calorific values that have been reported in the literature and which are calculated through correlation equation in this study are given below:

Table 4.5: Calorific value used in this study

Fuel	Lower calorific value (MJ/kg)	Source
Kerosene	43.3	Zhng et al., 2000
Biodiesel	37.5	Smith et al., 2001
B5	42.9926	Calculated
B10	42.691	Calculated
B15	42.4	Calculated
B20	42.0835	Calculated

The performance characteristics of the test protocols such as water boiling test (WBT), control cooking test (CCT), and kitchen performance test (KPT) were evaluated for wick/Butagas stove using neat (B100) and pure kerosene as well as kerosene-biodiesel blends (B5, B10, B15, and B20).

Table 4.6: Wick/Butagas stove specification used in this study

Model	62
Capacity of oil (kg)	1.3
Consumption per hour (kg)	0.13
Length with height (cm)	¢ 20.5 * 17
Measurement of case (cm)	64 * 43 *37

a b

Figure 4.8: a) Hash for emission measurement and b) Different wick used during fuels investigation

4.6.1 Water boiling test (WBT)

Water boiling teste (WBT) is a laboratory test that involves the investigation of the cooking stove in a controlled environment to evaluate or reveal its technical performance WBT, version 3.0.

a) B15

b) B10

c) B5

d) B100

e) pure kerosene

f) B20

Figure 4.9: Fuels performance investigation during cooking test protocol

The water boiling test (WBT) consists of three phase that immediately follow each other SHRI P. N BHAMBI, 1987. These are discussed below:

4.6.1.1 Phase 1: Cold-start high-power test

The tester begins with the stove at room temperature and uses a pre-weighted bundle of biodiesel or blends or pure kerosene to boil a measure quantity of water in a standard pot. The tester then replaces the boiled water with a fresh pot of ambient-temperature water to perform the second phase of the test

Variables that were directly measured during cold-start includes;

- Weight of fuel before test (M_{cfi} in kg)
- Weight of Pot with water before test (M_{cwi} in kg)
- Water temperature before test (T_{cwi} in ^oC)
- Time at start of test (t_{ci} in minutes)
- Weight of fuel after test (M_{cff} in kg)
- Weight of Pot with water after test (Wc_{wf} in kg)
- Water temperature after test (T_{cwf} in ^oC)
- Time at end of test (t_{cf} in min)

Variables that were calculated during this cold-start includes;

- Weight of water remaining after test (M_{cwr} in kg)
- Duration of phase ($\triangle t_c$ in min)
- Thermal efficiency (η_{cth} in %)
- Water vaporized (M_{cwv} in kg)
- Burning rate (R_{cb} in kg used/min)
- Specific fuel consumption (SFC_c kg fuel used/kg water remaining)
- Temp-corrected specific consumption (SC^T_c kg fuel used/kg water)
- Firepower (FP_c in W)

4.6.1.2 Phase 2: Hot-start high-power test

This test is conducted after the first test while stove is still hot. Again, the tester uses a pre-weighted bundle of fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot.

Variables that were directly measured during hot-start includes;

- Weight of fuel before test (M_{hfi} in kg)
- Weight of Pot with water before test (M_{hwi} in kg)
- Water temperature before test (T_{hwi} in ºC)
- Time at start of test (t_{hi} in minutes)
- Weight of fuel after test (M_{hff} in kg)
- Weight of Pot with water after test (W_{hwf} in kg)
- Water temperature after test (T_{hwf} in ºC)
- Time at end of test (t_{hf} in min)

Variables that were calculated during hot-start includes;

- Weight of water remaining after test (M_{hwr} in kg)
- Duration of phase ($\triangle t_h$ in min)
- Temp –adjusted time to boil pot ($\triangle t^T_h$ in minutes)
- Thermal efficiency (η_{thh} in %)
- Water vaporized (M_{hwv} in kg)
- Burning rate (R_{hb} in kg/min)
- Specific fuel consumption (SFC_h kg fuel/kg water remaining)
- Temp-corrected specific consumption (SC^T_c kg fuel used/kg water remaining)
- Firepower (FP_h in W)

4.6.1.3 Phase 3: Simmer low-power test

The simmering test provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world.

Variables that are directly measured during simmering phase includes;

- Weight of fuel when the water first boils (M_{sfi} in kg)
- Weight of Pot with water when the water first boils (M_{swi} in kg)
- Water temperature at boiling ($T_{swi} = T_b$) (ºC)
- Time at start of simmer phase test (t_{si} in min)
- Weight of fuel remaining after test (M_{sff} in kg)

- Weight of Pot with water after test (M_{swf} in kg)
- Water temperature at end of test (T_{swf} in ^oC)
- Time at end of test (t_{sf} in min)

Variable that were calculated during simmering includes;

- Weight of fuel consumed (M_{fused})
- Water vaporized (M_{swv} in kg)
- Water remaining at end of test (M_{sf} in kg)
- Duration of phase ($\triangle t_s$ in min)
- Thermal efficiency (η_{ths})
- Burning rate (R_{sb} in kg/min)
- Specific fuel consumption (SFC_s in kg fuel/kg water remaining)
- Firepower (FP_s)
- Turn-down ratio (TDR)

The variables which remain constant during the three phases are;

- Weight of empty pot (M_p = 254.45 g)
- Weight of the stove (M_{stove} = 784.15 g))
- Local boiling temperature (T_b = 94.3 ℃)

These three phases simulate common cooking process (boiling and simmering) to obtain appropriate stove performance metrics.

The testing apparatus for the three phases of water boiling test (WBT) which were used includes;

- Thermometer
- Cooking pot
- Digital timer
- One wick/Butagas stove
- Fuel (pure biodiesel and pure kerosene as well as kerosene-biodiesel blends)
- Fire lighter (match)

- Electric balance
- Flue gas analyzer

Explanation of the test processes for variables determination during phases of water boiling test;

Step 1: Measure the amount of water at initial (M_{wi} in g)

Step 2: Measure the amount of fuel at initial (M_{fi} in g) and stove (M_{stove} in g), and pour the fuel into stove

Step3: Light the cook stove and wait for the fire to catch

Step 4: Measure and record the initial temperature of water in degree Celsius (T_{wi})

Step 5: Place the pot on the stove, fix the thermometer prove in the water and start the timer

Step 6: Record the temperature every 5 minutes for 45 minutes (simmering)

Step 7: After boiling remove the pot from stove, measure the weight and record the final weight of water (M_{wf} in g). And Then, calculate the weight of water evaporated;

$$M_{wv} = ((M_{wi} + M_p) - (M_{wf} + M_p)) \quad (4.10)$$

Where

M_{wv} is the weight of evaporated water, M_{wi} is the weight of water initially, M_{wf} is the weight of water at final, and M_p is the weight of empty pot (aluminum dish).

The local boiling temperature (T_b) Bailis et al., 2001 of the adama is calculated from adama altitude (h), which is given by;

$$T_b = (100 - \frac{h}{300})℃ \quad (4.11)$$

Where; T_b is the local boiling point of Adama city and is (T_b = 1712 m) which implies that the boiling point temperature of adama city is 94.3℃.

Step 8: Measure and record the final weight of the fuel (M_{ff} in g). Then, the weight of fuel used/consumed during the test can be calculated as;

$$M_{fused} = ((M_{fi} + M_{stove}) - (M_{ff} + M_{stove})) \quad (4.12)$$

Where

M_{fused} is the weight of fuel consumed/used during test, M_{fi} is the weight of fuel at initial, M_{ff} is the weight of fuel at final, and M_{stove} is the weight of empty stove.

First-law thermal efficiency (η_{th}): This is the ratio work done by heating and evaporated water to the energy consumed by burning fuel. It is calculated in the following way.

$$\eta_{th} = \frac{M_{wi} * C_{pw} * \triangle T_w + M_{wv}\, h_{fg}}{M_{fused}\, LHV} \quad (4.13)$$

Where;

η_{th} is the thermal efficiency of the stove, Mwi is the initial mass of water in kg, C_{pw} is the specific heat capacity of water (4.18 kj/kg.℃), $\triangle$ T is the temperature difference between initial and final of the water in ℃, M_{wv} is the weight of evaporated water in kg, h_{fg} is the latent heat of evaporation of water (2,260 kj/kg), M_{fused} is the mass of the fuel used in kg and LHV is the lower heating value of the fuel in Mj/kg.

Second-law thermal efficiency: This is the ratio of the final stove temperature minus initial/ambient stove temperature to the final stove temperature. It can be calculated as;

$$\eta_{thII} = (T_b - \frac{T_{ambient}}{T_b}) \quad (4.14)$$

Water remaining at end of test (M_{wf}): This is a measure of the amount of water heated to boiling. It is simply calculated by subtracting of final weight of empty pot and water minus weight of empty pot.

$$M_{wf} = (M_{wf} + M_p) - (M_p)) \quad (4.15)$$

Time to boil ($\triangle t$): This is simply the time taken to perform the test. It is a simple clock difference.

$$\triangle t = t_f - t_i \quad (4.16)$$

Temperature-corrected time to boil ($\triangle t^T$): This is the same as above, but adjust the result to standard 75 ℃ temperature change (from 25 ℃ to 100 ℃). This may have used water with higher or lower initial temperatures. This can be calculated as.

$$\triangle t^T = t_i - t_i * 75/(T_{wf} - T_{wi}) \quad (4.17)$$

Burning rate (R_b): This is a measure of the rate of fuel consumption while bringing water to a boil. It is calculated by dividing the fuel used during the test by the time of the test.

$$R_b = M_{fused}/(t_i - t_f) \quad (4.18)$$

Specific fuel consumption (SFC): Specific fuel consumption can be defined for any number of cooking tasks and should be considered "the fuel required to produce a unit output" whether the output is boiled water, cooked beans, or loaves of bread. In the case of the WBT, it is a measure of the amount of fuel required to produce one liter (a kilo) of boiled water starting with cold stove. It is calculated as:

$$SFC = \frac{M_{fused}}{M_{wf}} \quad (4.19)$$

Temperature-corrected-specific fuel consumption (SFC^T): This corrects specific consumption to account for differences in initial water temperatures. This comparison of fuels tested on different days due to weather changes. The correction is a simple factor that "normalizes" the temperature change observed in test conditions to a "standard" temperature change of 75 ℃ (from 25 to 100). It is calculated in the following way.

$$SFC^T = \frac{M_{fused}}{M_{wf}} * \frac{75}{T_{wf} - T_{wi}} \quad (4.20)$$

Firepower (FP): This is a ratio of the fuel energy consumed/used by the stove per unit time. It tells the average output of the stove (in watts) during the high-power test. This given by;

$$FP = \frac{M_{fused} * LHV}{60 * (t_i - t_f)} \quad (4.21)$$

Turn-down ratio (TDR): This is the ratio of the low-power (simmering) to the high-power (hot-start) during the test. It is calculated as:

$$TDR = \frac{FP_s}{FP_h} \quad (4.22)$$

Where;

FP_h is the firepower of hot-start and FP_s is the firepower of simmering.

There is no temperature-corrected specific fuel consumption in the simmer phase because the test starts at T_b and change in temperature should be limited to a few degrees Bailis et al., 2001. It is important to remember that the goal of this part of the test is to maintain the water at temperature just under boiling, and one should interpret the results accordingly. Whereas the specific consumption in the high power tests (SFC_c and SFC_h) indicated the mass of fuel required to produce one liter (or kilogram) of boiling water, the specific consumption in simmer phase (SFCs) indicates the mass of fuel required to maintain each liter (or kilo) of water six degrees below boiling temperature. These are not directly comparable, but rather tell two different measures of stove performance. The same is true for other indicators, like burning rate and firepower.

4.6.2 Control cooking test (CCT)

Control cooking test (CCT) is a laboratory or field test that evaluate the performance of the stove using a standardized local cooking task (s) Philp et al., 2011. The key indicators that was measured during this technique were;

- Specific fuel consumption and
- speed of cooking (time of cooking)

Considering that, this procedure simulates the actual cooking during pure biodiesel or kerosene and Kerosene-biodiesel blends investigation, it is therefore capable of providing reliable result as compared to water boiling test (WBT) with regard to predicting actual performance and fuel consumption in the field Bailis, 2004. During this test rice was used as cooked for determining the specific fuel consumption and speed of cooking.

Figure 4.10: Rice cooked during CCT

The test apparatus of the control cooking test during this project work includes;

- Balance
- Pot
- Wick/Butagas stove
- Fuel (pure biodiesel, kerosene and blends)
- Timer
- Rice

The test procedures during conducting this test were;

Step 1: Record weight of the pot (M_p) (empty) in kg

Step 2: Record weight of fuel at the initial and final in kg

$$\text{Weight of fuel used } (M_{fused}) = (\text{Initial weight of fuel } M_{fi} - \text{Final weight of fuel } M_{ff}) \quad (4.23)$$

Step 3: Record weight of water to be added to the food before cooking in kg

Step 4: Record weight of food before cooks and after cooks

$$\text{Weight of food cooked } (M_{fc}) = (\text{weight of food after cook } (M_{fac}) - \text{ weight of pot } (M_p)) \quad (4.24)$$

Therefore; the specific fuel consumption (SFC) was calculated as Bailis, 2004;

$$SFC = \frac{M_{fused}}{M_{fc}} \times 1000 \quad (4.25)$$

The total cooking time ($\triangle t$) was calculated as (Rob bailis, 2004);

$$\triangle t = t_f - t_i \quad (4.26)$$

4.6.3 Kitchen performance test (KPT)

The kitchen performance test (KPT) is the principal field-based test procedure to measure household specific fuel consumption, either in daily or monthly Bailis, 2018, KPT version 4.0. The primary objective of the kitchen performance test (KPT) is to quantify fuel consumption under typical household and stove usage conditions. In this study, only daily fuel consumption of the actual cooking was estimated for one householder's.

The daily fuel consumption was investigated by cooking 1000 ml of water for tea as break past, rice for launch and Gambella local stew (dry fish in figure) assumed it will be eating by breads.

Figure 4.11: a) boiled water as tea b) cooked rice as launch c) dry fish as stew before cooking and d) cooked dry fish as stew (or Investigation of (KPT) by actual cooking)

So, the specific fuel consumption for kitchen performance test (KPT) investigation can be determined by adding the fuel consumed during tea boiled, rice cooked and stew cooked divided volume summation of boiled water, cooked rice and stew cooked. This can be given as;

$$SFC_{KPT} = \frac{M_{fboiledwater} + M_{fricecooked} + M_{fstewcooked}}{Day} \quad (4.27)$$

4.7 Emission characteristic of fuels during cooking protocol test

The emission characteristics of the fuels were evaluated for wick/Butagas stove using B100 and pure kerosene as well as the blends fuel (B5, B10, B15 and B20) while performing the cooking test protocols. The emission of CO and CO_2 was evaluated using flue gas analyzer for all pure and the blend fuels. During this investigation, the values of CO and CO2 were recorded by percent volume basis.

Figure 4.12: Flue gas analyzer

4.8 Combustion of fuels

In thermodynamic concept, combustion reaction is an exothermic redox chemical reaction where a fuel reacts with oxygen (or air) to produce gaseous products and a large quantity of energy is released. The oxidizer most often used in combustion processes is air. Composition of air on a mole or a volume basis, dry air is composed of 20.9 percent oxygen, 78.1 percent nitrogen, 0.9 percent argon, and small amounts of carbon dioxide, helium, neon, and hydrogen. In the analysis of combustion processes, the argon in the air is treated as nitrogen, and the gases that exist in trace amounts are disregarded.

Then dry air can be approximated as 21 percent oxygen and 79 percent nitrogen by mole numbers. Therefore, each mole of oxygen entering a combustion chamber is accompanied by 0.79/0.21=3.76mol of nitrogen.

That is; $1\text{kmol } O_2 + 3.76 \text{ kmol } N_2 = 4.76\text{kmol of air}$

During combustion, nitrogen behaves as an inert gas and does not react with other elements, other than forming a very small amount of nitric oxides.

Combustion process could be [Thermodynamic principle]:

1. **Complete combustion**: - if all the combustible components of a fuel are burned to completion. That is, if all the carbon in the fuel burns to CO_2, all the hydrogen burns to H_2O, and all the sulfur (if any) burns to SO_2. No unburned fuel and no free oxygen in products. The minimum amount of air needed for the complete combustion of a fuel is called the stoichiometric or theoretical air. Thus, when a fuel is completely burned with theoretical air, no uncombined oxygen is present in the product gases. The theoretical air is also referred to as the chemically correct amount of air, or 100 percent theoretical air. The ideal combustion process during which a fuel is burned completely with theoretical air is called the stoichiometric or theoretical combustion of that fuel.
2. **Incomplete combustion**: - Insufficient oxygen is an obvious reason for incomplete combustion, but it is not the only one. Incomplete combustion occurs even when more oxygen is present in the combustion chamber than is needed for complete combustion. This may be attributed to insufficient mixing in the combustion chamber during the limited time that the fuel and the oxygen are in contact.

3. **Actual combustion**: - In actual combustion processes, it is common practice to use more air than the stoichiometric amount to increase the chances of complete combustion or to control the temperature of the combustion chamber. The amount of air in excess of the stoichiometric amount is called excess air. The amount of excess air is usually expressed in terms of the stoichiometric air as percent excess air or percent theoretical air. For example, 50 percent excess air is equivalent to 150 percent theoretical air, and 200 percent excess air is equivalent to 300 percent theoretical air. Of course, the stoichiometric air can be expressed as 0 percent excess air or 100 percent theoretical air. Amounts of air less than the stoichiometric amount are called deficiency of air and are often expressed as percent deficiency of air. For example, 90 percent theoretical air is equivalent to 10 percent deficiency of air. The amount of air used in combustion processes is also expressed in terms of the equivalence ratio, which is the ratio of the actual fuel–air ratio to the stoichiometric fuel–air ratio.

The important of this part (combustion) in this study, is to predict the chemical composition of combustion reactant amount of **fuel** and **air** used during fuels burning in the wick/Butagas stove while determining the combustion efficiency of each fuel using first-and-second law (η_{cI} and η_{CII}) of thermodynamic principle.

Note that, the analysis which was used in this thermodynamic principle is volumetric analysis since the composition of the product were recorded in dry volume basis.

The following are the equations used during the fuel and air composition amount prediction while determining the **combustion performances** of each fuel.

From thermochemical principles on combustion efficiency, one can write the chemical equation of the fuel with air (Oxygen) and balance the number of moles present in the reactant and product side of the equation, then proceed to find the air-fuel ratio (AF), and heating value (or heat of combustion h_C) depending if the product result of H_2O is liquid or gas form. In this study, the H2O in the product was assumed liquid. And the chemical exergy of the environment was recorded (CO_2 is 0.04%, O_2 is 20.94 % and H_2O was assumed as 3.8%).

Hence, the performance of combustion during each fuel investigation can be calculated using the following equations;

$$\eta_{cI} = \frac{\text{energy output}}{\text{energy input}} = \frac{Q_{out}}{Q_{in}} \quad (4.28)$$

Where

$$Q = hc = \sum nH_{pro} - \sum nH_{react} \quad (4.29)$$

$\boldsymbol{\eta_{cI}}$ is the first-law combustion efficiency of the fuel**,** $\mathbf{Q_{in}}$ is the input energy in kJ, $\mathbf{Q_{out}}$ is the output energy in kJ, **hc** is the heat combustion, **n** is the number of moles of the reactant and product sides in kmoles, **H** is the enthalpy of formation in KJ/kmoles.

$$\text{Heating value (HHV)} = |h_c| \qquad \text{in kJ/kg of fuel} \quad (4.30)$$

$$\eta_{CII} = \frac{W_{rev}}{M_{fuel}\,\bar{a}_{ch}} \quad (4.31)$$

Where;

$$W_{rev} = \sum_R n_i \bar{g}_i - \sum_P n_e \bar{g}_e \quad (4.32)$$

$$\bar{a}_{ch} = \left[\bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}\ co - \frac{c}{2}\bar{g}_{H_2O}\right](at\ T_oP_o) - + \bar{R}T_0 ln \frac{(x_{O_2})^{a+\frac{b}{4}}}{(x_{CO_2})^a (x_{H_2O})^{\frac{b}{2}}} \quad (4.33)$$

$\boldsymbol{\eta_{CII}}$ is the second-law combustion efficiency in %, $\mathbf{W_{rev}}$ is the actual work of the fuel in kJ, $\mathbf{M_{fuel}}$ is the mass of fuel supplied in kg, $\bar{\boldsymbol{a}}_{\boldsymbol{ch}}$ is the chemical exergy in kJ/kg, $\bar{\boldsymbol{g}}_{\boldsymbol{i}}$ and $\bar{\boldsymbol{g}}_{\boldsymbol{e}}$ are the inlet and exit Gibbs function in kJ/kmoles at 25 ℃, $\mathbf{n_i}$ and $\mathbf{n_e}$ are the number of moles inlet and exit.

Note: In this study, the coefficients of the product gas were recorded using flue gas analyzer.

$$\text{Air} - \text{fuel ratio (AF)} = \frac{\text{mass of air}}{\text{mass of fuel}} \quad (4.34)$$

$$\text{Percentage theoretical air} = \frac{\text{Mass of air,actual}}{\text{Mass of air,theiretical}} \quad (4.35)$$

CHAPTER FIVE

5. Thermal and combustion performances of the Biodiesel and its blends

5.0 Introduction

This section gives the results and discusses the properties of the extracted biodiesel from waste sunflower oil and the thermal and combustion performances of the biodiesel and its blend with kerosene. The details of the number of tests conducted on the wick stove under the standard cook stove test protocols, the chemical reaction mole balance during combustion and the estimation of the first and second law efficiency of the stove are shown in Appendix C and D.

5.1 Impurity contents ($W_{s,i}$ C)

Slag and impurity content of the waste oil is the weight of the solid particles obtained after filtering the waste sunflower oil to proceed with other process. By equation 4.1, we can get the impurity as;

$$W_{s,i\,C} = \frac{958.5-944.7}{958.5} \times 100\%$$

$$W_{s,i\,C} = 0.0144 \text{ or } 1.44\%$$

The weight or content of the slag and impurity contents ($W_{s,i}$) which was obtained during filtration was 0.0144 grams or 1.44%. The slag and impurity content of this waste sunflower oil is smaller because the oil pass through fine containers.

