Development of a small-scale biochar production

Kanchanit Chawalitsoonthorn

Satapoorn Sringam

Advisor

Asst.Prof.Dr. Nuttapol Lerkkasemsan

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SCHOOL OF INTERNATIONAL & INTERDISCIPLINARY ENGINEERING PROGRAMS

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PROJECT CERTIFICATE

Report Title	Development of a small-scale biochar production	
Student Name	Miss Kanchanit Chawalitsoonthorn	Student ID: 62011129
	Miss Sataporn Sringam	Student ID: 62011244
Degree	Bachelor of Engineering in Chemical Engineering (International Program)	

Project Advisor Signed: ______________________

(Asst. Prof. Dr. Nuttapol Lerkkasemsan)

Committee Signed: Apinan N.

(Asst. Prof. Dr. Apinan Namkanisorn)

Committee Signed: W. Ch.

(Asst. Prof. Dr. Walairat Chandra-Ambhorn)

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ABSTRACT

Biomass from agricultural residues is used as a raw material for biochar preparation. The utilization of biochar for various applications is dependent on its properties, such as pore structure, stable aliphatic chain structure, and high mineral content. The biochar structure development has resulted in controlling pollution and gas release. Additionally, consideration in the economy is related to the biochar yield. This research focuses on the development of biochar production, including optimization of gasification condition that increase the heat transfer in the gasifier and improve quality of biochar products, which will increase economic benefits and prevent the release of pollution from agricultural burning. The gasifier is designed from SketchUp program. Biomass is transformed during at high temperatures (550 – 1200°C) and with sufficient oxygen. The gasifier height is 177 cm and diameter are 50 cm. From testing, this system can produce 23.4 kg of biochar from 48 kg of biomass in 2 hours and the iodine value reaches 342.315 mg/g.

Keywords: Gasifier, pyrolysis, biochar, syngas, biomass

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Kanchanit Chawalitsoonthorn
Sataporn Sringam

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CHAPTER I

INTRODUCTION

1.1 Introduction and Background

Agriculture in Thailand plays a vital role because the terrain is suitable, and the large population in the country is engaged in agriculture. No matter how much the industry in the country has developed, it still relies on agriculture in tandem. The evolution of agriculture has changed with the times, and technology is becoming more advanced. However, some agricultural products can also be developed more efficiently. Biomass is the residues from agriculture such as sugar cane, rice husk, sawdust, etc. Most of them have no benefits to the industry and eventually burn as waste. Crop residues of straw from the northern part in 2020 are 23,177 tons, which is a significant proportion. Furthermore, the burning of agricultural crop residues is the leading cause of dust formation today. Carbon dioxide and dust released due to large quantities of crop residues are 29,318 tons, contributing to air pollution and human health issues. Biomass from agricultural residues is used as a raw material for biochar preparation. The utilization of biochar for various applications is dependent on its properties, such as pore structure, stable aliphatic chain structure, and high mineral content. The biochar structure development has resulted in controlling pollution and gas release. Additionally, consideration in the economy is related to the biochar yield. Therefore, this research focuses on the development of biochar production, including optimization of gasification condition that increase the heat transfer in the gasifier and improve quality of biochar products, which will increase economic benefits and prevent the release of pollution from agricultural burning.

1.2 Project scopes

1.2.1 Design a pilot scale gasifier for biochar production that uses agricultural residues as a feedstock.

1.2.2 Optimize the gasification condition to increase the heat transfer in the gasifier.

1.3 Objectives

1.3.1 To study the principle of biochar production from biomass.

1.3.2 To design and develop a high efficiency gasifier for biochar production.

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1.4 Expected benefits.

1.4.1 We can apply the basic principle of chemical engineering to design a high efficiency gasifier for biochar production.

1.4.2 The gasifier, we designed, can be operated effectively, and can produce good-quality biochar.

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CHAPTER II

THEORIES AND LITERATURE REVIEWS

2.1 Theories

2.1.1 Principle of heat transfer

Heat transfer is the process of energy transfer from one system or substance to another due to a temperature difference between them. It occurs when two systems with different temperatures come into contact, and the energy flows from the system with higher temperature to the one with lower temperature until they reach thermal equilibrium. There are three primary modes of heat transfer: conduction, convection, and radiation.

a) Conduction

Conduction is the transfer of heat through a solid material or between objects in direct contact. In this mode, heat energy is transferred by the vibration and collisions of atoms and molecules within a material. The rate of heat transfer depends on the thermal conductivity of the material, the cross-sectional area through which the heat is transferred, the temperature difference, and the distance between the hot and cold regions.

