CHAPTER I
INTRODUCTION

1.1 Research Background

The greenhouse effect occurs when gases like carbon dioxide methane and water vapor trap some of the heat released from the Earth's surface. This process helps keep the Earth warm enough for life to exist. Nevertheless this process becomes problematic when intensified by human activities especially the large scale burning of fossil fuels which elevates greenhouse gas concentrations in the atmosphere and leads to excessive heat retention (Irma & Gusmira, 2024). One way to reduce greenhouse gas concentrations is to replace cooking with fossil fuels with a new alternative: biomass.

Biomass is bioenergy derived from biological sources, such as plants. Biomass has a wide variety of classifications, but specifically refers to waste, for example from agricultural waste such as straw, corn cobs, rice husks, and so on. A key difference between fossil fuels and biomass lies in how each interacts with the carbon cycle. Fossil fuels release carbon that has been stored beneath the Earth's surface for millions of years when they are burned, whereas biomass returns carbon that plants have recently absorbed, allowing it to approach carbon neutrality when managed sustainably. Indonesia has great potential to produce bio-pellets sustainably, as can be seen from the abundance of the main biomass ingredients, for example rambutan peel waste (Herlambang et al., 2017).

Based on the Central Statistics Agency of *Badan Pusat Statistik* (BPS), the amount of rambutan production in 2023 reached 15,778 tonnes (Badan Pusat Statistik, 2023). The potential of rambutan peel as an alternative energy source originates from its chemical composition, which is dominated by lignocellulosic components consisting of cellulose at 24.28 percent, hemicellulose at 11.62 percent, and lignin at 35.34 percent (Tingting et al., 2022). Since rambutan peel has flammable compounds, it indicates that this material can be processed into alternative fuels. The rambutan peel used in this research is red rambutan peel *(Nephelium lappaceum).*

According to the previous study by Rahmawati (2013), rambutan peel can be used as a bio-briquette as an alternative solid material for bio-briquettes to produce heat energy as an energy source. The results of testing the quality of bio-briquette products from rambutan peel, obtained: density (0.59 g/cm^3 - 0.62 g/cm^3), water content (6.21%), ash content (4.19%), volatile matter content (16.33%), calorific value of (6,302.775) kcal/g, and fix carbon content (79.48%). This study meets the standard.

Biomass pellets and bio briquettes are manufactured differently. Bio briquettes are ground using a disc mill, and the material is then carbonized. The result of carbonization is charcoal, which is then pressed into bio briquettes using a hydraulic press. Bio briquettes are larger in size than biomass pellets. Biomass pellets offer moderate heat and durability, making them suitable for household use. Their small size is also more advantageous for household use because they are easier to store without requiring a lot of space. Meanwhile, bio briquettes are larger in size and therefore have a higher combustion value, making them more beneficial for the industrial sector (Wulandari et al., 2024).

This study used the Top-Lit Updraft (TLUD), a type of biomass gasifier stove that burns fuel from the top, creating a gasification process that produces clean heat and charcoal (biochar) as a by product (Birzer & Medwell, 2013). This operating principle distinguishes TLUD stoves from conventional stoves, which rely on direct and less controlled combustion mechanisms. In traditional stove, combustion occurs directly without a gasification process. It is the gasification process that gives TLUD stoves advantages. The gasification process in the TLUD stove occurs when the fuel is heated under limited-oxygen conditions. During operation the heat generated within the stove induces pyrolysis of the biomass fuel, a thermochemical process in which solid material decomposes into combustible gases such as hydrogen, carbon monoxide, and methane, commonly referred to as synthesis gas or syngas (Setyawan et al., 2024).

In contrast to traditional stoves that rely on direct fuel combustion, the TLUD stove operates by initiating only limited combustion at the early stage in order to supply the thermal energy required for gasification. The combustible gases generated from

this process, known as syngas, are subsequently directed into a secondary combustion zone, where they combine with additional air and burn in a clean and stable manner. This staged combustion mechanism allows the TLUD stove to perform more efficiently than conventional stoves, as it promotes more complete fuel utilization while significantly minimizing exhaust emissions (Setyawan et al., 2024).

Another type of biomass gasifier stove is the Bottom-Lit Updraft (BLUD) stove. The fundamental distinction between TLUD and BLUD stoves lies in the ignition point and airflow pattern. In a BLUD stove, combustion begins under the fuel bed, while the gasification air moves upward through the biomass. Performance comparisons reported by Makonese et al. (2017) indicate that the TLUD stove delivers a higher thermal output of 6.9 kW with a cooking efficiency of 12.6%, whereas the BLUD stove produces a lower firepower of 4.4 kW and achieves a cooking efficiency of 8.2%. In terms of particulate emissions, the TLUD stove records a $PM_{2.5}$ and PM_{10} emission factor of 0.65 g/MJ, which is substantially lower than that of the BLUD stove at 3.3 g/MJ. Similarly, the emission factors for carbon monoxide and carbon dioxide are slightly lower for the TLUD stove, measuring 4.0 g/MJ and 100 g/MJ respectively, compared to 4.1 g/MJ and 102 g/MJ for the BLUD stove. These performance indicators demonstrate that the TLUD stove exhibits superior efficiency and environmental performance relative to the BLUD configuration.