5.2 Humidity content (W_w C)

Moisture content of the waste sunflower oil is the weight of the water present in the waste oil obtained after heating the oil. By using equation 4.2, we have;

$$W_{w,C} = \frac{944.7 - 936.3}{936.3} \times 100\%$$

$$W_{w,C} = 0.00889 \text{ or } 0.889\%$$

So the weight or water content (W_w C) obtained during heating was 0.00889 grams or 0.889%. The water content of the waste sunflower oil is low because it was heated by the street vendors before bringing it to the process.

5.3 Biodiesel yield (%wt)

The result obtained after transesterification, separation, washing and drying is the biodiesel yield (%wt.). By equation 4.4, we get the biodiesel yield as;

$$\text{Biodiesel yield (before washing \& drying) (\%)} = \frac{V_{ester1}}{V_{oil}} \times 100\%$$

$$= \frac{4\times370}{4\times400} \times 100\% = 0.925$$

Yield (%) = 92.5 % before washing and drying of the biodiesel and by equation 4.5, we have;

$$\text{Biodiesel yield (after washing and drying) (\%)} = \frac{V_{ester2}}{V\ oil V_{oil}} \times 100\%$$

$$= \frac{4\times367.45}{4\times400} \times 100\% = 0.9186 \text{ or}$$

Yield = 91.86 % after washing and drying of the biodiesel

The yield obtained during all these process before washing and drying, and after washing and drying was 92.5% and 91.86% respectively. The other loss of 7.5% of the yield may be due to the present of the free fatty acid (FFA) of the waste oil and 0.64% loss may be due to the removal of the remaining catalyst and methanol during biodiesel washing and drying.

5.4 Properties of biodiesel

Density and acid value were determined at Chemical Engineering laboratory in ASTU campus, and the viscosity was characterized at Materials Science and Engineering laboratory in Adama Science and Technology campus. The other properties were also determined at Materials Science and Engineering Laboratory. The important parameters which were investigated during this study includes;

- Density
- Viscosity
- Cetante number
- Acid value
- Flash and fire points
- Heating values

Table 5.1: Instruments used during biodiesel characterization

Property	Instrument
Density	Mass and volume measurement
Viscosity	Viscometer
Acid value	Titration
Cetane number	ASTMD613
Flash and fire point	Heat capacity measurement
Heating values	Calculated

Table 5.2: International standard and experimental values of pure biodiesel comparison

Property	ASTM method	International standard value	Experimental value	Unit
Density	D1298	0.87	0.846	g/ml
Kinematic Viscosity	D445	1.9-6.5	3.463	mm^2/sec
Acid value	D664	0.5 (max)	0.44	mg KOH/g
Cetane number	D613	>47	58	no
Flash point	D93	>130	132	℃
Fire point	-	-	146	℃
Heating value of B5	-	-	42.9926	kJ/kg
Heating value of B10	-	-	42.691	kJ/kg
Heating value of B15	-	-	42.4	kJ/kg
Heating value of B20	-	-	42.0835	kJ/kg

Table 5.1 gives the instruments used during biodiesel characterization. Table 5.2 compares the international standard and the experimental values which were obtained after characterization of the biodiesel using the instruments indicated in Table 5.1. The method which was used during properties determination is ASTM D6751 (or United States). In the table 5.2, the experimental values meet the international standard values which result the safety of biodiesel in this investigation. So, the biodiesel obtained in this study can be used in either I.C engine or in household applications. Which mean that, this biodiesel can be proceeded to the household wick/Butagas stove investigation either blended or in pure form. Next topics will show the cost

of biodiesel production, and the investigated cooking performance test protocols results of the pure biodiesel or pure kerosene or kerosene-biodiesel blends in wick/Butagas stove.

5.5 Cost of the biodiesel

The costs of the biodiesel are the amount of money wasted during biodiesel production. The amount of money expended during this output result is 1775 Ethiopian birr. The cost of biodiesel production is expensive. This may be because the biodiesel was not commercially extracted or produced.

5.6 Performance cooking test experimental results

The performance cooking test experimental results are the results obtained during fuels investigation in wick/Butagas stove using water boiling test (WBT), control cooking test (CCT), and kitchen performance test (KPT). The measured variables and the trials which have been done for all fuels investigation during this experiment were placed in appendix C. The tests were performed in different days, so the ambient temperature of the water and the stove may vary. In this study, the performance of the wick/Butagas stove for all fuels were compared. The averages of the trials were just taken as the calculated variables or the true results of the experiment investigated.

5.6.1 Water boiling Test (WBT)

The results obtained during water boiling test (WBT) for all fuels in wick/Butagas stove investigation were presented as a follow;

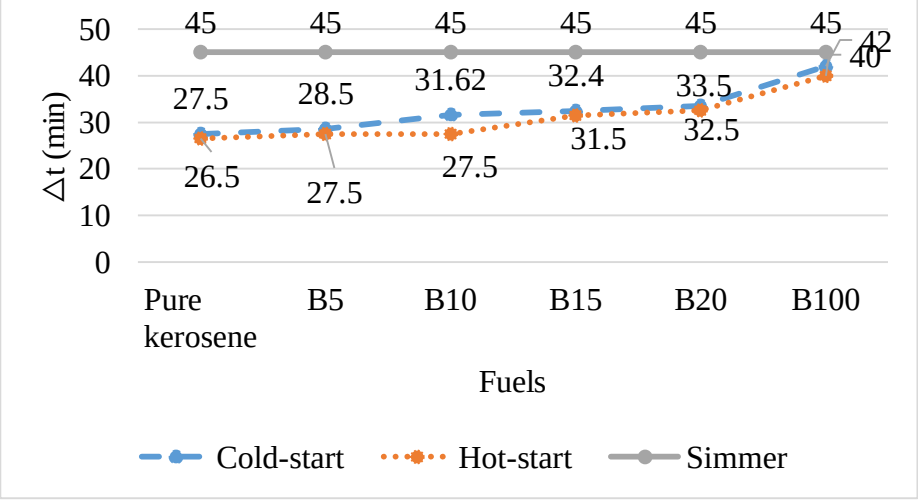


Figure 5.1: Phases duration/time taken (min) of the boiled water

As seen in Figure 5.1, the duration (time) of the water boiled increase as the percent of the blends of kerosene with biodiesel increase. This may be due to the decrease of volatility as the percentage of the biodiesel increases. Flame height also contributed to the delay of water boiling because each fuel has different flame height.

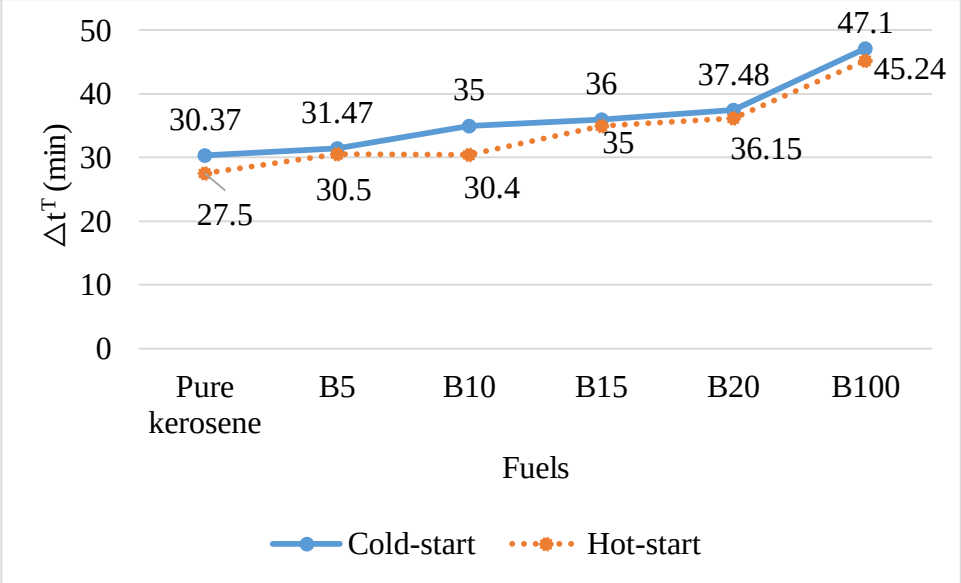


Figure 5.2: Temperature-corrected time to boil pot during investigation

As shown in figure 5.2, the temperature-corrected time to boil water increase to the same trend as of figure 5.1. From figure observation, there is no temperature-corrected time to boil for Simmer phase. This is because the test starts at the boiling temperature (T_b) as mentioned earlier in chapter four.

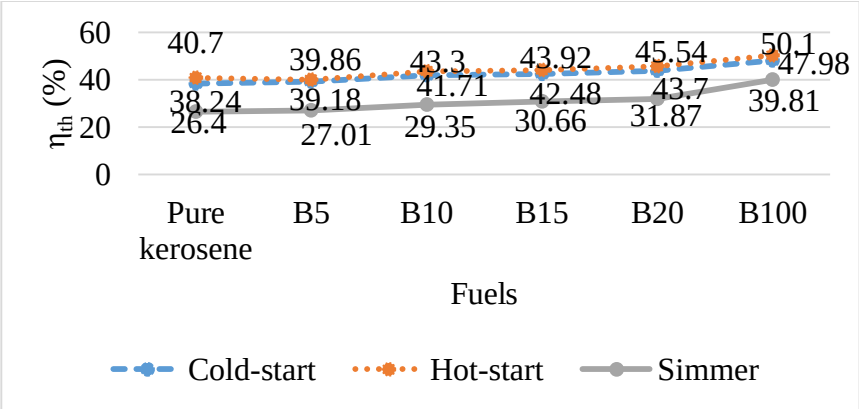


Figure 5.3: Thermal efficiency of each fuel in wick/Butagas stove based on energy output and energy input

In figure 5.3, the thermal efficiency of the fuels investigated increase by increasing the biodiesel percentage. This may be due to the high viscous of the fuel as the blend percent increase which results less transfer of the fuel through the wick. The complete combustion of the fuel when the biodiesel percent increase in the blend increase the thermal efficiency also. In B5, the thermal efficiency decrease, this is because the ambient temperature of the water increase during this investigation since the experiments was not done in the same day.

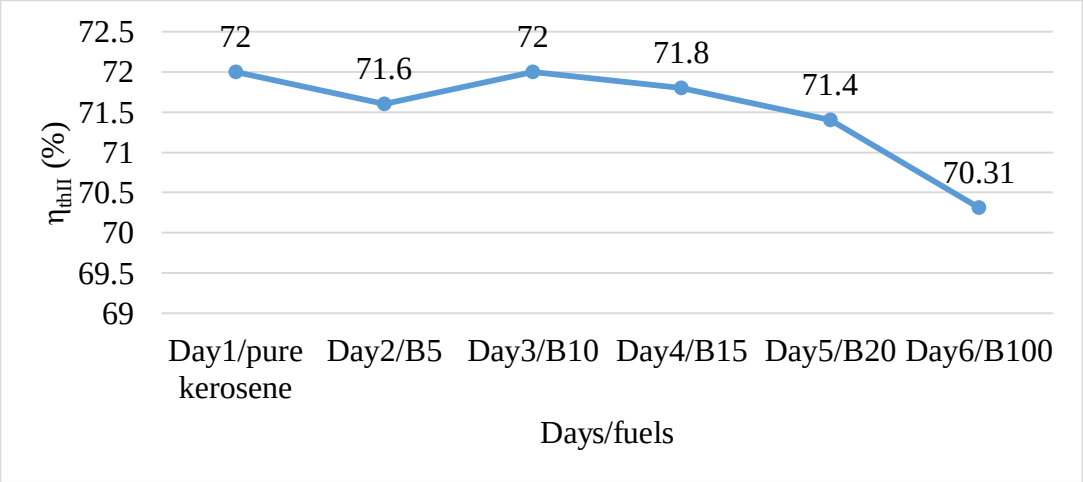


Figure 5.4: Second-law thermal efficiency of the stove

Figure 5.4, shows the second-law thermal efficiency of the stove. In this study, the ambient water temperature was assumed to be equal with Butagas stove ambient temperature and the Butagas stove final temperature was assumed to be equal with local boiling point temperature (Tb). Hence; as you see from the figure, the thermal efficiency of the stove is fluctuating from day1-day 4 and decreases from day5 and day6. This may be due to ambient stove temperature different since the investigation was done in different days.

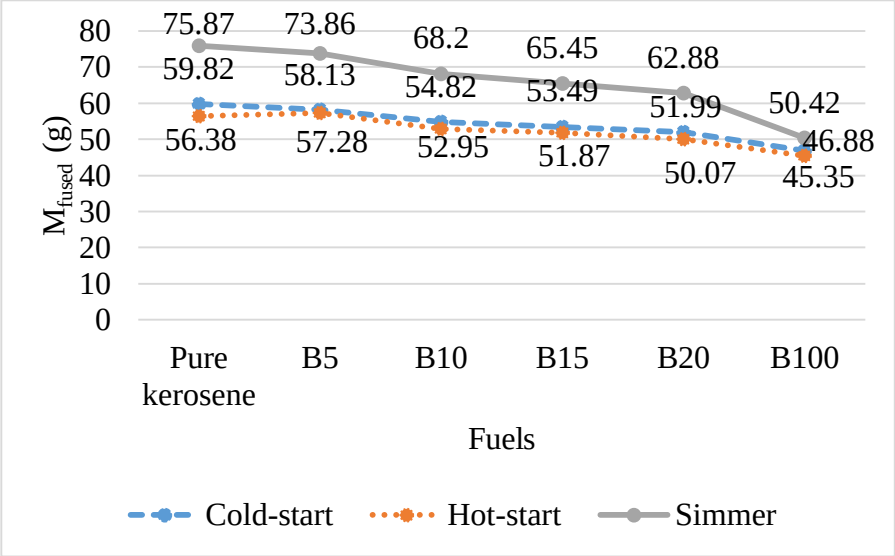


Figure 5.5: Mass of fuel used/consumed for each phase during fuel investigation

From figure 5.4, the fuel used/consumed during fuel investigation for each phase decrease by increasing the biodiesel percent during fuel blends. This may be because the transfer of the fuel through the wick reduce due to the high viscous when the biodiesel blend increase.

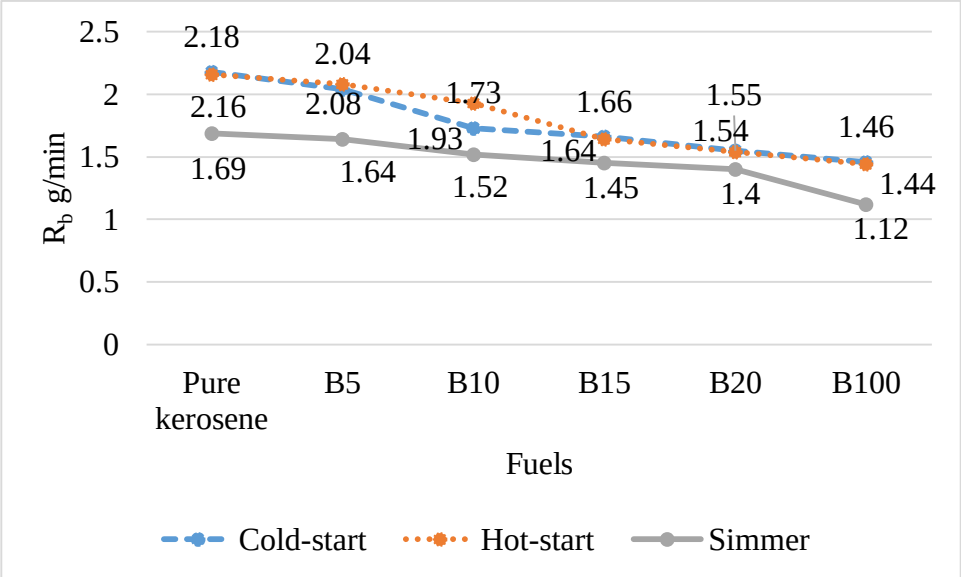


Figure 5.6: Burning rate of each fuel during each phase

From the figure shown above, the burning rate of the fuels for each phase decrease by increasing the biodiesel percent during blending. This may be due to the decrease of fuel consumption when the pure kerosene percent reduce as well as the time increments due to the

fuel transfer through the wick. As observed from the figure, B5 and B10 burning rate for cold-start and hot-start fluctuate, this may be due to the more less time taken during hot-start phase investigation.

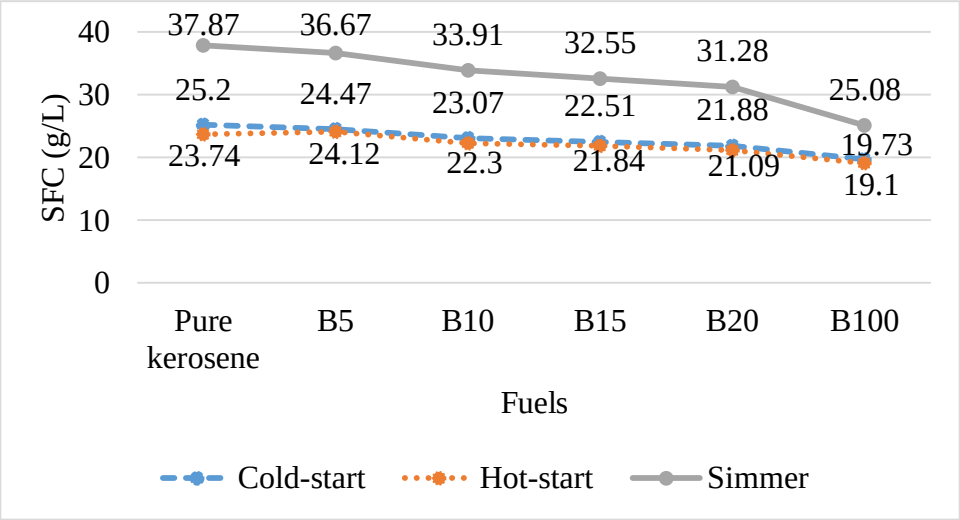


Figure 5.7: Specific fuel consumption for each fuel during phase investigation

As observed in the figure above, the specific fuel consumption decrease when the biodiesel percent increase during blending. This is because when the pure kerosene percent decrease, the specific fuel consumption also reduces due to the less transfer of the fuel through the wick since viscosity increase by increasing biodiesel percent during blends.

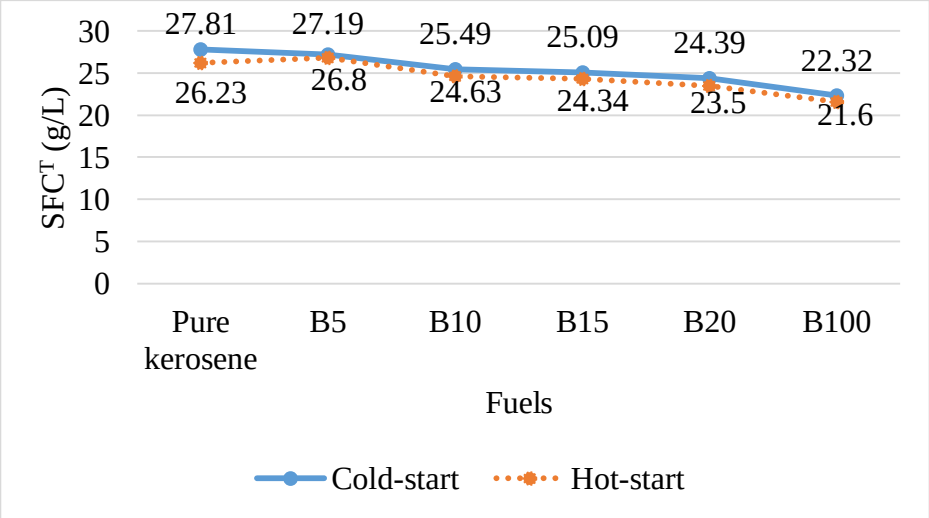


Figure 5.8: Temperature-corrected specific fuel consumption for each fuel

In this figure, the temperature-corrected specific fuel consumption decrease to the same cases mentioned in figure 5.6. Also there is no Simmering phase to the same cases in figure 5.2.

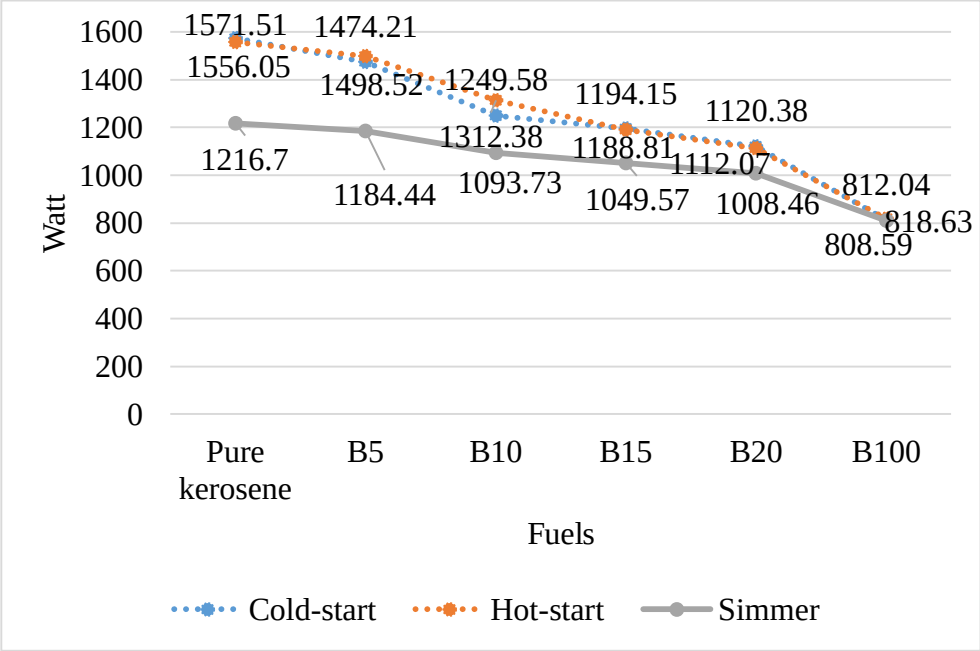


Figure 5.9: Firepower of each fuel during phase investigation

As you observed from the figure, the firepower decrease by increasing the biodiesel percentage increase. This may be due to the less fuel transfer through the wick which results less fuel consumption. In figure, B5 and B10 for cold-start and hot-start fluctuate, this may be due to the more decrease of time in hot-start phase.