b) Convection

Convection is the transfer of heat in fluids (liquids and gases) due to the movement of the fluid itself. In this mode, heat is transferred by the circulation of fluid particles carrying thermal energy from one region to another. There are two types of convection: natural (or free) convection and forced convection. In natural convection, fluid motion is driven by buoyancy forces caused by temperature differences. In forced convection, fluid motion is driven by external means, such as a fan or a pump.

c) Radiation

Radiation is the transfer of heat in the form of electromagnetic waves, primarily infrared radiation. Unlike conduction and convection, radiation does not require a medium to transfer heat; it can occur in a vacuum. All objects emit and absorb thermal radiation, and the net heat transfer is determined by the difference between the emission and absorption of radiation by the

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objects. The rate of radiative heat transfer depends on the temperature, surface area, and emissivity of the objects involved, as well as the distance between them.

2.1.2 Heat transfer in various shapes

Table 1: The heat transfer in conical shape

Advantages	Explanation
Streamlined Shape	The conical shape allows for smoother flow around the object, reducing drag and improving heat transfer efficiency in forced convection situations, especially when the fluid flows along the axis of the cone.
Uniform Temperature Distribution	Due to the gradual change in the cross-sectional area of the conical shape, temperature distribution can be more uniform along the surface compared to other shapes. This could be beneficial in certain applications, such as heat exchangers.
Easier Mold Removal	In manufacturing processes that involve molds, such as casting, the conical shape can make it easier to remove the solidified part from the mold, as there are no sharp edges or corners that could cause the part to get stuck.
Self-draining Capability	In systems that require periodic draining, such as heat exchangers, the conical shape can facilitate self-draining due to its tapered geometry. Gravity aids in moving fluids out of the system, reducing the need for additional draining mechanisms.
Improved Mixing and Heat Transfer in Fluids	The conical shape can enhance mixing in fluids when used as a mixing element, such as a static mixer, which can improve the heat transfer between the fluids. The shape can induce vortex formation and turbulent flow, which can promote better heat transfer.
Focused Radiative Heat Transfer	The conical shape can be used to focus or direct radiative heat transfer in certain applications, such as solar concentrators or infrared heaters. The shape can collect and direct the incoming radiation towards a specific point or area, improving energy efficiency.

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Table 2: Heat transfer in cylindrical shape

Advantages	Explanation
Uniform cross-sectional area	A constant cross-sectional area allows for more predictable and even heat distribution, simplifying heat transfer calculations.
Easy to manufacture	Cylindrical shapes can be more easily produced using standard manufacturing processes, making them more cost-effective.
Higher volume-to-surface-area ratio	Cylinders have a higher volume-to-surface-area ratio compared to other shapes, which can help minimize heat loss.
Easier to insulate	The uniform geometry of cylinders makes it simpler to apply insulation, which can help to reduce heat loss and conserve energy.
Simplified conduction calculations	The use of cylindrical coordinates simplifies the conduction calculations, making it easier to analyze and design heat transfer systems.
Widespread use in industrial applications	Cylindrical shapes are commonly used in various industrial applications, such as pipes, heat exchangers, and storage tanks, due to their simplicity and effectiveness in managing heat transfer.

Table 3: Comparison of the heat transfer performance in conical and cylindrical shape

	Cylindrical Shape	Conical Shape
Geometry	Uniform cross-sectional area	Variable cross-sectional area
Heat Distribution	More predictable and even	Less predictable and uneven
Manufacturing Ease	Easier to manufacture	More complex manufacturing process
Surface Area to Volume Ratio	Lower surface area to volume ratio (better for minimizing heat loss)	Higher surface area to volume ratio (more prone to heat loss)
Insulation Ease	Easier to insulate due to uniform geometry	More complex insulation requirements

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	Cylindrical Shape	Conical Shape
Conduction Calculations	Simplified calculations in cylindrical coordinate system	More complex calculations in conical coordinate system
Convection Efficiency	Depends on application, fluid properties, and flow characteristics	Depends on application, fluid properties, and flow characteristics
Heat Transfer Coefficient	Varies with geometry, material, and boundary conditions	Varies with geometry, material, and boundary conditions
Industrial Applications	More widespread use in industrial applications, e.g., pipes, heat exchangers, storage tanks	More specialized use, e.g., funnels, rocket nozzles

2.1.3 Temperature gradient

A temperature gradient is a physical parameter that indicates the rate of and in what direction the temperature changes around a specific point.