The study that was conducted on TLUD stove using rambutan peel and utilizing rambutan peel as bio-pellet are not yet available. Therefore, in this study, TLUD stove method and rambutan peel as bio-pellet will be conducted. This study will refer to the Indonesian National Standard (SNI) 8675:2018 on Bio-pellets for Energy. The selection of Particulate Matter 2.5 ($PM_{2.5}$), carbon monoxide (CO), and carbon dioxide (CO_2) as the tested parameters is based on their relevance as mandatory indicators in biomass stove performance evaluations. These emission parameters are required to assess combustion quality and environmental impact. Fuel performance and suitability assessment in bio pellets follows quality requirements established by SNI standards which include moisture content ash content volatile matter fixed carbon and calorific value. SNI 7926:2013 on Biomass

Stove Performance will also be used as a reference in this study. This research will focus on the biomass stove.

1.2 Research Purpose and Objectives

1.2.1 Research Purpose

This research aims to examine the operational performance of a Top-Lit Updraft TLUD biomass stove based on the performance requirements outlined in SNI 7926:2013 while also evaluating the potential of rambutan peel bio pellets as an environmentally friendly biomass-based fuel. The focus of this research is to evaluate the performance of the TLUD biomass stove.

1.2.2 Research Objectives

The research objectives are as follows:

1. To assess the quality characteristics of bio-pellets produced from rambutan peel based on the requirements set forth in SNI 8675:2018 for energy bio-pellets.
2. To determine the levels of particulate matter $PM_{2.5}$ carbon monoxide CO and carbon dioxide CO_2 released from the combustion of rambutan peel bio pellets in a Top Lit Updraft TLUD biomass stove by applying the performance requirements specified in SNI 7926:2013.
3. To analyze the performance of the TLUD biomass stove fueled with rambutan peel bio-pellets by measuring specific fuel consumption, combustion efficiency, and thermal efficiency, based on the performance indicators established in SNI 7926:2013.

1.3 Research Benefit

The benefits of this research are as follows:

1. Providing alternative solutions to overcome the problem of rambutan peel waste and the dependence on fossil fuels.
2. Supporting policy and innovation in biomass energy of rambutan peel as an alternative fuel and becoming a reference for further research on the utilization of biomass waste, especially rambutan peel.

3. Become the source of information for the government and the community, regarding the potential of rambutan peel as an alternative fuel.

1.4 Research Problem Limitations

The problem limitations of this research are as follows:

1. This study utilizes a Top-Lit Updraft (TLUD) biomass stove as the primary combustion system to examine biomass stove performance.
2. All performance testing takes place at the Air Quality Laboratory LKU of the Department of Environmental Engineering Faculty of Engineering Andalas University and this study evaluates biomass stove performance using SNI 7926:2013 through emission analysis of $PM_{2.5}$ CO and CO_2 together with efficiency related parameters.
3. Rambutan peel bio-pellets are employed as the fuel source in this research, highlighting their potential as an alternative biomass energy material.
4. The manufacturing process of rambutan peel bio-pellets is performed at the Integrated Waste Processing Center (PPST), Andalas University.
5. The evaluation of bio-pellet quality includes the analysis of density, moisture content, volatile matter, ash content, fixed carbon, calorific value, and sulfur content, following the standards outlined in SNI 8675:2018. These analyses are conducted at the Solid Waste Laboratory (LBP), Department of Environmental Engineering, Faculty of Engineering, Andalas University.

1.5 Research Writing Systematic

The writing system of this research are as follows:

CHAPTER I **INTRODUCTION**

This chapter explains the research background, the purposes, the objectives of the research, the benefits of the research, the problem limitations of the research, and writing systematic research.

CHAPTER II **LITERATURE REVIEW**

This chapter explains the theoretical basis of the research material, supporting research data, what biomass, bio

pellets, and biomass stoves are, along with related research from previous study.

CHAPTER III RESEARCH METHODOLOGY

This chapter explains the research materials, research design, data collection, processing, analysis and interpretation of data as well as the location and time of the research.

CHAPTER IV RESULT AND DISCUSSION

This chapter presents the results that are obtained through the research, along with their explanation.

CHAPTER V CONCLUSIONS AND SUGGESTIONS

This chapter contains conclusions and suggestions according to the research that has been conducted and the discussion that have been described.