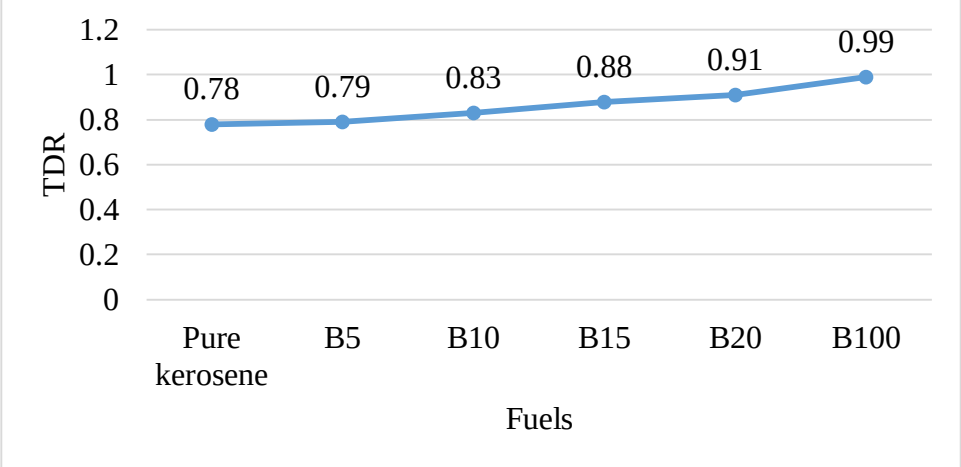
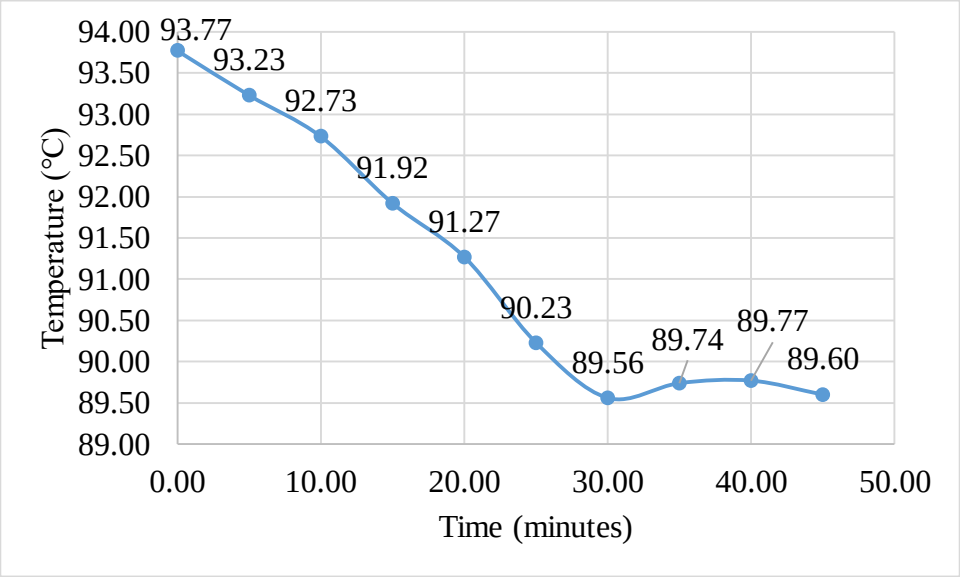
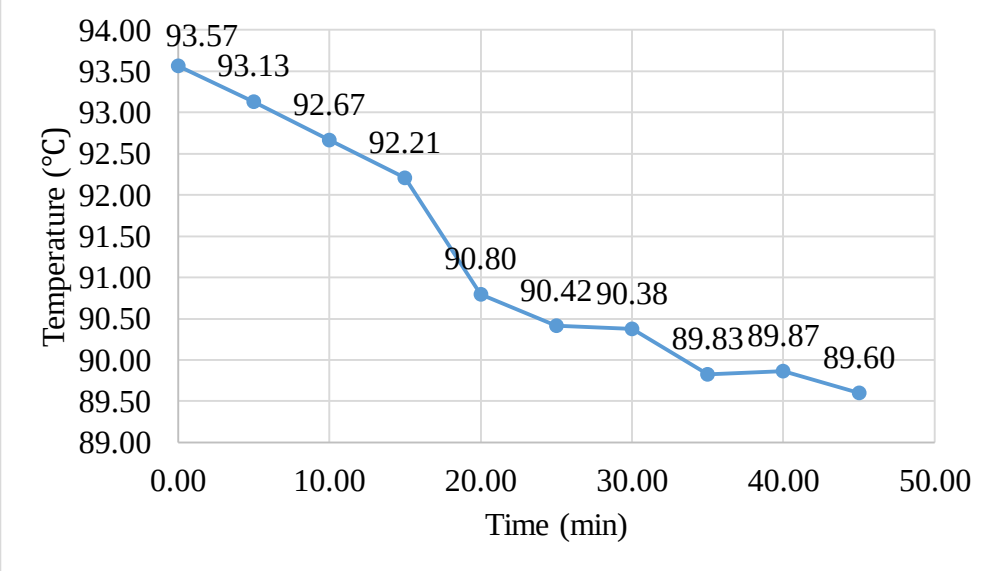


Figure 5.10: Turn-down ratio of each fuel during investigation

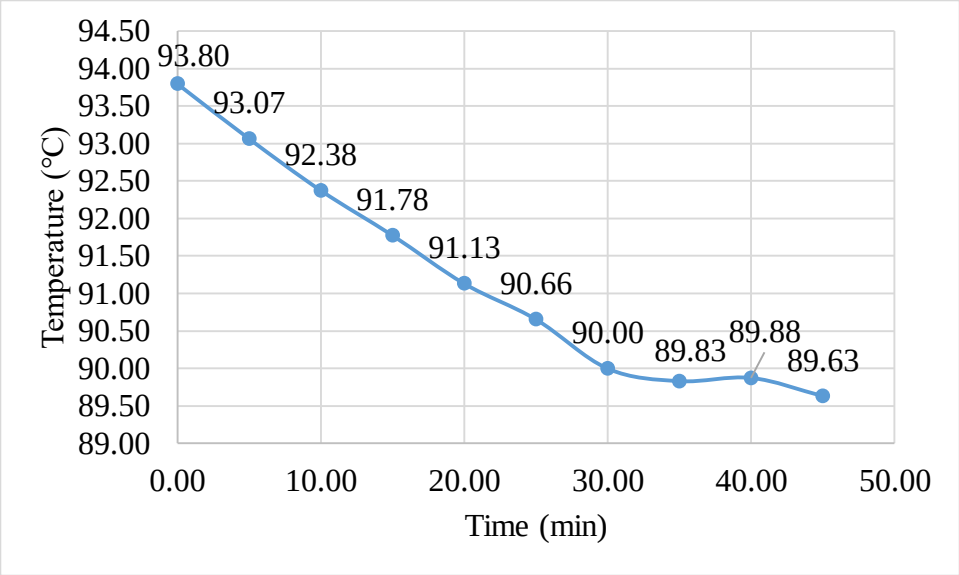
The turn-down ratio increases by reducing the percent of pure kerosene during blending. This may be due to the firepower decreases during fuel consumption in the stove.



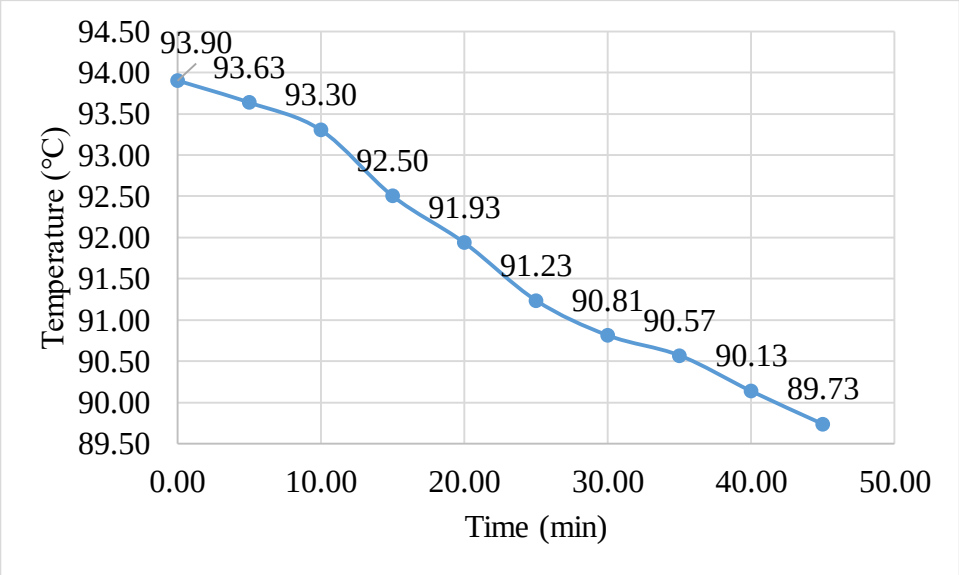
a) Pure kerosene Simmering



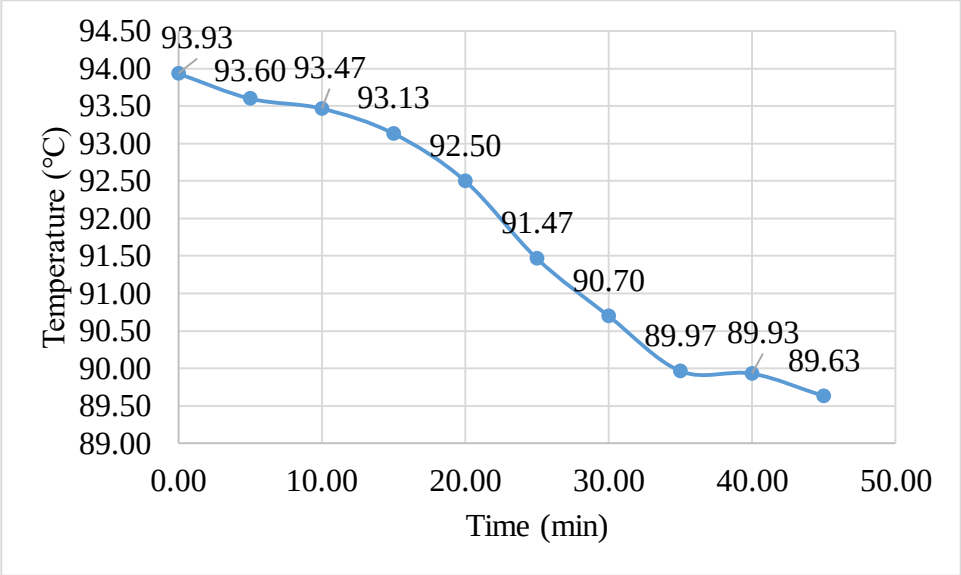
b) B5 Simmering



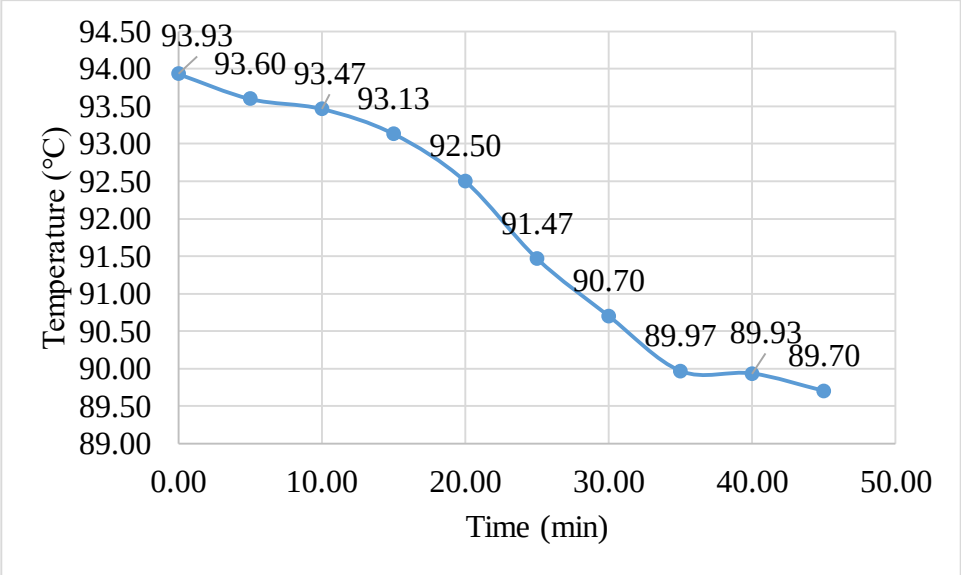
c) B10 Simmering



d) B15 Simmering



e) B20 Simmering



f) B100 Simmering

Figure 5.11: Temperature reduction for all fuels investigation in stove during Simmering

As you can see from figure 5.10a to figure 5.10f, the temperature for all fuels investigation during simmering phases is randomly decreasing and sometime fluctuate. This may be due to whether different during testing because experimental investigation was not done in the same days. During this experiment, the wick/Butagas stove stick valve was keep at maximum fire and the simmering was done by turning the valve down two times for all fuels investigation

since the valve itself could be off when it turned four times. Flame height also can contribute to random decrements of the temperature since each fuel has different flame height.

5.6.2 Control cooking test (CCT)

The control cooking test (CCT) results are the values obtained during six different fuels investigation when the local food chosen was cooked. The results here are presented in graph form. For more detail trails, see Appendix C. The following are the results obtained during fuels investigation;

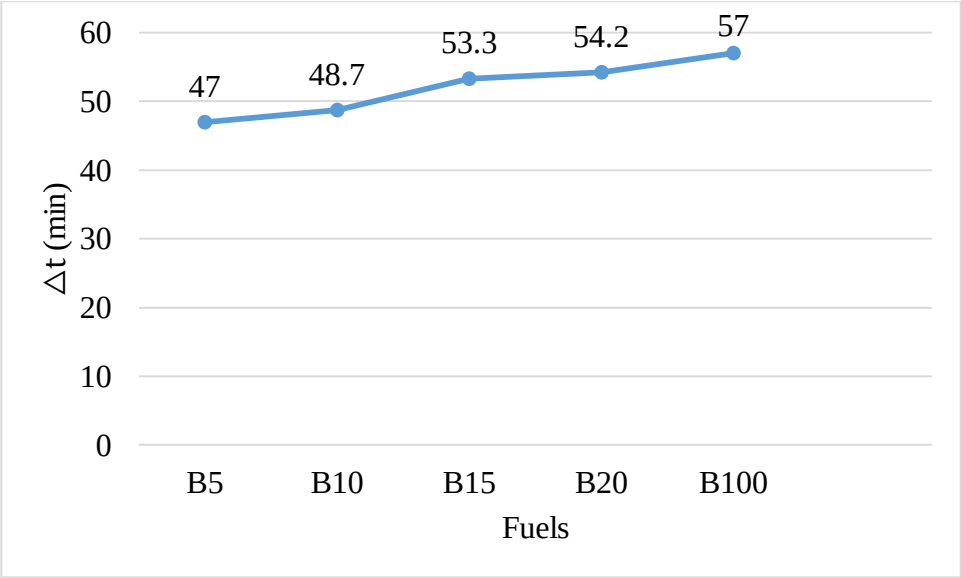


Figure 5.12: Duration of food cooked

As shown in figure 5.11, the duration (or time taken) during food cooking increase by increasing the biodiesel percent during the blends. This may be due to the less transfer of the fuel through the wick when the biodiesel percent increases. Also flame height different contribute to the delay of the cook.

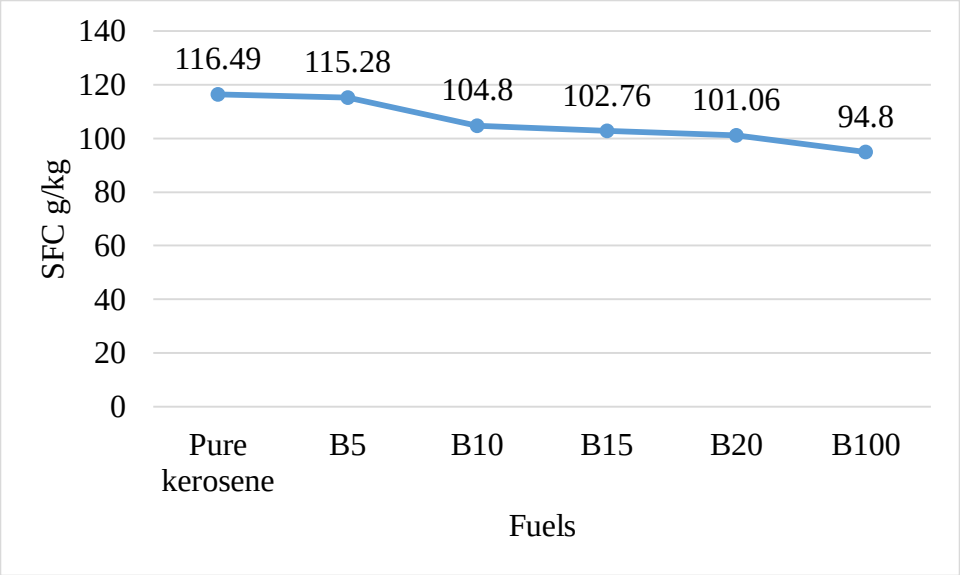


Figure 5.13: Specific fuel consumption during food cooking

As you can see from figure 5.12, the specific fuel consumption was recorded by grams of fuel consumed by kilogram of food cooked. In the figure above, the specific fuel consumption decrease by reducing the percent of pure kerosene. This may be due to the fact that, when the pure kerosene percent decreases then the fuel transfer through the wick also decreases.

5.6.3 Kitchen performance test (KPT)

The Kitchen performance test (KPT) results are the results obtained during fuels investigation in the stove and were recorded in the grams of fuel consumed per day. For more detail trails, please see Appendix C;

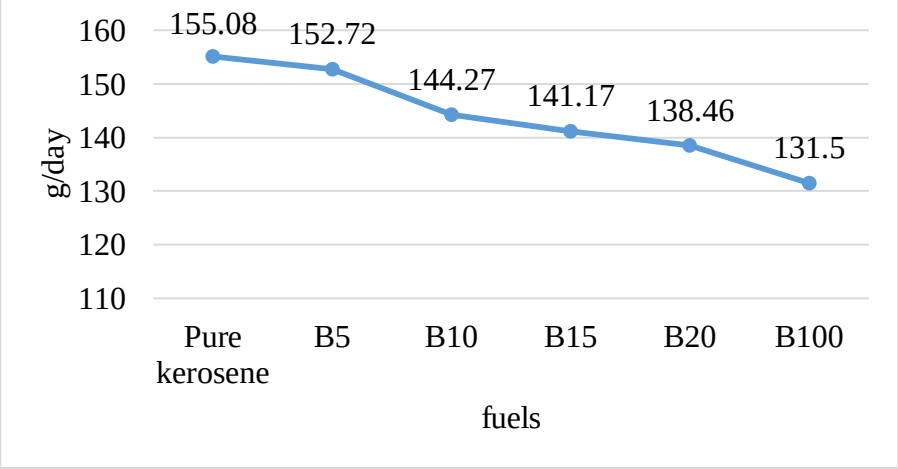
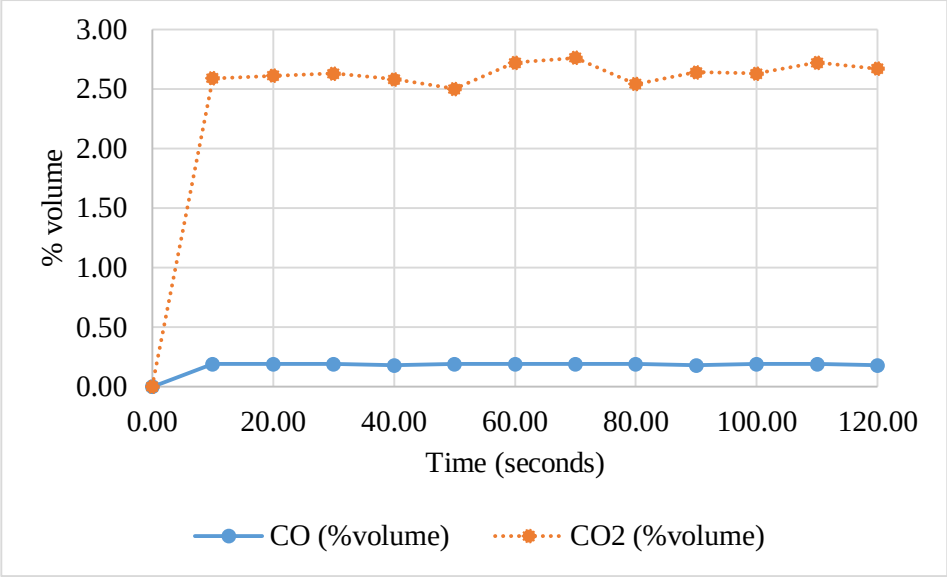


Figure 5.14: Specific fuel consumption per day during KPT

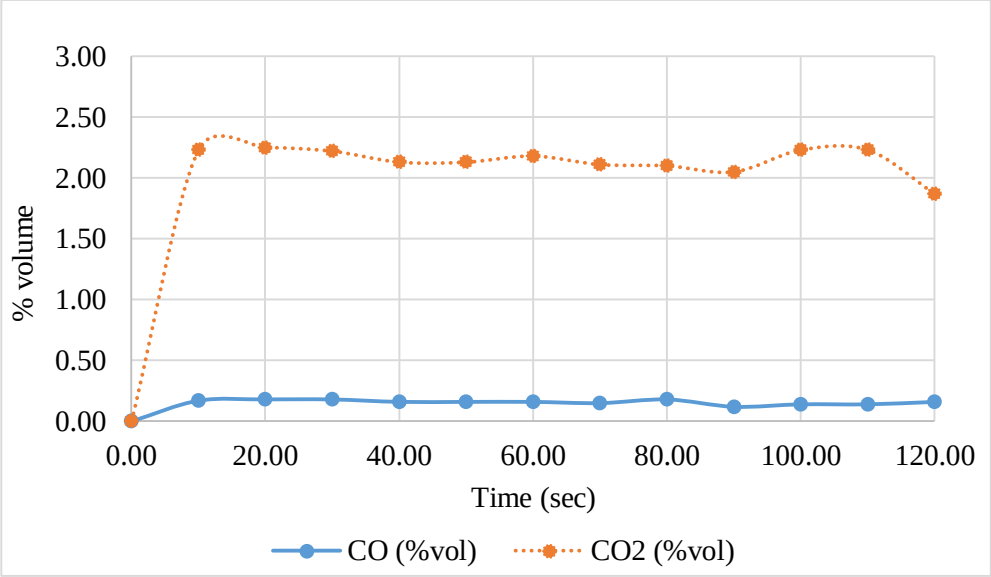
As you can see from the figure 5.13, the fuels consumed per day can decreases by decreasing the pure kerosene percent. This may be due to the same cases presented in figure 5.12.

5.7 Emission of CO and CO_2

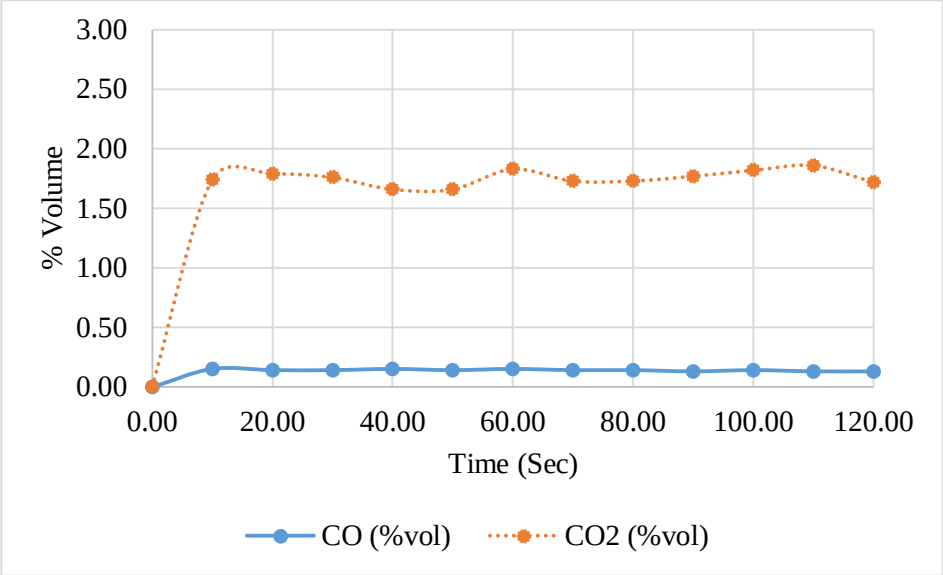
The emission characteristics of CO and CO_2 during stove exhaust system were recorded and presented by volume basis. The following figures shows the emission characters of CO and CO_2. For more detail trails, please see appendix C.



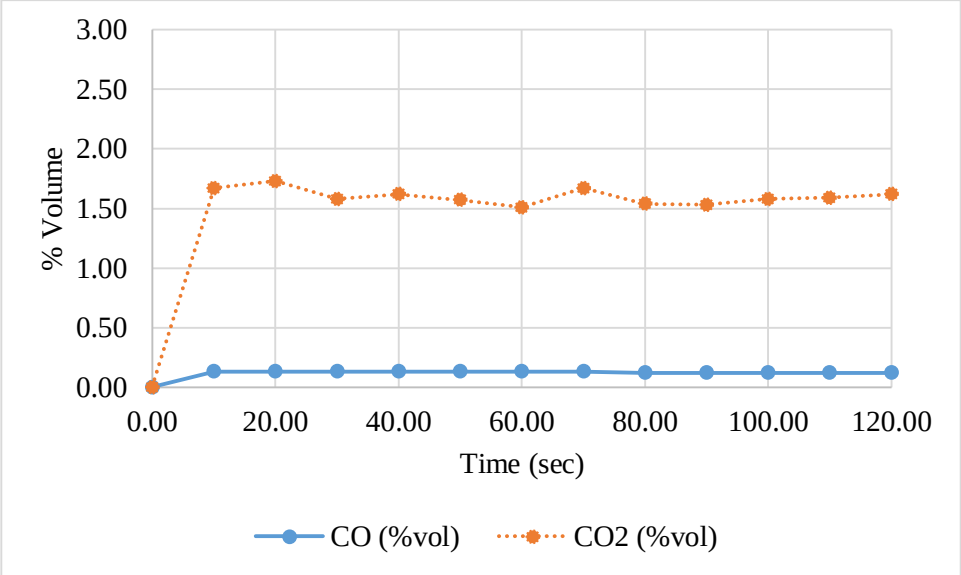
a) Pure kerosene emission



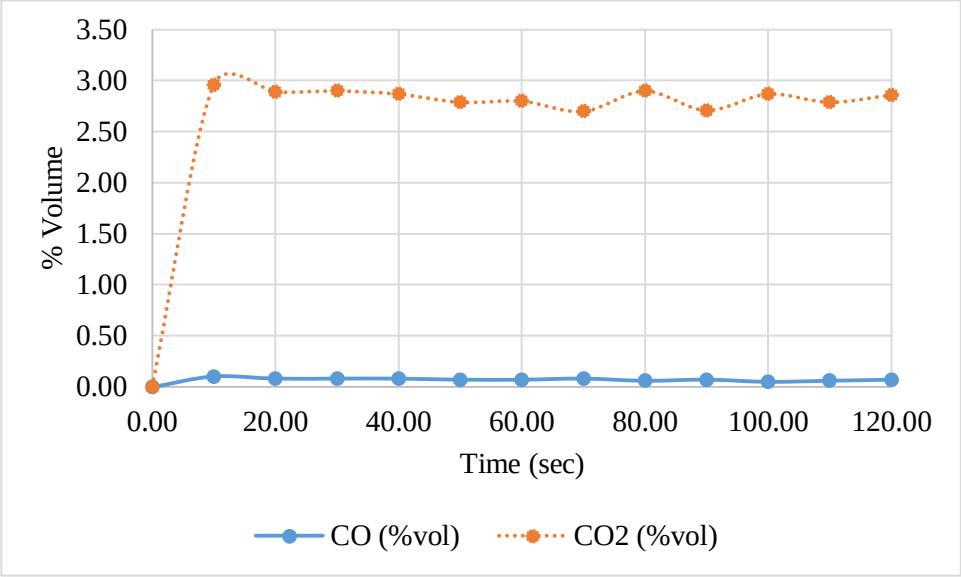
b) B5 emission



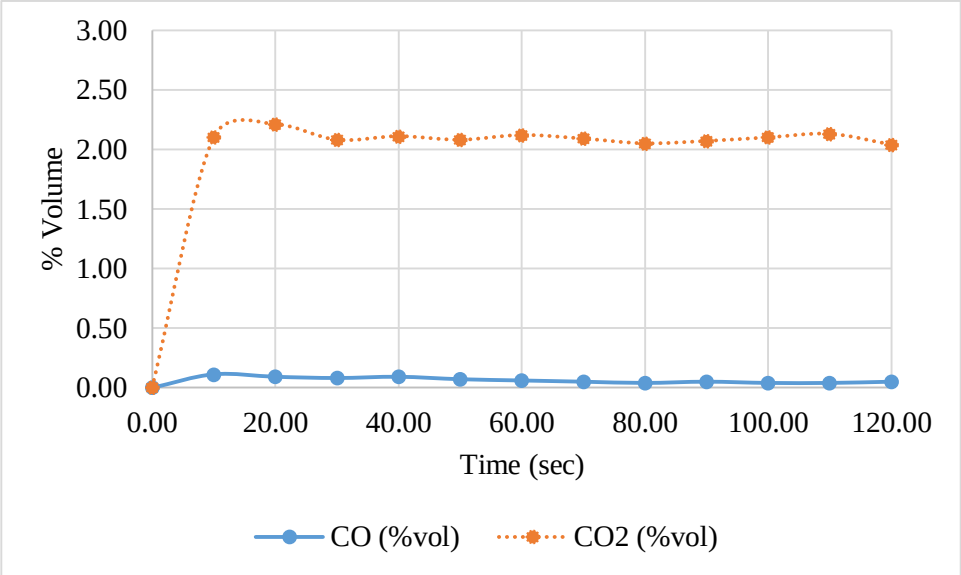
c) B10 emission



d) B15 emission



e) B20 emission



f) B100 emission

Figure 5.15: Fuel emission characteristics

As you observed from figure 5.14a to 5.14f, the emission soot of the exhaust decrease by increasing the percent of biodiesel when blended with kerosene. This may be due to the complete combustion and low volatility of the fuel when the biodiesel percent increases. In

B20 (or e) and B100 (or f), the CO2 increases more while that of CO decreases more. This may be due to the fact that, increasing biodiesel percent CO will decrease and that of CO2 will increase since biodiesel is more complete combustion than conventional kerosene.

5.8 Fuels combustion performance

The combustion performance which are presented here includes; heat of combustion (h_c in Kj/kg of fuel), first-law combustion efficiency (η_{cI} in %), chemical exergy ($\bar{a}_{ch}$ in Kj/kg of fuel), and second-law efficiency (η_{cII}). For more detail calculations, please see Appendix D. In this section, only determined values are presented.

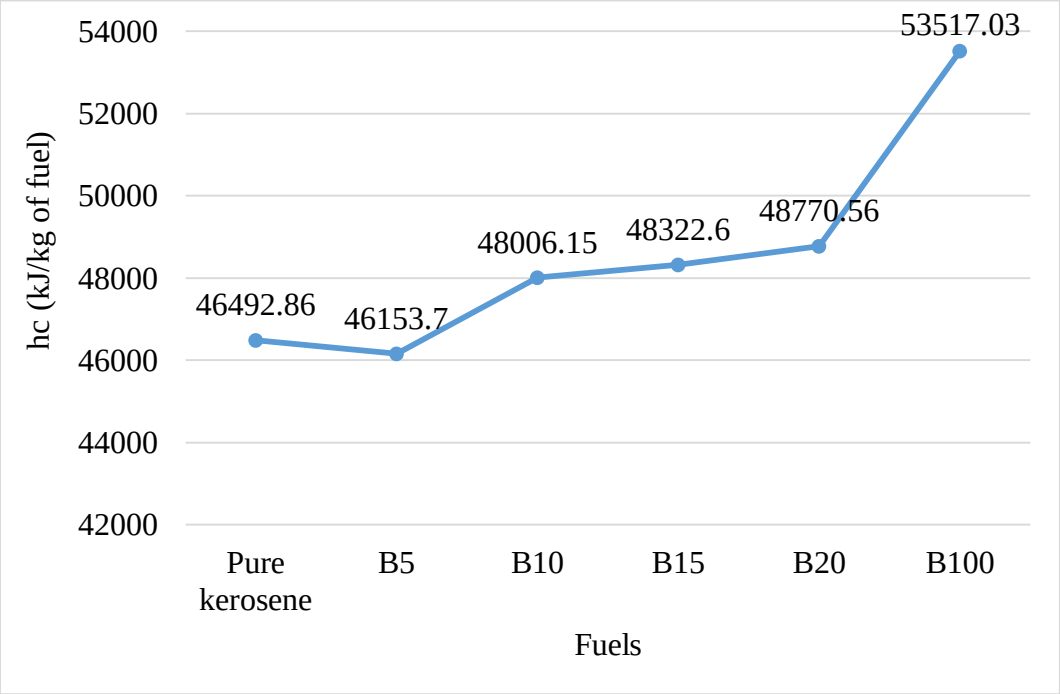


Figure 5.16: Heat of combustion of each fuel

As you see from figure 5.15, heat of combustion increases by increasing the biodiesel percent during the blend. This may be due to the fact that; biodiesel is more combustible than those of conventional petroleum products.

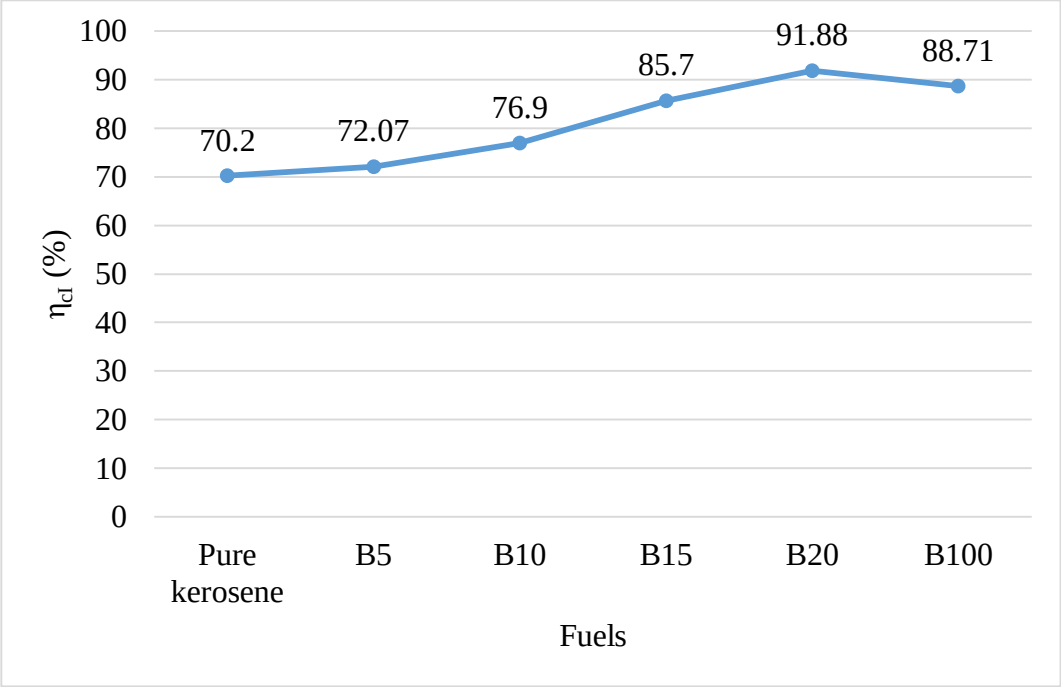


Figure 5.17: First-law combustion efficiency of each fuel

As shown in figure 5.16; the combustion efficiency increase by reducing the pure kerosene percent. This is because when the kerosene percent reduce then the combustion will increase. As in B20 and B100 the reason is the deficient of air in B100 and that is why the combustion efficiency in B100 reduce.

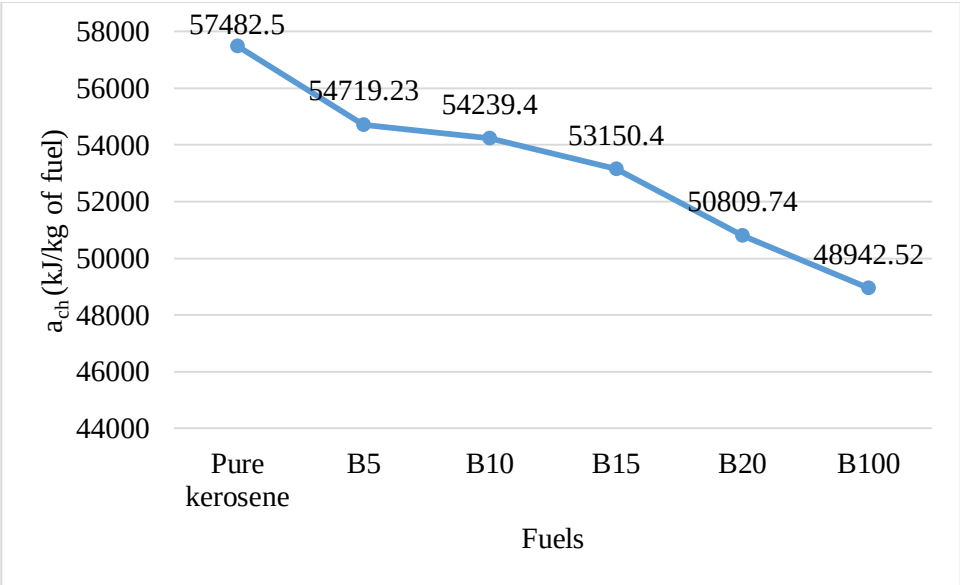


Figure 5.18: Chemical exergy of each fuel

As you see in figure 5.17; the chemical exergy reduces by increasing the percent of biodiesel during the blend. This may be due to the fact that; when we increase the biodiesel percent in the blend then the chemical exergy which will be added to the environment will reduce. Which means biodiesel fuel is an environmental friendly compared to kerosene.

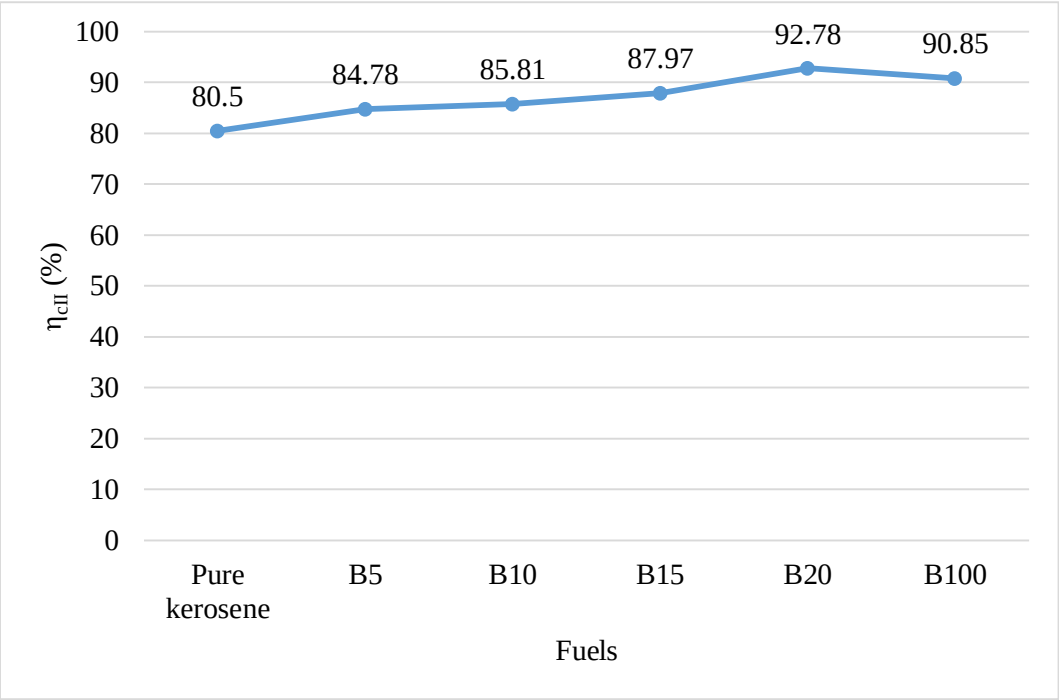


Figure 5.19: Second-law combustion efficiency of each fuel

As you see in figure 5.18, the second-law combustion efficiency increase by reducing pure kerosene percent during the blend. This may be due to the same cases in figure 5.16. Also B100 combustion efficiency reduce to the same case in figure 5.16.

CHAPTER SIX

6. Conclusions and Recommendations

6.1 Conclusions

In this thesis, thermal and combustion performance of biodiesel extracted from waste cooking sunflower oil was combusted on a wick stove with blending and without blending it with kerosene. Catalytic extraction procedure using KOH was used to obtain biodiesel using transesterification process. The extracted biodiesel was characterized using ASTM procedure. The thermal and combustion performances of pure biodiesel and its blend with kerosene were tests using the three phases of water boiling tests (cold start, hot start and simmering); controlled cooking test and kitchen performance test using the biodiesel and its blend as alternative fuel for wick stoves known as Butagas. Based on the study findings the following conclusions were drawn:

The biodiesel feed stocks, production of biodiesel from waste cooking oil and the use of biodiesel in domestic are reviewed. Some of the physicochemical parameters were measured according to ASTM methods. Most of the analyzed biodiesel properties results were closer to diesel fuel. There are few biodiesel samples not meeting the standard but it did not significantly affect the performance of fuel properties. The yield of biodiesel obtained from waste cooking oil was found as 92.5% before purified and 91.86% after purified and the washing of biodiesel was washed three times. The major physicochemical properties of waste cooking oil make it an attractive alternative application of the existing feed stocks for biodiesel production in Ethiopia. From cooking test protocols experimental results, we observed that pure biodiesel and kerosene-biodiesel blend operation results in higher thermal efficiency as compared to the pure kerosene. This may be due to the presence of oxygen in the molecular structure of the biodiesel which results in better combustion of the fuel. Since the kerosene operation produces more soot emission, it results in higher fuel consumption and lower thermal efficiency. This may be due to less volatility of the (B5, B10, B15, B20 and B100). The CO and CO_2 opacity of the wick stove with pure kerosene is higher than that of kerosene-biodiesel blend and B100. This may be due to the better combustion of the pure biodiesel and kerosene-biodiesel blend which results in lower soot emission.

Thus, biodiesel can be considered as feasible alternative substitution fuel for kerosene in household with little modification of the stoves or by settling the wick in the pure biodiesel fueled wick stove and kerosene-biodiesel blends (from B5-B20) can be used in the stove without any modification. Biodiesel derived from waste cooking oil is an acceptable for use as an alternative in household stoves when we modify the stove by settled wick in it or blended with kerosene. Hence fuel economy can be achieved by the use of pure biodiesel and kerosene-biodiesel blend.

6.2 Recommendations

According to the experience gained from this study, several items can be improved with immediate action as follows:

- Standardization of the treatment of waste oil before extraction biodiesel from it and determinations of the biodiesel properties using different international standard could be further researched in order to know the safety and effective use of the biodiesel in IC engine such as generators or vehicles.
- In application of pure biodiesel (B100) for cooking blending should be needed to improve the fuel flow quality for ease of combustion.
- Without any modification of the stove, B5, B10, B15 & B20 can be used in household cooking activities stove application for health promotion.
- B100 should not be used in household application since modification on the design of stove combustion mechanism is needed.
- In general, this alternative fuel (B5-B100) can be used in domestic cooking application that would help reduce the scarcity of the conventional kerosene and to bring wick/Butagas back into service.
- Further research on the use of pure biodiesel for cooking application on newly developed cook stoves with atomized or droplet combustion system design is recommended

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Appendix A: Some definitions in the study

Waste cooking oil: - It is an oil obtained after food (chips, samosa, qoqor, boblino, breads, fish etc.) frying/cooking by street and hotels vendor's.

Waste cooking oil filtration: - This is the process of removing unwanted impurity from waste cooking oil by filtering the oil.

Waste cooking oil heating: - This is the process of removing the moisture content of the waste cooking oil by heating the oil.

Transesterification: - This is the process of converting waste cooking oil into biodiesel (or diesel fuel from biological source) by mixing the waste cooking oil with methanol (or alcohol) and catalyst (or to speed up the reaction).

Biodiesel: - This is a fuel obtained from biological sources (such as; waste cooking oil, pure vegetables oil, animal fats and fish fats).

Pure kerosene: - This is a conventional fuel obtained after refining petroleum next to gasoline and without mixed with any other fuel.

Biodiesel-kerosene blend: - This is the process of mixing biodiesel and pure kerosene.

Wick/Butagas stove: - This is a stove in which wick/cottons insert in it and used by householder cook their food or prepare tea with it when fueled by kerosene.

Water boiling test (WBT): - This is a test conducted during boiling some amount of water to determine thermal efficiency of the stove.

Control cooking test (CCT): - This is a test conducted after identified local meal/food and after WBT to determine the duration of cooking and fuel consumed/used during cooking.

Kitchen performance test (KPT): - This is a test conducted after CCT and can be identified by investigated the fuel consumed/used per daily or monthly or yearly.

Appendix B: ASTM and EN 14214 International standard of biodiesel

Biodiesel Standard ASTM D6751

Property	Test method	Limits	Units
Flash point (closed cup)	D 93	93 min	°C
Alcohol control. One of the following must be met:			
1. Methanol content	EN 14110	0.2 max	% volume
2. Flash point	D 93	130 min	130 min
Water and sediment	D 2709	0.050 max	% volume
Kinematic viscosity, 40 °C	D 445	1.9-6.0	mm^2 / s
Sulfated ash	D 874	0.020 max	% mass
Sulfur	D5453	0.05 or 0.0015 max [a]	% mass
Copper strip corrosion	D 130	No. 3 max	
Cetane number	D 613	47 min	
Cloud point	D 2500	Report	°C
Carbon residue	D 4530	0.050 max	% mass
Acid number	D 664	0.50 max	mg KOH / g
Free glycerin	D 6584	0.020	% mass
Total glycerin	D 6584	0.240	% mass
Phosphorus content	D 4951	0.001 max	% mass
Distillation temperature, Atmospheric equivalent temperature, 90% recovered	D 1160	360 max	°C
Sodium and potassium, combined	EN 14538	5 max	ppm (µg/g)
Calcium and magnesium, comb.	EN 14538	5 max	ppm (µg/g)
Oxidation stability	EN 15751	3 min	hours
Cold soak filterability	D7501	360 max	sec

a) The limits are for Grade S15 and Grade S500 biodiesel, respectively. S15 and S500 refer to maximum sulfur specifications (ppm).

Biodiesel Standard EN 14214

Property	Test method	Limits	Units
Ester content	EN 14103	96.5 min	% (m/m)
Density; 15°C	EN ISO 3675, 12185	860-900	kg/m^3
Viscosity, 40 °C	EN ISO 3104, ISO 3105	3.5-5.0	mm^2/s
Flash point	EN ISO 2719, 3679	101 min	°C
Sulfur content	EN ISO 20846, 20884	10.0 max	mg/kg
Carbon residue (10% dist. res.)	EN ISO 10370	0.30 max	% (m/m)
Cetane number	EN ISO 5165	51 min	
Sulfated ash	ISO 3987	0.02 max	% (m/m)
Water content	EN ISO 12937	500 max	mg/kg
Total contamination	EN 12662	24 max	mg/kg
Copper strip corrosion (3h, 50°C)	EN ISO 2160	1	
Oxidative stability, 110 °C	EN 14112, 15751	8.0 min	h
Acid value	EN 14104	0.50 max	mg KOH / g
Iodine value	EN 14111	120 max	g iodine /100g
Linolenic acid content	EN 14103	12 max	%(m/m)
Content of FAME with ≥ 4 double bonds		1 max	% (m/m)
Methanol content	EN 14110	0.20 max	% (m/m)
Monoglyceride content	EN 14105	0.80 max	% (m/m)
Diglyceride content	EN 14105	0.20 max	% (m/m)
Triglyceride content	EN 14105	0.20 max	%(m/m)
Free glycerine	EN 14105, 14106	0.02 max	%(m/m)
Total glycerine	EN 14105	0.25max	%(m/m)
Alkali metals (Na + K)	EN 14108, 14109, 14538	5.0 max	mg/kg
Earth alkali metals (Ca + Mg)	prEN 14538	5.0 max	mg/kg
Phosphorus content	EN 14107	4.0 max	mg/kg

Appendixes C: Fuels investigation variables

The performance test protocol variables of each fuel investigated and determined with trials are in sub-appendix C. The averages were the determined variables presented in chapter 5.

Appendix C.1: pure kerosene investigation determined

Name of the test	kerosene			
Test number	1	**Location**	Adama city	
Date	4/3/2022	**Fuel species**	Pure kerosene	
Stove type/model	Butagas/model 62	**Wind condition**	Normal	
Latent heat of evaporation (hfg) at 94.3 ℃	2,260 kj/kg			
Air temperature	24.6 ℃	**Specific heat of water (Cpw)**	4.18 kj/kg.℃	
Average fuel dimension	400 millileter			
Weight of empty pot	254.45 g	**Local boiling point**	94.3 ℃	
Weight of stove	784.15 g			

Appendix C.1.1: Water boiling test (WBT)

WBT Test 1		**High power test (Cold-start)**			
		Start		**end when water boil**	
Measurement	**Unit**	**Data**	**Label**	**Data**	**Label**
Time	min	5:04:00	tci	5:31:30	tcf
Weight of fuel	g	337.55	Mcfi	278.45	Mcff
Water temperature	℃	26.4	Tcwi	93.7	Tcwf
Weight of water	g	2500	Mcwi	2375.69	Mcwf

High power test (Hot-start)			
Start		**end when water boil**	
Data	**Label**	**Data**	**Label**
5:32:00	thi	5:58:00	thf
278.45	Mhfi	221.15	Mhff
26.4	Thwi	93.8	Thwf
2500	Mhwi	2374.2	Mhwf

Low power test (Simmering)			
Start		**end when water boil: 45 minutes**	
Data	**Label**	**Data**	**Label**
5:58:30	tsi	6:43:30	tsf
221.15	Msfi	145.55	Msff
93.8	Tswi	89.4	Tswf
2374.2	Mswi	2010.54	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϫt	min	0:27:30	0:26:00	0:45:00
ϫtT	min	0:30:37	0:28:52	
Mwr	g	2375.69	2374.2	2010.54
ηth	%	38.7	40.05	26.44
Mfused	g	59.1	57.3	75.6
Rb	g/min	2.15	2.20	1.68
Mwv	g	124.31	125.8	363.66
SFC	g/L	24.9	24.13	37.6
SFCT	g/L	27.48	26.66	
FP	W	1550.93	1590.44	1212.4
TDR	no			0.76

WBT Test 2		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	6:44:00	tci	7:12:30	tcf
Weight of fuel	g	337.55	Mcfi	277.84	Mcff
Water temperature	℃	26.4	Tcwi	93.9	Tcwf
Weight of water	g	2500	Mcwi	2375.63	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
7:13:00	thi	7:38:30	thf	7:39:00	tsi	8:24:00	tsf
277.84	Mhfi	221.6	Mhff	221.6	Msfi	145.2	Msff
26.4	Thwi	93.5	Thwf	93.5	Tswi	89.6	Tswf
2500	Mhwi	2374.7	Mhwf	2374.7	Mswi	2010.61	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
△t	min	0:28:30	0:25:30	0:45:00
$\triangle t^T$	min	0:31:45	0:28:20	
Mwr	g	2375.63	2374.7	2010.61
ηth	%	38.32	40.77	26.36
Mfused	g	59.71	56.24	76.4
Rb	g/min	2.10	2.21	1.70
Mwv	g	124.37	125.3	364.09
SFC	g/L	25.13	23.68	38.00
SFC^T	g/L	27.76	26.16	
FP	W	1511.95	1591.63	1225.23
TDR	no			0.77

WBT Test 3		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	8:25:00	tci	8:51:30	tcf
Weight of fuel	g	337.55	Mcfi	276.9	Mcff
Water temperature	℃	26.4	Tcwi	94	Tcwf
Weight of water	g	2500	Mcwi	2375.72	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
8:52:00	thi	9:19:00	thf	9:19:30	tsi	10:04:30	tsf
276.9	Mhfi	221.3	Mhff	221.3	Msfi	145.7	Msff
26.4	Thwi	93.5	Thwf	94	Tswi	89.8	Tswf
2500	Mhwi	2374.1	Mhwf	2374.1	Mswi	2011.63	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϰt	min	0:26:30	0:27:00	0:45:00
ϰtT	min	0:29:30	0:29:43	
Mwr	g	2375.72	2374.1	2011.63
ηth	%	37.71	41.29	26.36
Mfused	g	60.65	55.6	75.6
Rb	g/min	2.29	2.06	1.68
Mwv	g	124.28	125.9	362.47
SFC	g/L	25.53	23.42	38.00
SFCT	g/L	28.20	25.87	
FP	W	1651.66	1486.10	1212.40
TDR	no			0.82

Averages variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϰt	min	0:27:30	0:26:30	0:45:00
ϰtT	min	0:30:37	0:27:50	
Mwr	g	2375.68	2374.33	2010.93
ηth	%	38.24	40.70	26.40
Mfused	g	59.82	56.38	75.87
Rb	g/min	2.18	2.16	1.69
Mwv	g	124.32	125.7	363.4
SFC	g/L	25.20	23.74	37.87
SFCT	g/L	27.81	26.23	
FP	W	1571.51	1556.05	1216.70
TDR	no			0.78

Appendix C.1.2: Control cooking test (CCT)

Control cooking test (CCT)						
	Test1		Test2		Test3	
Measured variables	start	end	start	end	start	end
time of boiling water (min)	10:10:00	10:25:30	11:00:00	11:16:00	11:50:00	12:06:00
time of rice cooking (min)	10:25:30	10:56:00	11:16:00	11:45:30	12:06:00	12:36:00
initial&final Mass of fu1 l (g)	145.55	105.24	154.2	104.82	145.7	106.7
Mass of water (g)	1000		1000		1000	
Mass of food (g)	500	846.1	500	855.2	500	847.8
initial &finalMass of fuel2 (g)	105.24	50.6	104.82	48.7	106.7	49.2

Calculated variables	Test1	Test2	Test3	Average
Ⱬtboiledwater	0:15:30	0:16:00	0:16:00	16.00
Ⱬtricecooked	0:30:30	0:29:30	0:30:00	30.00
Mfused1	40.31	49.38	39	42.90
Mfc	846.1	855.2	847.8	849.70
Mfused2	54.64	56.12	57.5	56.09

Averages variables		
Time of cooking (△t)	min	46
M_{fused} total	g	98.98
SFC	g/kg	116.49

Appendix C.1.3: Kitchen performance test (KPT)

Kitchen performance test (KPT)		
Measured	unit	Values
Mfused1	g/day	42.90
Mfused2	g/day	56.09
Mfused3	g/day	56.09
Total	g/day	155.08

Appendix C.1.4: Emission characteristic of pure kerosene in wick/Butagas stove

Pure kerosene	CO (%volume)				CO2 (%volume)			
Time (sec)	Test1	Test2	Test3	Average	Test1	Test2	Test3	Average
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	0.18	0.19	0.19	0.19	2.59	2.70	2.48	2.59
20.00	0.19	0.18	0.19	0.19	2.44	2.72	2.66	2.61
30.00	0.20	0.19	0.18	0.19	2.35	2.88	2.65	2.63
40.00	0.18	0.18	0.19	0.18	2.45	2.61	2.67	2.58
50.00	0.18	0.19	0.20	0.19	2.48	2.37	2.66	2.50
60.00	0.19	0.19	0.19	0.19	2.82	2.69	2.64	2.72
70.00	0.18	0.18	0.19	0.19	2.86	2.71	2.70	2.76
80.00	0.18	0.18	0.20	0.19	2.44	2.45	2.72	2.54
90.00	0.19	0.18	0.18	0.18	2.62	2.63	2.68	2.64
100.00	0.18	0.19	0.19	0.19	2.64	2.61	2.63	2.63
110.00	0.18	0.20	0.20	0.19	2.66	2.70	2.81	2.72
120.00	0.17	0.19	0.20	0.18	2.48	2.71	2.82	2.67

Appendix C.1.5: Pure kerosene simmer

Pure kerosene simmer				
Simmer	Temperature (℃)			
Time (min)	Test1	Test2	Test3	Average
0.00	93.80	93.50	94.00	93.77
5.00	92.60	93.20	93.90	93.23
10.00	91.50	92.90	93.80	92.73
15.00	90.70	92.60	92.45	91.92
20.00	90.20	91.80	91.80	91.27
25.00	89.80	91.10	89.80	90.23
30.00	89.60	89.36	89.71	89.56
35.00	89.80	89.80	89.62	89.74
40.00	89.70	89.70	89.90	89.77
45.00	89.40	89.60	89.80	89.60

Appendix C.2: B5 investigation in wick/Butagas stove

Appendix C.2.1: Water boiling test (WBT)

Name of the test	**kerosene-biodiesel blend (B5)**							
Test number	2			**Location**	Adama city			
Date	5/3/2022			**Fuel species**	B5			
Stove type/model	Butagas/model 62			**Wind condition**	Normal			
Latent heat of evaporation (hfg) at 94.3 ℃ (kj/kg)				2,260				
Air temperature (℃)	24.2			**Specific heat of water (Cpw)**			4.18kj/kg. ℃	
Average fuel dimension	400 millileter							
Weight of empty pot(g)	254.45			**Local boiling point (℃)**			94.3	
Weight of stove (g)	784.15							
WBT Test 1		**High power test (Cold-start)**						
		Start				**end when water boil**		
Measurement	**Unit**	**Data**	**Label**			**Data**	**Label**	
Time	min	4:35:00	tci			5:05:00	tcf	
Weight of fuel	g	338.65	Mcfi			280.14	Mcff	
Water temperature	℃	26.8	Tcwi			93.5	Tcwf	
Weight of water	g	2500	Mcwi			2375.98	Mcwf	
High power test (Hot-start)					**Low power test (Simmering)**			
Start		**end when water boil**			**Start**		**end when water boil: 45 minutes**	
Data	**Label**	**Data**	**Label**		**Data**	**Label**	**Data**	**Label**
5:05:30	thi	5:35:00	thf		5:35:30	tsi	6:20:30	tsf
280.14	Mhfi	224.1	Mhff		224.1	Msfi	147.52	Msff
26.8	Thwi	93.4	Thwf		93.4	Tswi	89.7	Tswf
2500	Mhwi	2374.86	Mhwf		2374.86	Mswi	2016.84	Mswf
Calculated variables	**Unit**	**High power (Cold-start)**		**High power (Hot-start)**				**Low power (Simmering)**
ɤt	min	0:30:00		0:29:30				0:45:00
ɤtT	min	0:33:23		0:32:52				
Mwr	g	2375.98		2374.86				2016.84
ηth	%	38.91		40.72				25.78
Mfused	g	58.51		56.04				76.58
Rb	g/min	1.95		1.90				1.70
Mwv	g	124.02		125.14				358.02
SFC	g/L	24.63		23.60				37.97
SFCT	g/L	27.36		26.22				
FP	W	1407.49		1370.92				1228.12
TDR	no							0.90

WBT Test 2		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	6:22:00	tci	6:50:30	tcf
Weight of fuel	g	338.65	Mcfi	280.26	Mcff
Water temperature	℃	26.8	Tcwi	93.9	Tcwf
Weight of water	g	2500	Mcwi	2375.51	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
6:51:00	thi	7:18:00	thf	7:18:30	tsi	8:03:30	tsf
280.26	Mhfi	222.41	Mhff	222.41	Msfi	149.32	Msff
26.8	Thwi	93.6	Thwf	93.6	Tswi	89.7	Tswf
2500	Mhwi	2374.71	Mhwf	2374.71	Mswi	2012.87	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϫt	min	0:28:30	0:27:00	0:45:00
ϫtT	min	0:31:42	0:30:00	
Mwr	g	2375.51	2374.71	2012.87
ηth	%	39.03	39.46	27.44
Mfused	g	58.39	57.85	73.09
Rb	g/min	2.05	2.14	1.62
Mwv	g	124.49	125.29	361.84
SFC	g/L	24.58	24.36	36.31
SFCT	g/L	27.31	27.07	
FP	W	1478.53	1546.24	1172.15
TDR	no			0.76

WBT Test 3		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	8:04:00	tci	8:31:00	tcf
Weight of fuel	g	338.65	Mcfi	281.16	Mcff
Water temperature	℃	26.8	Tcwi	93.2	Tcwf
Weight of water	g	2500	Mcwi	2375.87	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	**Label**	**Data**	**Label**	**Data**	**Label**	**Data**	**Label**
8:31:30	thi	8:58:00	thf	8:58:30	tsi	9:43:30	tsf
281.16	Mhfi	223.2	Mhff	223.2	Msfi	151.3	Msff
26.8	Thwi	93.7	Thwf	93.7	Tswi	89.4	Tswf
2500	Mhwi	2374.67	Mhwf	2374.67	Mswi	2013.21	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
‘xt	min	0:27:00	0:26:30	0:45:00
‘xtT	min	0:30:00	0:29:24	
Mwr	g	2375.87	2374.67	2013.21
ηth	%	39.62	39.39	27.80
Mfused	g	57.49	57.96	71.9
Rb	g/min	2.13	2.19	1.60
Mwv	g	124.13	125.33	361.46
SFC	g/L	24.20	24.41	35.71
SFCT	g/L	26.89	27.13	
FP	W	1536.62	1578.41	1153.06
TDR	no			0.73

Averages variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
‘xt	min	0:28:30	0:27:30	0:45:00
‘xtT	min	0:31:47	0:30:30	
Mwr	g	2375.79	2374.75	2014.31
ηth	%	39.18	39.86	27.01
Mfused	g	58.13	57.28	73.86
Rb	g/min	2.04	2.08	1.64
Mwv	g	124.21	125.25	360.44
SFC	g/L	24.47	24.12	37.87
SFCT	g/L	27.19	26.80	
FP	W	1474.21	1498.52	1184.44
TDR	no			0.79

Appendix C.2.2: Control cooking test (CCT)

Control cooking test (CCT)						
	Test1		Test2		Test3	
Measured variables	start	end	start	end	start	end
time of boiling water (min)	9:50:00	10:05:30	10:40:00	10:56:30	11:35:00	11:52:30
time of rice cooking (min)	10:05:30	10:35:00	10:56:30	11:28:30	12:06:00	12:36:00
initial Mass of fue1 l (g)	151.3	106.9	155.82	107.31	158.1	112.26
Mass of water (g)	1000		1000		1000	
Mass of food (g)	500	847.1	500	853.2	500	846.29
initial Mass of fuel2 (g)	106.9	53.3	107.31	55.2	112.26	63.85

Calculated variables	Test1	Test2	Test3	Average
Ⱦtboiledwater	0:15:30	0:16:30	0:17:30	16.50
Ⱦtricecooked	0:29:30	0:32:00	0:30:00	30.00
Mfused1	44.4	48.51	45.84	46.25
Mfc	847.1	853.2	846.29	848.86
Mfused2	53.6	52.11	48.41	51.37

Time of cooking	min	46.50
SFC total	g/kg	115.28

Appendix C.2.3: Kitchen performance test (KPT)

Kitchen performance test (KPT)		
Measured	**unit**	
Mfused1	g/day	46.25
Mfused2	g/day	51.37
Mfused3	g/day	55.10
Total	g/day	152.72

Appendix C.2.4: Emission characteristic of B5

B5		CO (%volume)			CO2 (%volume)			
Time (sec)	Test1	Test2	Test3	Average	Test1	Test2	Test3	Average
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	0.17	0.17	0.16	0.17	2.35	2.31	2.03	2.23
20.00	0.19	0.18	0.17	0.18	2.44	2.21	2.10	2.25
30.00	0.19	0.19	0.17	0.18	2.12	2.33	2.22	2.22
40.00	0.16	0.14	0.16	0.16	2.04	2.36	2.00	2.13
50.00	0.15	0.15	0.16	0.16	2.07	2.01	2.32	2.13
60.00	0.16	0.16	0.16	0.16	2.33	2.08	2.12	2.18
70.00	0.17	0.18	0.10	0.15	2.14	2.09	2.11	2.11
80.00	0.15	0.19	0.20	0.18	2.03	2.12	2.16	2.10
90.00	0.12	0.12	0.13	0.12	1.99	2.00	2.17	2.05
100.00	0.15	0.12	0.14	0.14	2.30	2.40	2.00	2.23
110.00	0.15	0.13	0.16	0.14	2.41	2.15	2.14	2.23
120.00	0.16	0.16	0.17	0.16	1.55	2.01	2.06	1.87

Appendix C.2.5: B5 simmer

B5 simmer				
Simmer	Temperature (°C)			
Time (min)	Test1	Test2	Test3	Average
0.00	93.40	93.60	93.70	93.57
5.00	92.70	93.20	93.50	93.13
10.00	92.80	92.40	92.80	92.67
15.00	92.58	91.90	92.15	92.21
20.00	90.10	91.40	90.89	90.80
25.00	91.16	90.10	89.99	90.42
30.00	91.34	89.99	89.80	90.38
35.00	89.98	89.80	89.70	89.83
40.00	90.13	89.86	89.61	89.87
45.00	89.70	89.70	89.40	89.60

Appendix C.3: B10 investigation in wick/Butagas stove

Appendix C.3.1: Water boiling test (WBT)

Name of the test	kerosene-biodiesel blend (B10)		
Test number	3	**Location**	Adama city
Date	6/3/2022	**Fuel species**	B10
Stove type/model	Butagas/model 62	**Wind condition**	Normal
Latent heat of evaporation (hfg) at 94.3 ℃ (kj/kg)	2,260		
Ambient temperature (℃)	24.6	**Specific heat of water (Cpw)**	4.18 kj/kg.℃
Average fuel dimension	400 milliliter		
Weight of empty pot(g)	254.45	**Local boiling point (℃)**	94.3
Weight of stove (g)	784.15		

WBT Test 1		**High power test (Cold-start)**			
		Start		**end when water boil**	
Measurement	**Unit**	**Data**	**Label**	**Data**	**Label**
Time	min	3:40:00	tci	4:12:30	tcf
Weight of fuel	g	338.65	Mcfi	283.05	Mcff
Water temperature	℃	26.4	Tcwi	93.7	Tcwf
Weight of water	g	2500	Mcwi	2375.8	Mcwf

High power test (Hot-start)				**Low power test (Simmering)**			
Start		**end when water boil**		**Start**		**end when water boil: 45 minutes**	
Data	**Label**	**Data**	**Label**	**Data**	**Label**	**Data**	**Label**
4:13:00	thi	4:43:00	thf	4:43:30	tsi	5:28:30	tsf
283.05	Mhfi	229.39	Mhff	229.39	Msfi	160.55	Msff
26.4	Thwi	93.8	Thwf	93.8	Tswi	89.6	Tswf
2500	Mhwi	2374.42	Mhwf	2374.42	Mswi	2009.48	Mswf

Calculated variables	**Unit**	**High power (Cold-start)**	**High power (Hot-start)**	**Low power (Simmering)**
ϫt	min	0:32:30	0:30:00	0:45:00
ϫtT	min	0:35:59	0:33:02	
Mwr	g	2375.8	2374.42	2009.48
ηth	%	41.12	42.71	29.23
Mfused	g	55.6	53.66	68.84
Rb	g/min	1.71	1.79	1.53
Mwv	g	124.2	125.58	364.94
SFC	g/L	23.40	22.60	34.26
SFCT	g/L	25.85	24.96	
FP	W	1234.61	1290.82	1103.99
TDR	no			0.86

WBT Test 2		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	5:32:00	tci	6:03:00	tcf
Weight of fuel	g	338.65	Mcfi	284.14	Mcff
Water temperature	℃	26.4	Tcwi	93.8	Tcwf
Weight of water	g	2500	Mcwi	2375.92	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
6:03:30	thi	6:33:30	thf	6:34:00	tsi	7:19:00	tsf
284.14	Mhfi	231.84	Mhff	231.84	Msfi	163.97	Msff
26.4	Thwi	93.7	Thwf	93.7	Tswi	89.6	Tswf
2500	Mhwi	2374.62	Mhwf	2374.62	Mswi	2010.2	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϫt	min	0:31:00	0:30:00	0:45:00
ϫtT	min	0:34:24	0:33:02	
Mwr	g	2375.92	2374.62	2010.2
ηth	%	41.94	43.85	29.55
Mfused	g	54.51	52.3	67.87
Rb	g/min	1.76	1.74	1.51
Mwv	g	124.08	125.38	364.42
SFC	g/L	22.94	22.02	33.76
SFCT	g/L	25.34	24.33	
FP	W	1268.97	1258.11	1088.43
TDR	no			0.87

WBT Test 3		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	7:30:00	tci	8:01:30	tcf
Weight of fuel	g	338.65	Mcfi	284.3	Mcff
Water temperature	℃	26.4	Tcwi	93.6	Tcwf
Weight of water	g	2500	Mcwi	2375.91	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
8:02:00	thi	8:29:30	thf	8:30:00	tsi	9:15:00	tsf
284.3	Mhfi	231.4	Mhff	231.4	Msfi	163.51	Msff
26.4	Thwi	93.9	Thwf	93.9	Tswi	89.7	Tswf
2500	Mhwi	2374.69	Mhwf	2374.69	Mswi	2014.11	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϰt	min	0:31:30	0:27:30	0:45:00
ϰtT	min	0:34:59	0:30:27	
Mwr	g	2375.91	2374.69	2014.11
ηth	%	42.07	43.34	29.27
Mfused	g	54.35	52.9	67.89
Rb	g/min	1.73	1.92	1.51
Mwv	g	124.09	125.31	360.58
SFC	g/L	22.88	22.28	33.71
SFCT	g/L	25.27	24.61	
FP	W	1245.16	1388.22	1088.75
TDR	no			0.78

Averages variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϰt	min	0:31:42	0:27:30	0:45:00
ϰt	min	0:35:00	0:30:40	
Mwr	g	2375.88	2374.58	2011.26
ηth	%	41.71	43.30	29.35
Mfused	g	54.82	52.95	68.20
Rb	g/min	1.73	1.93	1.52
Mwv	g	124.12	125.42	363.31
SFC	g/L	23.07	22.30	37.87
SFCT	g/L	25.49	24.63	
FP	W	1249.58	1312.38	1093.73
TDR	no			0.83

Appendix C.3.2: Control cooking test (CCT)

Control cooking test (CCT)						
	Test1		Test2		Test3	
Measured variables	start	end	start	end	start	end
time of boiling water (min)	9:30:00	9:47:00	10:45:00	11:01:30	11:50:00	12:06:30
time of rice cooking (min)	9:47:00	10:20:00	11:01:30	11:33:30	12:06:30	12:38:00
initial Mass of fue1 l (g)	163.51	126.31	163.97	127.17	160.55	124.85
Mass of water (g)	1000		1000		1000	
Mass of food (g)	500	847.1	500	853.2	500	846.29
initial Mass of fuel2 (g)	126.31	73.51	127.17	74.87	124.85	72.14

Calculated variables	Test1	Test2	Test3	Average
Ⅹtboiledwater	0:17:00	0:16:30	0:16:30	16.50
Ⅹtricecooked	0:33:00	0:32:00	0:31:30	32.20
Mfused1	37.2	36.8	35.7	36.57
Mfc	854	851.29	847.22	850.84
Mfused2	52.8	52.3	52.71	52.60

Time of cooking	min	48.70
SFC total	g/kg	104.80

Appendix C.3.3: Kitchen performance test (KPT)

Kitchen performance test (KPT)		
Measured	unit	
Mfused1	g/day	36.57
Mfused2	g/day	52.60
Mfused3	g/day	55.10
Total	g/day	144.27

Appendix C.3.4: B10 emission characteristics

B10		CO (%volume)			CO2 (%volume)			
Time (sec)	Test1	Test2	Test3	Average	Test1	Test2	Test3	Average
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	0.16	0.15	0.14	0.15	1.76	1.72	1.75	1.74
20.00	0.14	0.15	0.14	0.14	1.82	1.81	1.73	1.79
30.00	0.15	0.14	0.14	0.14	1.77	1.63	1.88	1.76
40.00	0.16	0.14	0.14	0.15	1.78	1.59	1.62	1.66
50.00	0.14	0.14	0.15	0.14	1.65	1.79	1.55	1.66
60.00	0.15	0.13	0.16	0.15	1.81	1.99	1.69	1.83
70.00	0.15	0.13	0.13	0.14	1.68	1.79	1.72	1.73
80.00	0.14	0.14	0.14	0.14	1.63	1.88	1.69	1.73
90.00	0.14	0.12	0.12	0.13	1.66	1.82	1.84	1.77
100.00	0.14	0.14	0.12	0.14	1.77	1.83	1.85	1.82
110.00	0.16	0.11	0.11	0.13	1.87	1.86	1.85	1.86
120.00	0.14	0.13	0.11	0.13	1.69	1.89	1.59	1.72

Appendix C.3.5: B10 simmer

B10 simmer				
Simmer	Temperature (°C)			
Time (min)	Test1	Test2	Test3	Average
0.00	93.80	93.70	93.90	93.80
5.00	92.50	93.50	93.20	93.07
10.00	92.30	92.13	92.70	92.38
15.00	91.10	92.10	92.13	91.78
20.00	90.80	91.00	91.60	91.13
25.00	91.70	89.87	90.40	90.66
30.00	90.20	89.90	89.90	90.00
35.00	89.90	89.80	89.80	89.83
40.00	90.00	89.70	89.93	89.88
45.00	89.60	89.60	89.70	89.63

Appendix C.4: B15 investigation in wick/Butagas stove

Appendix C.4.1: Water boiling test (WBT)

Name of the test	kerosene-biodiesel blend (B15)		
Test number	4	**Location**	Adama city
Date	7/3/2022	**Fuel species**	B15
Stove type/model	Butagas/model 62	**Wind condition**	Normal
Latent heat of evaporation (hfg) at 94.3 ℃ (kj/kg)	2,260		
Air temperature (℃)	24.5	**Specific heat of water (Cpw)**	**4.18 kj/kg.k**
Average fuel dimension	400 millileter		
Weight of empty pot(g)	254.45	**Local boiling point (℃)**	94.3
Weight of stove (g)	784.15	Flue gas temperature(℃)	28.3

WBT Test 1		**High power test (Cold-start)**			
		Start		**end when water boil**	
Measurement	**Unit**	**Data**	**Label**	**Data**	**Label**
Time	min	3:30:00	tci	4:03:00	tcf
Weight of fuel	g	339.2	Mcfi	285.8	Mcff
Water temperature	℃	27	Tcwi	93.8	Tcwf
Weight of water	g	2500	Mcwi	2375.9	Mcwf

High power test (Hot-start)				**Low power test (Simmering)**			
Start		**end when water boil**		**Start**		**end when water boil: 45 minutes**	
Data	**Label**	**Data**	**Label**	**Data**	**Label**	**Data**	**Label**
4:03:30	thi	4:34:30	thf	4:35:00	tsi	5:20:00	tsf
285.8	Mhfi	234.1	Mhff	234.1	Msfi	168.34	Msff
27	Thwi	93.9	Thwf	93.9	Tswi	89.8	Tswf
2500	Mhwi	2374.83	Mhwf	2374.83	Mswi	2008.75	Mswf

Calculated variables	**Unit**	**High power (Cold-start)**	**High power (Hot-start)**	**Low power (Simmering)**
ɤt	min	0:33:00	0:31:00	0:45:00
ɤtT	min	0:36:50	0:34:34	
Mwr	g	2375.9	2374.83	2008.75
ηth	%	42.55	44.05	30.62
Mfused	g	53.4	51.7	65.76
Rb	g/min	1.62	1.67	1.46
Mwv	g	124.1	125.17	366.08
SFC	g/L	22.48	21.77	32.74
SFCT	g/L	25.05	24.26	
FP	W	1167.79	1203.55	1054.60
TDR	no			0.88

WBT Test 2		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	5:35:00	tci	6:07:00	tcf
Weight of fuel	g	339.2	Mcfi	286.23	Mcff
Water temperature	℃	27	Tcwi	93.7	Tcwf
Weight of water	g	2500	Mcwi	2375.84	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
6:07:30	thi	6:40:00	thf	6:40:30	tsi	7:25:30	tsf
286.23	Mhfi	234.23	Mhff	234.23	Msfi	169.33	Msff
27	Thwi	93.9	Thwf	94	Tswi	89.8	Tswf
2500	Mhwi	2374.77	Mhwf	2374.77	Mswi	2009.26	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϫt	min	0:32:00	0:32:30	0:45:00
ϫtT	min	0:35:46	0:36:21	
Mwr	g	2375.84	2374.77	2009.26
ηth	%	42.90	43.80	30.98
Mfused	g	52.97	52	64.9
Rb	g/min	1.66	1.6	1.44
Mwv	g	124.16	125.23	365.51
SFC	g/L	22.30	21.90	32.30
SFCT	g/L	24.85	24.40	
FP	W	1194.58	1154.67	1040.80
TDR	no			0.90

WBT Test 3		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	7:30:00	tci	8:02:00	tcf
Weight of fuel	g	339.2	Mcfi	285.1	Mcff
Water temperature	℃	27	Tcwi	93.9	Tcwf
Weight of water	g	2500	Mcwi	2375.78	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
8:02:30	thi	8:33:30	thf	8:34:00	tsi	9:19:00	tsf
285.1	Mhfi	233.2	Mhff	233.2	Msfi	167.52	Msff
27	Thwi	93.8	Thwf	93.8	Tswi	89.6	Tswf
2500	Mhwi	2374.73	Mhwf	2374.73	Mswi	2013.31	Mswf
Calculated variables	**Unit**	**High power (Cold-start)**		**High power (Hot-start)**		**Low power (Simmering)**	
ϰt	min	0:32:00		0:31:00		0:45:00	
ϰtT	min	0:35:46		0:34:34			
Mwr	g	2375.78		2374.73		2013.31	
ηth	%	42.01		43.89		30.36	
Mfused	g	54.1		51.9		65.68	
Rb	g/min	1.69		1.67		1.46	
Mwv	g	124.22		125.27		361.42	
SFC	g/L	22.77		21.86		32.62	
SFCT	g/L	25.38		24.36			
FP	W	1220.07		1208.21		1053.31	
TDR	no					0.87	

Averages variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϰt	min	0:32:20	0:31:30	0:45:00
ϰt	min	0:36:00	0:35:00	
Mwr	g	2375.84	2374.78	2010.44
ηth	%	42.48	43.92	30.66
Mfused	g	53.49	51.87	65.45
Rb	g/min	1.66	1.65	1.45
Mwv	g	124.16	125.22	364.34
SFC	g/L	22.51	21.84	37.87
SFCT	g/L	25.09	24.34	
FP	W	1194.15	1188.81	1049.57
TDR	no			0.88

Appendix C.4.2: Control cooking test (CCT)

Control cooking test (CCT)						
		Test1		Test2		Test3	
Measured variables		start	end	start	end	start	end
time of boiling water (min)		9:30:00	9:47:30	10:40:00	10:58:30	11:40:00	11:57:30
time of rice cooking (min)		9:47:30	10:22:00	10:58:30	11:30:30	11:57:30	12:30:00
initial Mass of fue1 l (g)		167.52	136.2	169.33	138.8	168.34	135.2
Mass of water (g)		1000		1000		1000	
Mass of food (g)		500	858.2	500	859.1	500	821.26
initial Mass of fuel2 (g)		136.2	81.65	138.8	82.27	135.2	80.4
			81.65				

Calculated variables	Test1	Test2	Test3	Average
Ƶtboiledwater	0:17:30	0:18:30	0:17:30	19.30
Ƶtricecooked	0:34:30	0:32:00	0:32:30	34.00
Mfused1	31.32	30.53	33.14	31.66
Mfc	858.2	859.1	821.26	846.19
Mfused2	54.55	56.53	54.8	55.29

Time of cooking	min	53.30
SFC total	g/kg	102.76

Appendix C.4.3: Kitchen performance test (KPT)

Kitchen performance test (KPT)		
Measured	unit	
Mfused1	g/day	31.66
Mfused2	g/day	
Mfused3	g/day	54.21
Total	g/day	141.17

Appendix C.4.4: B15 emission characteristic

B15		CO (%volume)			CO2 (%volume)			
Time (sec)	Test1	Test2	Test3	Average	Test1	Test2	Test3	Average
0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
10.00	0.15	0.14	0.11	0.13	1.63	1.66	1.71	1.67
20.00	0.14	0.14	0.11	0.13	1.84	1.68	1.68	1.73
30.00	0.14	0.15	0.11	0.13	1.71	1.75	1.28	1.58
40.00	0.15	0.13	0.12	0.13	1.59	1.67	1.59	1.62
50.00	0.15	0.14	0.12	0.13	1.55	1.62	1.54	1.57
60.00	0.14	0.13	0.13	0.13	1.44	1.61	1.48	1.51
70.00	0.13	0.13	0.13	0.13	1.83	1.70	1.49	1.67
80.00	0.13	0.12	0.11	0.12	1.71	1.44	1.46	1.54
90.00	0.13	0.11	0.12	0.12	1.66	1.45	1.47	1.53
100.00	0.13	0.11	0.11	0.12	1.59	1.68	1.46	1.58
110.00	0.13	0.10	0.12	0.12	1.55	1.66	1.55	1.59
120.00	0.13	0.12	0.11	0.12	1.49	1.72	1.66	1.62

Appendix C.4.5: B15 simmer

B15 simmer				
Simmer	Temperature (°C)			
Time (min)	Test1	Test2	Test3	Average
0.00	93.90	94.00	93.80	93.90
5.00	93.70	93.60	93.60	93.63
10.00	93.20	93.20	93.50	93.30
15.00	92.80	91.80	92.90	92.50
20.00	92.50	90.80	92.50	91.93
25.00	91.40	90.50	91.80	91.23
30.00	92.20	90.10	90.13	90.81
35.00	91.70	89.90	90.10	90.57
40.00	90.60	89.90	89.90	90.13
45.00	89.80	89.80	89.60	89.73

Appendix C.5: B20 data investigated during test in wick/Butagas stove

Appendix C.5.1: Water boiling test (WBT)

Name of the test		kerosene-biodiesel blend (B20)									
Test number		5		**Location**		Adama					
Date		8/3/2022		**Fuel species**		B20					
Stove type/model		Butagas/model: 62		**Wind condition**		Normal					
Latent heat of evaporation (hfg) at 94.3 ℃ (kj/kg)		2,260									
Air temperature (℃)		24.8		**Specific heat of water (Cpw)**						4.18 kj/kg.℃	
Average fuel dimension		400 millileter									
Weight of empty pot(g)		254.45		**Local boiling point (℃)**		94.3					
Weight of stove (g)		784.15		Flue gas temperature(℃)							
WBT Test 1		**High power test (Cold-start)**									
		Start				**end when water boil**					
Measurement	**Unit**	**Data**		**Label**		**Data**		**Label**			
Time	min	3:20:00		tci		3:54:30		tcf			
Weight of fuel	g	339.6		Mcfi		287.3		Mcff			
Water temperature	℃	27		Tcwi		94		Tcwf			
Weight of water	g	2500		Mcwi		2375.89		Mcwf			
High power test (Hot-start)						**Low power test (Simmering)**					
Start		**end when water boil**				**Start**		**end when water boil: 45 minutes**			
Data	**Label**	**Data**	**Label**			**Data**	**Label**	**Data**	**Label**		
3:55:00	thi	4:28:00	thf			4:28:30	tsi	5:13:30	tsf		
287.3	Mhfi	237.2	Mhff			237.2	Msfi	174.48	Msff		
27	Thwi	93.8	Thwf			93.9	Tswi	89.6	Tswf		
2500	Mhwi	2373.9	Mhwf			2373.9	Mswi	2009.82	Mswf		
Calculated variables	**Unit**	**High power (Cold-start)**			**High power (Hot-start)**			**Low power (Simmering)**			
ɤt	min	0:34:30			0:33:00			0:45:00			
ɤt	min	0:38:30			0:36:50						
Mwr	g	2375.89			2373.9			2009.82			
ηth	%	43.44			45.56			32.02			
Mfused	g	52.3			50.1			62.72			
Rb	g/min	1.52			1.52			1.39			
Mwv	g	124.11			126.1			364.08			
SFC	g/L	22.01			21.10			31.21			
SFCT	g/L	24.53			23.52						
FP	W	1094.00			1095.62			1005.84			
TDR	no							0.92			

WBT Test 2		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	5:30:00	tci	6:03:00	tcf
Weight of fuel	g	339.6	Mcfi	287.57	Mcff
Water temperature	℃	27	Tcwi	94.1	Tcwf
Weight of water	g	2500	Mcwi	2375.91	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
6:03:30	thi	6:36:00	thf	6:36:30	tsi	7:21:30	tsf
287.57	Mhfi	237.61	Mhff	237.61	Msfi	174.93	Msff
27	Thwi	94.2	Thwf	94.2	Tswi	89.6	Tswf
2500	Mhwi	2374.15	Mhwf	2374.15	Mswi	2007.39	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϫt	min	0:33:00	0:32:30	0:45:00
ϫt	min	0:36:50	0:36:20	
Mwr	g	2375.91	2374.15	2007.39
ηth	%	43.67	45.66	32.26
Mfused	g	52.03	49.96	62.68
Rb	g/min	1.58	1.54	1.39
Mwv	g	124.09	125.85	366.76
SFC	g/L	21.90	21.04	31.22
SFCT	g/L	24.40	23.45	
FP	W	1137.83	1109.37	1005.20
TDR	no			0.91

WBT Test 3		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	7:22:00	tci	7:55:00	tcf
Weight of fuel	g	339.6	Mcfi	287.96	Mcff
Water temperature	℃	27	Tcwi	94.15	Tcwf
Weight of water	g	2500	Mcwi	2375.81	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
7:55:30	thi	8:27:30	thf	8:28:00	tsi	9:13:00	tsf
287.96	Mhfi	237.8	Mhff	237.8	Msfi	174.55	Msff
27	Thwi	93.7	Thwf	93.7	Tswi	89.7	Tswf
2500	Mhwi	2374.95	Mhwf	2374.95	Mswi	2015.34	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ɤt	min	0:33:00	0:32:00	0:45:00
ɤt	min	0:36:50	0:35:40	
Mwr	g	2375.81	2374.95	2015.34
ηth	%	44.00	45.39	31.34
Mfused	g	51.64	50.16	63.25
Rb	g/min	1.56	1.57	1.41
Mwv	g	124.19	125.05	359.61
SFC	g/L	21.74	21.12	31.42
SFCT	g/L	24.22	23.54	
FP	W	1129.30	1131.21	1014.34
TDR	no			0.90
Averages variables	**Unit**	**High power (Cold-start)**	**High power (Hot-start)**	**Low power (Simmering)**
ɤt	min	0:33:30	0:32:30	0:45:00
ɤt	min	0:37:30	0:36:20	
Mwr	g	2375.87	2374.33	2010.85
ηth	%	43.70	45.54	31.87
Mfused	g	51.99	50.07	62.88
Rb	g/min	1.55	1.54	1.40
Mwv	g	124.13	125.67	363.48
SFC	g/L	21.88	21.09	31.28
SFCT	g/L	24.39	23.50	
FP	W	1120.38	1112.07	1008.46
TDR	no			0.91

Appendix C.5.2: Control cooking test (CCT)

Control cooking test (CCT)						
	Test1		Test2		Test3	
Measured variables	start	end	start	end	start	end
time of boiling water (min)	9:30:00	9:47:00	10:30:00	10:48:30	11:30:00	11:47:30
time of rice cooking (min)	9:47:00	10:20:00	10:48:30	11:20:30	11:47:30	12:22:00
initial Mass of fue1 l (g)	174.48	144.3	174.55	147.26	174.93	143.2
Mass of water (g)	1000		1000		1000	
Mass of food (g)	500	847.1	500	856.3	500	838.41
initial Mass of fuel2 (g)	144.3	87.63	147.26	89.23	143.2	90.22

Calculated variables	Test1	Test2	Test3	Average
𝛥tboiledwater	0:17:00	0:18:30	0:17:30	20.00
𝛥tricecooked	0:33:00	0:32:00	0:34:30	34.20
Mfused1	30.18	27.29	31.73	29.73
Mfc	847.1	856.3	838.41	847.27
Mfused2	56.67	58.03	52.98	55.89

Time of cooking	min	54.20
SFC total	g/kg	101.06

Appendix C.5.3: Kitchen performance test (KPT)

itchen performance test (KPT)		
Measured	unit	
Mfused1	g/day	29.73
Mfused2	g/day	55.89
Mfused3	g/day	52.83
Total	g/day	138.46

Appendix C.5.4: Emission characteristics

B20		CO (%volume)			CO2 (%volume)			
Time (sec)	Test1	Test2	Test3	Average	Test1	Test2	Test3	Average
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	0.11	0.10	0.10	0.10	3.00	2.99	2.88	2.96
20.00	0.06	0.09	0.09	0.08	2.93	2.89	2.84	2.89
30.00	0.06	0.09	0.07	0.08	2.99	2.87	2.85	2.90
40.00	0.08	0.08	0.08	0.08	2.93	3.00	2.67	2.87
50.00	0.11	0.06	0.06	0.07	3.00	2.67	2.71	2.79
60.00	0.10	0.05	0.07	0.07	2.94	2.68	2.77	2.80
70.00	0.09	0.08	0.07	0.08	2.66	2.57	2.88	2.70
80.00	0.07	0.05	0.05	0.06	2.84	2.88	2.99	2.90
90.00	0.08	0.10	0.05	0.07	2.93	2.47	2.73	2.71
100.00	0.04	0.02	0.09	0.05	2.87	2.98	2.76	2.87
110.00	0.05	0.08	0.05	0.06	2.82	2.99	2.56	2.79
120.00	0.06	0.09	0.06	0.07	2.85	2.91	2.83	2.86

Appendix C.5.5: B20 Simmering

B20 simmer				
Simmer	Temperature (℃)			
Time (min)	Test1	Test2	Test3	Average
0.00	93.90	94.20	93.70	93.93
5.00	93.50	93.80	93.50	93.60
10.00	93.70	93.50	93.20	93.47
15.00	93.90	92.70	92.80	93.13
20.00	92.90	92.10	92.50	92.50
25.00	91.90	90.40	92.10	91.47
30.00	91.50	90.20	90.40	90.70
35.00	89.90	89.80	90.20	89.97
40.00	90.20	89.70	89.90	89.93
45.00	89.60	89.60	89.70	89.63

Appendix C.6: B100 data investigated during test in wick/Butagas stove

Appendix C.6.1: Water boiling test (WBT)

Name of the test	**Pure biodiesel (B100)**					
Test number	6		**Location**		Adama city	
Date	9/3/2022		**Fuel species**		B100	
Stove type/model	Butagas/model 62		**Wind condition**			
Latent heat of evaporation (hfg) at 94.3 ℃ (kj/kg)			2,260			
Air temperature (℃)	24.7		**Specific heat of water (Cpw)**		**4.18 kj/kg.k**	
Average fuel dimension	400 millileter					
Weight of empty pot(g)	254.45		**Local boiling point (℃)**		94.3	
Weight of stove (g) 784.15			Flue gas temperature(℃)		28.2	

WBT Test 1		**High power test (Cold-start)**			
		Start		**end when water boil**	
Measurement	**Unit**	**Data**	**Label**	**Data**	**Label**
Time	min	3:25:00	tci	4:06:30	tcf
Weight of fuel	g	351.4	Mcfi	304.6	Mcff
Water temperature	℃	28	Tcwi	93.9	Tcwf
Weight of water	g	2500	Mcwi	2375.88	Mcwf

High power test (Hot-start)				**Low power test (Simmering)**			
Start		**end when water boil**		**Start**		**end when water boil: 45 minutes**	
Data	**Label**	**Data**	**Label**	**Data**	**Label**	**Data**	**Label**
4:07:00	thi	4:47:00	thf	4:47:30	tsi	5:32:30	tsf
304.6	Mhfi	259.8	Mhff	259.8	Msfi	209.86	Msff
27	Thwi	93.8	Thwf	93.9	Tswi	89.7	Tswf
2500	Mhwi	2374.25	Mhwf	2374.25	Mswi	2005.6	Mswf

Calculated variables	**Unit**	**High power (Cold-start)**	**High power (Hot-start)**	**Low power (Simmering)**
ɤt	min	0:41:30	0:40:00	0:45:00
ɤtT	min	0:47:00	0:45:24	
Mwr	g	2375.88	2374.25	2005.6
ηth	%	48.03	50.91	40.64
Mfused	g	46.8	44.8	49.94
Rb	g/min	1.13	1.12	1.11
Mwv	g	124.12	125.75	368.65
SFC	g/L	19.70	18.87	24.90
SFCT	g/L	22.28	21.35	
FP	W	813.83	808.27	800.89
TDR	no			0.99

WBT Test 2		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	5:45:00	tci	6:27:00	tcf
Weight of fuel	g	351.4	Mcfi	305.27	Mcff
Water temperature	℃	28	Tcwi	93.7	Tcwf
Weight of water	g	2500	Mcwi	2375.41	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
6:27:30	thi	7:08:30	thf	7:09:00	tsi	7:54:00	tsf
305.27	Mhfi	260.17	Mhff	260.17	Msfi	210.84	Msff
27	Thwi	94.2	Thwf	94.2	Tswi	89.6	Tswf
2500	Mhwi	2374.22	Mhwf	2374.22	Mswi	2009.18	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϫt	min	0:42:00	0:41:00	0:45:00
ϫtT	min	0:47:30	0:46:38	
Mwr	g	2375.41	2374.22	2009.18
ηth	%	48.78	50.03	40.81
Mfused	g	46.13	45.1	49.33
Rb	g/min	1.10	1.10	1.10
Mwv	g	124.59	125.78	365.04
SFC	g/L	19.42	19.00	24.55
SFCT	g/L	21.97	21.49	
FP	W	792.63	793.83	791.11
TDR	no			1.00

WBT Test 3		High power test (Cold-start)			
		Start		end when water boil	
Measurement	Unit	Data	Label	Data	Label
Time	min	8:10:00	tci	8:51:30	tcf
Weight of fuel	g	351.4	Mcfi	303.69	Mcff
Water temperature	℃	28	Tcwi	94.1	Tcwf
Weight of water	g	2500	Mcwi	2375.89	Mcwf

High power test (Hot-start)				Low power test (Simmering)			
Start		end when water boil		Start		end when water boil: 45 minutes	
Data	Label	Data	Label	Data	Label	Data	Label
8:52:00	thi	9:31:00	thf	9:31:30	tsi	10:16:30	tsf
303.69	Mhfi	257.55	Mhff	257.55	Msfi	205.56	Msff
28	Thwi	93.7	Thwf	93.7	Tswi	89.8	Tswf
2500	Mhwi	2374.94	Mhwf	2374.94	Mswi	2016.46	Mswf

Calculated variables	Unit	High power (Cold-start)	High power (Hot-start)	Low power (Simmering)
ϰt	min	0:41:30	0:39:00	0:45:00
ϰtT	min	0:47:00	0:44:10	
Mwr	g	2375.89	2374.94	2016.46
ηth	%	47.12	49.35	37.97
Mfused	g	47.71	46.14	51.99
Rb	g/min	1.15	1.18	1.16
Mwv	g	124.11	125.06	358.48
SFC	g/L	20.08	19.43	25.78
SFCT	g/L	22.72	21.98	
FP	W	829.66	853.79	833.77
TDR	no			0.98
Averages variables	**Unit**	**High power (Cold-start)**	**High power (Hot-start)**	**Low power (Simmering)**
ϰt	min	0:42:00	0:40:00	0:45:00
ϰt	min	0:47:31	0:45:20	
Mwr	g	2375.73	2374.47	2010.41
ηth	%	47.98	50.10	39.81
Mfused	g	46.88	45.35	50.42
Rb	g/min	1.12	1.13	1.12
Mwv	g	124.27	125.53	364.06
SFC	g/L	19.73	19.10	25.08
SFCT	g/L	22.32	21.60	
FP	W	812.04	818.63	808.59
TDR	no			0.99

Appendix C.6.2: Control cooking test (CCT)

Control cooking test (CCT)						
	Test1		Test2		Test3	
Measured variables	start	end	start	end	start	end
time of boiling water (min)	10:32:00	10:49:30	11:30:00	11:48:30	12:35:00	12:53:00
time of rice cooking (min)	10:49:30	11:23:00	11:48:30	12:24:30	12:53:00	13:34:00
initial Mass of fue1 l (g)	205.56	174.35	210.84	179.54	209.86	178.82
Mass of water (g)	1000		1000		1000	
Mass of food (g)	500	855.1	500	847.9	500	846.82
initial Mass of fuel2 (g)	174.35	124.75	179.54	129.74	178.82	130.04

Calculated variables	Test1	Test2	Test3	Average
Ⱦtboiledwater	0:17:30	0:18:30	0:18:00	18.00
Ⱦtricecooked	0:33:30	0:36:00	0:41:00	37.00
Mfused1	31.21	31.3	31.04	31.18
Mfc	855.1	847.9	846.82	849.94
Mfused2	49.6	49.8	48.78	49.39

Time of cooking	min	55.00
SFC total	g/kg	94.80

Appendix C.6.3: Kitchen performance test (KPT)

Kitchen performance test (KPT)		
Measured	unit	
Mfused1	g/day	31.18
Mfused2	g/day	49.39
Mfused3	g/day	50.92
Total	g/day	131.50

Appendix C.6.4: B100 emission characteristics

B100		CO (%volume)			CO2 (%volume)			
Time (sec)	Test1	Test2	Test3	Average	Test1	Test2	Test3	Average
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.00	0.13	0.11	0.09	0.11	2.11	2.09	2.11	2.10
20.00	0.12	0.09	0.05	0.09	2.05	2.51	2.07	2.21
30.00	0.12	0.08	0.04	0.08	2.13	2.07	2.05	2.08
40.00	0.12	0.07	0.07	0.09	2.16	2.11	2.06	2.11
50.00	0.12	0.05	0.05	0.07	2.06	2.06	2.11	2.08
60.00	0.12	0.05	0.02	0.06	2.22	2.03	2.12	2.12
70.00	0.11	0.02	0.01	0.05	2.09	2.04	2.14	2.09
80.00	0.09	0.01	0.01	0.04	2.04	2.08	2.02	2.05
90.00	0.10	0.04	0.01	0.05	2.06	2.08	2.06	2.07
100.00	0.08	0.01	0.01	0.04	2.12	2.09	2.09	2.10
110.00	0.09	0.02	0.01	0.04	2.37	2.01	2.01	2.13
120.00	0.10	0.03	0.01	0.05	2.10	2.01	2.00	2.04

Appendix C.6.5: B100 Simmering

B100 simmer				
Simmer	Temperature (℃)			
Time (min)	Test1	Test2	Test3	Average
0.00	93.90	94.20	93.70	93.93
5.00	93.50	93.80	93.50	93.60
10.00	93.70	93.50	93.20	93.47
15.00	93.90	92.70	92.80	93.13
20.00	92.90	92.10	92.50	92.50
25.00	91.90	90.40	92.10	91.47
30.00	91.50	90.20	90.40	90.70
35.00	89.90	89.80	90.20	89.97
40.00	90.20	89.70	89.90	89.93
45.00	89.70	89.60	89.80	89.70

Appendix D: Fuels combustion performance investigation in wick/Butagas stove

Appendix D.1: pure kerosene combustion investigation in wick/Butagas stove

The chemical equation of the pure kerosene can be written as,

$$xC_{12}H_{26} + a(O_2 + 3.76N_2) \rightarrow 2.63CO_2 + 0.2CO + bH_2O(l) + c3.76N_2$$

By balancing the equation, we have;

C: 12x = 2.63 + 0.2, x = 0.236;

H: 26x = 2b, b = (26*0.236)/2 = 3.068;

O: a = 2.63 + 0.1 + 3.068/2, a = 4.264

N: c = 4.264, 4.264*3.76 = 16

Writing the chemical equation against, we have the balanced equation as;

$C_{12}H_{26} + 18(O_2 + 3.76N_2) \rightarrow 11.144CO_2 + 0.847CO + 13H_2O(l) + 68N_2$

- Air- fuel ratio (AF) = $\frac{mass\ of\ air}{mass\ of\ fuel}$ (4.33)

We know that, from air; $\frac{(18kmole)\left(32\frac{kg}{kmole}\right)+(18*3.76\ kmole)(28\frac{kg}{kmole})}{(18\ kmole)+(18*3.76\ kmole)} = 29\ kg/kmole$

By substituting the values in equation 4.34, we have;

AF = $\frac{(18*4.76\ kmole)(29\frac{kg}{kmole})}{(12\ kmol)\left(\frac{12kg}{kmole}\right)+(13\ kmole)(2\frac{kg}{kmole})} = 14.62\ \frac{kg\ air}{kg\ fuel}$

- Percentage theoretical air = $\frac{Mass\ of\ air,actual}{Mass\ of\ air,theiretical}$ (4.35)

By writing the theoretical chemical equation, we have;

$C_{12}H_{26} + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O(l) + d3.76N_2$

By balancing the above equation, we have;

C: b = 12; H: c = 13; O: a = 18.5; N: d = 18.5

So, the balanced chemical equation becomes;

$C_{12}H_{26} + 18.5(O_2 + 3.76N_2) \rightarrow 12CO_2 + 13H_2O(l) + 69.56N_2$

By using equation 4.34, we have;

Percentage theoretical air = $\frac{(18*4.76\ kmole)}{(18.5*4.76\ kmole)} = 0.973 = 97.3\%$

Which means there is 2.7% deficient of air which was not used in this combustion.

By equation 4.29 and 4.30, and using enthalpy of formation from table A-26, hc becomes;

hc = ((11.144kmol*-393520kj/kmol) + (0.847kmol*-110530kj/kmol) + (13kmol*-285830kj/kmol))- (1kmol*-291010kj/kmol)

= -7903785.79 Kj/170 kg $C_{12}H_{26}$ = - 46492.86 Kj/kg

Which is partially identical to the listed value of 47470 kj/kg in table B3 appendix.

Q_{out} = (11.144 kmol*H_{co_2} kj/kmol) + (0.847 kmol*Hco kj/kmol) + (13kmole*H_{H2O})

Q_{out}=(11.144kmol*-393520kj/kmol)+(0.847kmol*-110530kj/kmol)+(13kmole*285830Kj/kmole

= - 8194795.79Kj

Q_{in} = (x*170kg/mole * H_{c12H26})

Q_{in} = (0.236*170 kmole * -291010kj/kmole C12H26) = - 11675321.2 kJ

By equation 4.28, we have;

$\eta_{ci} = \frac{-8194795.79}{-11675321.2}*100$

η_{cI} = 70.2%

To find second-law combustion efficiency, we have;

Using Gibbs function from table A-26, we get the actual work by equation 4.32 as;

$W_{rev} = \bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}_{H2O}$

= (50150) - (12*-394360) - (13*-237180)

= 7865810 kJ

And from equation 4.33 using Gibbs function against, we have chemical exergy as;

$$\bar{a}_{ch} = [50150 + (0) - (12 * -394360) - (13 * -237180)] - +(8.314)(298.15)ln\frac{(0.2094)^{18.5}}{(0.0004)^{12}(0.038)13}$$

= 9772024.95 kJ/170 = 57482.5 kJ/kg $C_{12}H_{26}$

From equation 4.31, we get the combustion efficiency as;

$$\eta_{cII} = \frac{7865810\ kJ}{(170kg)*(\frac{57482.5kJ}{kg})} * 100 = 0.8049 = 80.5\%$$

Appendix D.2: Kerosene-biodiesel blend (B5) combustion investigation in wick/Butagas stove

The chemical equation of the B5 can be written as,

$0.95C_{12}H_{26} + 0.05(C+H_2+O_2) + a(O_2 + 3.76N_2) \rightarrow 2.144CO_2 + 0.145CO + bH_2O(l) + z3.76N_2$

By balancing the equation, we have;

C: 11.45 =11.45; H: b = 12.35; O: a = 17.48,

N: z = 65.725

Writing the balanced chemical equation, we have;

$0.95C_{12}H_{26} + 0.05(C+H2+O2) + 17.52(O_2 + 3.76N_2) \rightarrow 11.3CO_2 + 0.15CO + 12.35H_2O(l) + 65.725N_2$

We know that, from air; $\frac{(18kmole)\left(32\frac{kg}{kmole}\right)+(18*3.76\ kmole)(28\frac{kg}{kmole})}{(18\ kmole)+(18*3.76\ kmole)} = 29\ kg/kmole$

By substituting the values in equation 4.34, we have;

$$AF = \frac{(17.52*4.76\ kmole)\left(29\frac{kg}{kmole}\right)}{(0.95*12\ kmol)\left(\frac{12kg}{kmole}\right)+\left(0.05*1kmol*\frac{12kg}{kmol}\right)+(0.95*13\ kmole)\left(2\frac{kg}{kmole}\right)+\left(0.05kmol*\frac{2kg}{kmol}\right)+\left(0.05kmol*\frac{32kg}{kmol}\right)}$$

$$= 14.76\ \frac{kg\ air}{kg\ fuel}$$

- Percentage theoretical air = $\frac{Mass\ of\ air,actual}{Mass\ of\ air,theiretical}$

By writing the theoretical chemical equation, we have;

$0.95C_{12}H_{26} + 0.05(C+H_2+O_2) + a(O_2 + 3.76N_2) \rightarrow bCO_2 + H_2O(l) + d3.76N_2$

By balancing the above equation, we have;

C: b = 11.45; H: c = 12.35; O: a = 17.575; N: d = 17.575

So, the balanced chemical equation becomes;

$0.95C_{12}H_{26}+0.05(C+H2+O2)+17.575(O_2 + 3.76N_2) \rightarrow 11.45CO_2 + 12.35H_2O(l) + 66.082N_2$

By using equation 4.35, we have;

Percentage theoretical air = $\frac{(17.52*4.76\ kmole)}{(17.575*4.76\ kmole)} = 0.99687 = 99.7\%$

Which means there is 0.3% deficient of air which was not used during combustion.

By equation 4.29 and 4.30, and using enthalpy of formation from table A-26, hc becomes;

hc = ((11.3kmol*-393520kj/kmol)+(0.15kmol*-110530kj/kmol)+(12.35kmol*-285830kj/kmol))-(0.95kmol*-291010kj/kmol)

= -7716896.5Kj/167.2 kg $C_{12}H_{26}$ = 46153.7Kj/kg

Which is partially identical to the listed value of 47470 kj/kg in table B3 appendix.

Q_{out} = (11.3 kmol*Hco_2 kj/kmol) + (0.15 kmol*Hco kj/kmol) + (12.35kmole*H_{H2O})

Q_{out}=(11.3kmol*-393520kj/kmol)+(0.15kmol*-110530kj/kmol) + (12.35kmole*285830Kj/kmole

= - 7993356 kJ

Q_{in} = (x*0.95*170kg/mole * H_{c12H26})

Q_{in} = (0.236*0.95*170 kmole * -291010kj/kmole C12H26) = - 11091555.14 kJ

By equation 4.28, we have;

$\eta_{ci} = \frac{-7993356}{-11091555.14}*100$

η_{cI} = 72.07%

To find second-law combustion efficiency, we have;

$W_{rev} = \bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}_{H2O}$

Using Gibbs function from table A-26, we get the actual work by equation 4.31 as;

W_{rev} = (0.95*50150) - (11.45*-394360) - (12.35*-237180)

= 7492237.5 kJ

And from equation 4.33 using Gibbs function against, we have chemical exergy as;

$$\bar{a}_{ch} = [(0.95 * 50150) + (0) - (11.45 * -394360) - (12.35 * -237180)]$$
$$- +(8.314)(298.15)ln\frac{(0.2094)^{17.575}}{(0.0004)^{11.45}(0.038)\text{^}12.35}$$

= 9302268.87 kJ/170 = 54719.23 kJ/kg $0.95C_{12}H_{26}$

From equation 4.31, we get the combustion efficiency as;

$\eta_{cII} = \frac{7492237.5kJ}{(0.95*170kg)*(\frac{54719.23J}{kg})} * 100 = 0.8478 = 84.78\%$

Appendix D.3: Kerosene-biodiesel blend (B10) combustion investigation in wick/Butagas stove

The chemical equation of the B10 can be written as,

$0.9C_{12}H_{26} + 0.1(C+H_2+O_2) + a(O_2 + 3.76N_2) \rightarrow 1.756CO_2 + 0.14CO + bH_2O(l) + z3.76N_2$

By balancing the equation, we have;

C: 10.9 =10.9; H: b = 11.75; O: a = 16.605,

N: z = 16.605

Writing the balanced chemical equation and divided by 0.9, we have;

$C_{12}H_{26} + 0.1(C+H_2+O_2) + 18.45(O_2 + 3.76N_2) \rightarrow 11.96CO_2 + 0.14CO + 13H_2O(l) + 65.9132N_2$

We know that, from air; $\frac{(18.45kmole)\left(32\frac{kg}{kmole}\right)+(18.45*3.76\ kmole)(28\frac{kg}{kmole})}{(18.45kmole)+(18.45*3.76\ kmole)} = 29\ kg/kmole$

By substituting the values in equation 4.34, we have;

$$AF = \frac{(18.45*4.76\ kmole)\left(29\frac{kg}{kmole}\right)}{(12\ kmol)\left(\frac{12kg}{kmole}\right)+\left(0.1*1kmol*\frac{12kg}{kmol}\right)+(13\ kmole)\left(2\frac{kg}{kmole}\right)+\left(0.1*1kmol*\frac{2kg}{kmol}\right)+\left(0.1*1kmol*\frac{32kg}{kmol}\right)}$$

$$= \quad 14.6\frac{kg\ air}{kg\ fuel}$$

- Percentage theoretical air = $\frac{Mass\ of\ air,actual}{Mass\ of\ air,theiretical}$

By writing the theoretical chemical equation, we have;

$0.9C_{12}H_{26} + 0.1(C+H_2+O_2)+a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O(l) + d3.76N_2$

By balancing the above equation, we have;

C: b = 10.9; H: c = 11.75; O: a = 16.675 N: d = 16.675

So, the balanced chemical equation and divided by 0.9 becomes;

$C_{12}H_{26}+0.1(C+H2+O2)+18.528(O_2 + 3.76N_2) \rightarrow 12.1CO_2 + 13.056H_2O(l) + 62.6982N_2$

By using equation 4.35, we have;

Percentage theoretical air = $\frac{(18.45*4.76\ kmole)}{(18.528*4.76\ kmole)} = 0.996 = 99.6\%$

Which means there is 0.4% deficient of air which was not used during combustion.

By equation 4.29 and 4.30, and using enthalpy of formation from table A-26, h_c becomes;

hc = ((11.96kmol*-393520kj/kmol)+(0.14kmol*-110530kj/kmol)+(13.05kmol*-285830kj/kmol))- (1kmol*-291010kj/kmol)

= -8161044.9kJ/170 kg $C_{12}H_{26}$ = 48006.15kJ/kg

Which is partially identical to the listed value of 47470 kj/kg in table B3 appendix.

Q_{out} = (11.96 kmol*Hco_2 kj/kmol) + (0.14 kmol*Hco kj/kmol) + (13.05kmole*H_{H2O})

Q_{out} = (11.96kmol*-393520kj/kmol) + (0.14kmol*-110530kj/kmol) + (11.75kmole*285830Kj/kmole)

= - 8080475.9 kJ

Q_{in} = (x*170kg/mole * H_{c12H26})

Q_{in} = (0.236*0.9*170 kmole * -291010kj/kmole C12H26) = - 10507789.08 kJ

By equation 4.28, we have;

$\eta_{ci} = \frac{-8080475.9}{-10507789.08}*100$

η_{cI} = 76.9%

To find second-law combustion efficiency, we have;

$W_{rev} = \bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}_{H2O}$

Using Gibbs function from table A-26, we get the actual work by equation 4.32 as;

W_{rev} = (0.9*+50150) - (12.1*-394360) - (13.05*-237180)

= 7912090 kJ

And from equation 4.33 using Gibbs function against, we have chemical exergy as;

$$\bar{a}_{ch} = [(+50150) + (0) - (12.1 * -394360) - (13.05 * -237180)] - +(8.314)(298.15)ln\frac{(0.2094)^{18.528}}{(0.0004)^{12.1}(0.038)\text{^}13.05}$$

= 9220692.535 kJ/170 = 54239.4 kJ/kg $0.9C_{12}H_{26}$

From equation 4.31, we get the combustion efficiency as;

$\eta_{cII} = \frac{7912090kJ}{(170kg)*(\frac{54239.4J}{kg})} * 100 = 0.8581 = 85.81\%$

Appendix D.4: Kerosene-biodiesel blend (B15) combustion investigation in wick/Butagas stove

The chemical equation of the B15 can be written as,

$0.85C_{12}H_{26}$ +0.15(C+H_2+O_2) + a(O_2 + 3.76N_2) ⟶ 1.6CO_2+0.126CO + bH_2O(l) + z3.76N_2

By balancing the equation, we have;

C: 10.35 =10.35; H: b = 11.2; O: a = 15.737,

N: z = 15.737

Writing the balanced chemical equation and divided by 0.85, we have;

$C_{12}H_{26}$ +0.15(C+H_2+O_2)+18.514(O_2 + 3.76N_2) ⟶ 12.028CO_2 + 0.126CO + 13.15H_2O(l) + 69.613N_2

We know that, from air; $\frac{(18.514kmole)\left(32\frac{kg}{kmole}\right)+(18.514*3.76\ kmole)(28\frac{kg}{kmole})}{(18.514kmole)+(18.514*3.76\ kmole)} = 29\ kg/kmole$

By substituting the values in equation 4.34, we have;

$$AF = \frac{(18.514*4.76\ kmole)\left(29\frac{kg}{kmole}\right)}{(12\ kmol)\left(\frac{12kg}{kmole}\right)+\left(0.15*1kmol*\frac{12kg}{kmol}\right)+(13\ kmole)\left(2\frac{kg}{kmole}\right)+\left(0.15*1kmol*\frac{2kg}{kmol}\right)+\left(0.15*1kmol*\frac{32kg}{kmol}\right)}$$

$$= \qquad 14.45\frac{kg\ air}{kg\ fuel}$$

- Percentage theoretical air = $\frac{Mass\ of\ air,actual}{Mass\ of\ air,theiretical}$

By writing the theoretical chemical equation, we have;

$0.85C_{12}H_{26} + 0.15(C+H_2+O_2)+a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O(l) + d3.76N_2$

By balancing the above equation, we have;

C: b = 10.35; H: c = 11.125; O: a = 15.762; N: d = 15.762

So, the balanced chemical equation and divided by 0.85 becomes;

$C_{12}H_{26}+0.15(C+H2+O2)+18.5435(O_2 + 3.76N_2) \rightarrow 12.176CO_2 + 13.088H_2O(l) + 69.72N_2$

By using equation 4.35, we have;

Percentage theoretical air = $\frac{(18.514*4.76\ kmole)}{(18.5435*4.76\ kmole)} = 0.9984 = 99.84\%$

Which means there is 0.16% deficient of air which was not used during combustion.

By equation 4.29 and 4.30, and using enthalpy of formation from table A-26, h_c becomes;

hc=((12.028kmol*-393520kj/kmol)+(0.126kmol*-110530kj/kmol)+(13.15kmol*-285830kj/kmol))- (1kmol*-291010kj/kmol)

= -8214839.84 kJ/170 kg $C_{12}H_{26}$ = 48322.6 kJ/kg

Which is partially identical to the listed value of 47470 kj/kg in table B3 appendix.

Q_{out} = (12.028 kmol*Hco_2 kj/kmol) + (0.126 kmol*Hco kj/kmol) + (13.55kmole*H_{H2O})

Q_{out} = (12.028kmol*-393520kj/kmol) + (0.126kmol*-110530kj/kmol) + (13.15kmole*285830Kj/kmole)

= - 8505849.84 kJ

Q_{in} = (x*170kg/mole * H_{c12H26})

Q_{in} = (0.236*0.85*170 kmole * -291010kj/kmole C12H26) = 9924023.02 kJ

By equation 4.28, we have;

$\eta_{ci} = \frac{-8505849.84}{-9924023.02} * 100$

η_{cI} = 85.7%

To find second-law combustion efficiency, we have;

$W_{rev} = \bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}_{H2O}$

Using Gibbs function from table A-26, we get the actual work by equation 4.32 as;

W_{rev} = (0.85*+50150) - (12.176*-394360) - (13.088*-237180)

= 7948566.7 kJ

And from equation 4.33 using Gibbs function against, we have chemical exergy as;

$$\bar{a}_{ch} = [(+50150) + (0) - (12.176 * -394360) - (13.088 * -237180)] - +(8.314)(298.15)ln\frac{(0.2094)^{18.545}}{(0.0004)^{12.176}(0.038)\text{^}13.088}$$

= 9035567.95 kJ/170 = 53150.4 kJ/kg $0.85C_{12}H_{26}$

From equation 4.31, we get the combustion efficiency as;

$\eta_{cII} = \frac{7948566.7kJ}{(170kg)*(\frac{53150.4kJ}{kg})} * 100 = 0.8797 = 87.97\%$

Appendix D.5: Kerosene-biodiesel blend (B20) combustion investigation in wick/Butagas stove

The chemical equation of the B20 can be written as,

$0.8C_{12}H_{26} + 0.2(C+H_2+O_2) + a(O_2 + 3.76N_2) \rightarrow 2.84CO_2 + 0.0725CO + bH_2O(l) + z3.76N_2$

By balancing the equation, we have;

C: 9.8 =9.8; H: b = 10.6; O: a = 14.864,

N: z = 14.864

Writing the balanced chemical equation and divided by 0.8, we have;

$C_{12}H_{26}$ +0.25(C+H_2+O_2)+18.58(O_2 + 3.76N_2) ⟶ 12.159CO_2 + 0.09CO + 13.25H_2O(l) + 69.86N_2

We know that, from air; $\frac{(18.58kmole)\left(32\frac{kg}{kmole}\right)+(18.58*3.76\ kmole)(28\frac{kg}{kmole})}{(18.58kmole)+(18.58*3.76\ kmole)} = 29\ kg/kmole$

By substituting the values in equation 4.34, we have;

AF = $\frac{(18.58*4.76\ kmole)\left(29\frac{kg}{kmole}\right)}{(12\ kmol)\left(\frac{12kg}{kmole}\right)+\left(0.2*1kmol*\frac{12kg}{kmol}\right)+(13\ kmole)\left(2\frac{kg}{kmole}\right)+\left(0.2*1kmol*\frac{2kg}{kmol}\right)+\left(0.2*1kmol*\frac{32kg}{kmol}\right)}$

$$= \quad 14.3124\frac{kg\ air}{kg\ fuel}$$

- Percentage theoretical air = $\frac{Mass\ of\ air,actual}{Mass\ of\ air,theiretical}$

By writing the theoretical chemical equation, we have;

0.8$C_{12}H_{26}$ +0.2(C+H_2+O_2)+a(O_2 + 3.76N_2) ⟶ bCO_2 + cH_2O(l) + d3.76N_2

By balancing the above equation, we have;

C: b = 9.8; H: c = 10.6; O: a = 15.1; N: d = 15.1

So, the balanced chemical equation and divided by 0.8, becomes;

$C_{12}H_{26}$+0.25(C+H2+O2)+18.6(O_2 + 3.76N_2)⟶ 12.25CO_2 + 13.25H_2O(l) + 69.9736N_2

By using equation 4.35, we have;

Percentage theoretical air = $\frac{(18.58*4.76\ kmole)}{(18.6*4.76\ kmole)} = 0.999 = 99.9\%$

Which means there is 0.1% deficient of air which was not used during combustion.

By equation 4.29 and 4.30, and using enthalpy of formation from table A-26, h_c becomes;

hc=((12.159kmol*-393520kj/kmol)+(0.09kmol*-110530kj/kmol)+(13.25kmol*-285830kj/kmol))- (1kmol*-291010kj/kmol)

= -8290994.88 kJ/170 kg $C_{12}H_{26}$ = 48770.56 kJ/kg

Which is partially identical to the listed value of 47470 kj/kg in table B3 appendix.

Q_{out} = (12.159kmol*Hco_2 kj/kmol) + (0.09kmol*Hco kj/kmol) + (13.25kmole*H_{H2O})

Q_{out} = (12.159kmol*-393520kj/kmol) + (0.09kmol*-110530kj/kmol) + (13.25kmole*285830Kj/kmole)

= - 8582004.88kJ

Q_{in} = (x*170kg/mole * H_{c12H26})

Q_{in} = (0.236*0.8*170 kmole * -291010kj/kmole C12H26) = 9340256.96 kJ

By equation 4.28, we have;

$\eta_{ci} = \frac{-8582004.88}{-9340256.96}*100$

η_{cI} = 91.88%

To find second-law combustion efficiency, we have;

$W_{rev} = \bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}_{H2O}$

Using Gibbs function from table A-27, we get the actual work by equation 4.32 as;

W_{rev} = (0.8*+50150) - (12.25*-394360) - (13.25*-237180)

= 8013665 kJ

And from equation 4.33 using Gibbs function against, we have chemical exergy as;

$$\bar{a}_{ch} = [(+50150) + (0) - (12.25 * -394360) - (13.25 * -237180)] - +(8.314)(298.15)ln\frac{(0.2094)^{18.61}}{(0.0004)^{12.25}(0.038)\text{^}13.25}$$

= 8637656.2 kJ/170 = 50809.74kJ/kg 0.8$C_{12}H_{26}$

From equation 4.31, we get the combustion efficiency as;

$\eta_{cII} = \frac{8013665kJ}{(170kg)*(\frac{50809.74kJ}{kg})} * 100 = 0.9278 = 92.78\%$

Appendix D.6: Pure biodiesel (B100) combustion investigation in wick/Butagas stove

The chemical equation of the B100 can be written as,

$C_xH_yO_z(l) + a(O_2 + 3.76N_2) \rightarrow 2.098CO_2 + 0.0642CO + b/2H_2O(g) + c3.76N_2$

By balancing the equation, we have;

C: x = 2.1622 = 2; H: b = 3; O: a = 3.63,

N: c = 3.63

Writing the balanced chemical equation, we have;

$C_{2.1622}H_6(l) + 3.63(O_2 + 3.76N_2) \rightarrow 2.098CO_2 + 0.0642\ 0.09CO + 3H_2O(l) + 13.6488N_2$

Note: In this analysis Oz was omitted because it is still zero even if we balance it. And 2.1622 is approximately equal to 2 which is ethane gas in hydrocarbon fuels table A-26. So writing the balanced equation again, we have;

$C_2H_6\ (g) + 3.63(O_2 + 3.76N_2) \rightarrow 2.098CO_2 + 0.0642CO + 3H_2O(g) + 13.6488N_2$

We know that, from air; $\frac{(3.63kmole)\left(32\frac{kg}{kmole}\right)+(3.63*3.76\ kmole)(28\frac{kg}{kmole})}{(3.63kmole)+(3.63*3.76\ kmole)} = 29\ kg/kmole$

By substituting the values in equation 4.34, we have;

$AF = \frac{(3.63*4.76\ kmole)\left(29\frac{kg}{kmole}\right)}{(2\ kmol)\left(\frac{12kg}{kmole}\right)+(3\ kmole)\left(2\frac{kg}{kmole}\right)} = 16.703\frac{kg\ air}{kg\ fuel}$

- Percentage theoretical air = $\frac{Mass\ of\ air,actual}{Mass\ of\ air,theiretical}$

By writing the theoretical chemical equation, we have;

$C_2H_6(g) + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O(l) + d3.76N_2$

By balancing the above equation, we have;

C: b = 2; H: c = 3; O: a = 3.5; N: d = 3.5

So, the balanced chemical equation and divided by 0.8, becomes;

$C_2H_6 + 3.5(O_2 + 3.76N_2) \rightarrow 2CO_2 + 3H_2O(l) + 13.16N_2$

By using equation 4.35, we have;

Percentage theoretical air = $\frac{(3.63*4.76\ kmole)}{(3.5*4.76\ kmole)} = 1.04 = 104\%$

Which means there is 4% excess air which was used during combustion of pure biodiesel in wick/Butagas stove.

By equation 4.29 and 4.30, and using enthalpy of formation from table A-26, h_c becomes;

hc=((2.098kmol*-393520kj/kmol)+(0.0642kmol*-110530kj/kmol)+(3kmol*-285830kj/kmol))- (1kmol*-84680kj/kmol)

= -1605510.986 kJ/30 kg C_2H_6 = -53517.03 kJ/kg

Which is partially identical to the listed value of -51,875 kJ/kg in table B3 appendix.

Q_{out} = (2kmol*Hco_2 kj/kmol) + (0.0642kmol*Hco kj/kmol) + (3kmole*H_{H2O})

Q_{out} = (2.098kmol*-393520kj/kmol) + (0.0642kmol*-110530kj/kmol) + (3kmole*285830Kj/kmole)

= - 1690190.986 kJ

Q_{in} = (x*30kg/mole * H_{c2H6})

Q_{in} = (30 kgkmole * -84680kj/kgkmole C12H26) = -1905300 kJ

By equation 4.28, we have;

$\eta_{ci} = \frac{-1690190.986}{-1905300}$*100

η_{cI} = 88.71%

To find second-law combustion efficiency, we have;

$W_{rev} = \bar{g}_{C_aH_b} + \left(a + \frac{b}{4}\right)\bar{g}_{O_2} - a\bar{g}_{CO_2} - b\bar{g}_{H2O}$

Using Gibbs function from table A-26, we get the actual work by equation 4.32 as;

W_{rev} = (-32890) - (2*-394360) - (3*-237180)

= 1,467,370 kJ

And from equation 4.33 using Gibbs function against, we have chemical exergy as;

$$\bar{a}_{ch} = [(-32890) + (0) - (2 * -394360) - (3 * -237180)] - +(8.314)(298.15)ln\frac{(0.2094)^{3.5}}{(0.0004)^2(0.038)\text{^}3}$$

= 1468275.52kJ/30 = 48942.52kJ/kg C_2H_6

From equation 4.31, we get the combustion efficiency as;

$$\eta_{cII} = \frac{8013665kJ}{(30kg)*(\frac{48942.52J}{kg})} * 100 = 0.90853 = 90.853\%$$

TABLE A–26

Enthalpy of formation, Gibbs function of formation, and absolute entropy at 25°C, 1 atm

Substance	Formula	$\bar{h}_f^\circ$ kJ/kmol	$\bar{g}_f^\circ$ kJ/kmol	$\bar{s}^\circ$ kJ/kmol-K
Carbon	C(s)	0	0	5.74
Hydrogen	$H_2(g)$	0	0	130.68
Nitrogen	$N_2(g)$	0	0	191.61
Oxygen	$O_2(g)$	0	0	205.04
Carbon monoxide	$CO(g)$	−110,530	−137,150	197.65
Carbon dioxide	$CO_2(g)$	−393,520	−394,360	213.80
Water vapor	$H_2O(g)$	−241,820	−228,590	188.83
Water	$H_2O(\ell)$	−285,830	−237,180	69.92
Hydrogen peroxide	$H_2O_2(g)$	−136,310	−105,600	232.63
Ammonia	$NH_3(g)$	−46,190	−16,590	192.33
Methane	$CH_4(g)$	−74,850	−50,790	186.16
Acetylene	$C_2H_2(g)$	+226,730	+209,170	200.85
Ethylene	$C_2H_4(g)$	+52,280	+68,120	219.83
Ethane	$C_2H_6(g)$	−84,680	−32,890	229.49
Propylene	$C_3H_6(g)$	+20,410	+62,720	266.94
Propane	$C_3H_8(g)$	−103,850	−23,490	269.91
n-Butane	$C_4H_{10}(g)$	−126,150	−15,710	310.12
n-Octane	$C_8H_{18}(g)$	−208,450	+16,530	466.73
n-Octane	$C_8H_{18}(\ell)$	−249,950	+6,610	360.79
n-Dodecane	$C_{12}H_{26}(g)$	−291,010	+50,150	622.83
Benzene	$C_6H_6(g)$	+82,930	+129,660	269.20
Methyl alcohol	$CH_3OH(g)$	−200,670	−162,000	239.70
Methyl alcohol	$CH_3OH(\ell)$	−238,660	−166,360	126.80
Ethyl alcohol	$C_2H_5OH(g)$	−235,310	−168,570	282.59
Ethyl alcohol	$C_2H_5OH(\ell)$	−277,690	−174,890	160.70
Oxygen	O(g)	+249,190	+231,770	161.06
Hydrogen	H(g)	+218,000	+203,290	114.72
Nitrogen	N(g)	+472,650	+455,510	153.30
Hydroxyl	OH(g)	+39,460	+34,280	183.70

Source: From JANAF, *Thermochemical Tables* (Midland, MI: Dow Chemical Co., 1971); *Selected Values of Chemical Thermodynamic Properties*, NBS Technical Note 270-3, 1968; and *API Research Project 44* (Carnegie Press, 1953).

Table B3: Enthalpy of combustion or heating values of some hydrocarbons at 25 °C [31].

Hydrocarbon	Formula	Liquid H_2O in products (negative of higher heating value)		Vapor H_2O in products (negative of lower heating value)	
		Liquid hydrocarbon, kJ kg^{-1} fuel	Gaseous hydrocarbon, kJ kg^{-1} fuel	Liquid hydrocarbon, kJ kg^{-1} fuel	Gaseous hydrocarbon, kJ kg^{-1} fuel
Paraffin family					
Methane	CH_4	-	-55,496	-	-50,010
Ethane	C_2H_6	-	-51,875	-	-47,484
Propane	C_3H_8	-49,975	-50,345	-45,983	-46,353
Butane	C_4H_{10}	-49,130	-49,500	-45,344	-45,714
Pentane	C_5H_{12}	-48,643	-49,011	-44,983	-45,351
Hexane	C_6H_{14}	-48,308	-48,676	-44,733	-45,101
Heptane	C_7H_{16}	-48,071	-48,436	-44,557	-44,922
Octane	C_8H_{18}	-47,893	-48,256	-44,425	-44,788
Decane	$C_{10}H_{22}$	-47,641	-48,000	-44,239	-44,598
Dodecane	$C_{12}H_{26}$	-47,470	-47,828	-44,109	-44,467
Olefin family					
Ethene	C_2H_4	-	-50,296	-	-47,158
Propene	C_3H_6	-	-48,917	-	-45,780
Butene	C_4H_8	-	-48,453	-	-45,316
Pentene	C_5H_{10}	-	-48,134	-	-44,996
Hexene	C_6H_{12}	-	-47,937	-	-44,800
Heptene	C_7H_{14}	-	-47,800	-	-44,662
Octene	C_8H_{16}	-	-47,693	-	-44,556
Nonene	C_9H_{18}	-	-47,612	-	-44,475
Decene	$C_{10}H_{20}$	-	-47,547	-	-44,410
Alkylbenzene family					
Benzene	C_6H_6	-41,831	-42,266	-40,141	-40,576
Methylbenzene	C_7H_8	-42,437	-42,847	-40,527	-40,937
Ethylbenzene	C_8H_{10}	-42,997	-43,395	-40,924	-41,322
Propylbenzene	C_9H_{12}	-43,416	-43,800	-41,219	-41,603
Butylbenzene	$C_{10}H_{14}$	-43,748	-44,123	-41,453	-41,828

Appendix E: 6th Annual research conference on Science, Technology & Innovation for Industry of Addis Ababa Science and Technology University participation certificate

Addis Ababa Science and Technology University

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CERTIFICATE

6th Annual Research Conference on Science, Technology & Innovation for Industry (STII 2022), May 09-10/2022.

This is to Certify that **Mr. Charan Tut Thiep, Adama Science & Technology University**

Has participated in the STII2022 event, and Presented a Research Paper entitled: **"Performance evaluation of kerosene stove fueled by blend of kerosene and bio-diesel extracted from waste cooking oil"**

Getachew Adam (PhD)
Research Director

Abraham Debebe (PhD)
V/president for RTT