Considering a cylindrical shell of radius r, length z, and radial thickness dr, heat transfer occurs only in the radial direction, as the aspect ratio is large enough so the heat transfer in the axial direction is negligible. It is assumed that heat transfer takes place within the solid by conduction only.

Based on the initial and boundary condition given below:

- Initial condition

  At $t = 0$, $T(r,0) = T_0$

- Boundary conditions

  $$t > 0,\ r=0,\ \frac{dt}{dr} = 0$$

  $$t = 0,\ r=R,\ \left(-k\frac{dt}{dr}\right) = h\left(T_f - T\right) + \sigma\epsilon\left(T_f^4 - T^4\right)$$

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The parameters are introduced in equation 2.1 in order to solve the heat transfer equation.

$$\alpha = \frac{k}{\rho C_p} \qquad 2.1$$

$$x = \frac{r}{R} \qquad 2.2$$

$$\tau = \frac{\alpha t}{R^2} \qquad 2.3$$

$$\theta = \frac{T_f - T}{T_f - T_0} \qquad 2.4$$

$$Q = \frac{(-\Delta H) + C_p T}{\rho C_p (T_f - T_0)} \qquad 2.5$$

The ordinary differential equation describing the mass change of the biomass based on the kinetic mechanism are given below for the process of pyrolysis:

$$\frac{dC_B}{dt} = -(k_1 + k_2)(C_B)^{n_1} \qquad 2.6$$

$$k_1 = A_1 \exp \boxed{f()} \left[\frac{D_1}{T} + \frac{L_1}{T^2} \right] \qquad 2.7$$

$$k_2 = A_2 \exp \boxed{f()} \left[\frac{D_2}{T} + \frac{L_2}{T^2} \right] \qquad 2.8$$

It is essential to solve the equation based on initial and boundary conditions in the equation below:

$$\frac{d\theta}{d\tau} = \frac{1}{x}\frac{d\theta}{dx} + \frac{d^2\theta}{dx^2} + \frac{QR^2 k_1 (C_B)^{n_1}}{\alpha} \qquad 2.9$$

2.1.4 Temperature profile

Pyrolysis time-temperature profiles are helpful for any thermal conversion process of biomass due to the information on the temperature trend and help in an understanding of the reaction mechanism. Every imaginary intermediate plane is equally affected by the heat that is transmitted from the inside to the outside of the wall.

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The surface area increases linearly as radius r increases. Consequently, it indicates that the heat flow is dispersed over an increasing area, or that the heat flux decreases as r increases according to equation 2.10.

$$dT=\frac{\dot{Q}}{\lambda \cdot A}\cdot dr \qquad 2.10$$

The equation indicates in the precise temperature trajectory T(r), with the thermal conductivity once more being assumed to be constant. The area is now a function of radius. The cylindrical shape's length, l, can be used to calculate the surface area A at a distance, r.

2.1.5 Biomass

Biomass is the mass of living organisms, including forest wood, agricultural crops, and agricultural residues (rice husks, straw, bagasse, sawdust, wood chips, bark, manure, etc.). Developing countries like Thailand still use charcoal in the household for cooking. Biomass is an essential source of energy that can be found in the country since Thailand is an agricultural country. There are two main types of biomasses:

1) Plant-based resources
    a) Woody crops

Forest is the central part to decrease the amount of carbon dioxide released into the atmosphere. To use woody crops as biomass, the carbon dioxide caused by combustion is approximately the same. Therefore, it will not cause the problem of releasing too much carbon dioxide to the environment. However, the number of forests in the world is decreasing. The usage of woody crops, therefore, is under consideration.

    b) Agricultural crops

These energy crops have no complications in planting, and the agricultural areas are more flexible. Nowadays, crops, such as corn and sugar cranes, are widely used as resources to produce liquid fuels.

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2) Residue resources

a) Wood residues

Wood residues are biomass energy sources in solid form produced by the forest industry. The rest of the unused wood for the intended purpose, including sawdust obtained from timber processing, can be used as a source of energy.

b) Agricultural residues

The total amount of these wastes each year is billions of tons. New rice crops were burnt in the past, which caused a pollution problem. Burning straws in the field has been subsequently banned. The cost of transport is high due to its energy density and handling. Thus, using agricultural waste as resources solves such problems.

3) Municipal wastes

As a result of human consumption, the average waste disposal of each household in industrialized countries is more than 1 ton per year. These remainders can be used as an energy source.

2.1.6 Thermochemical conversion

Thermochemical conversion is a process that contains energy consumption in the form of heat to change the chemical structure. Thermochemical conversion can be divided into three methods:

1) Combustion

Combustion allows biomass to have higher energy. The design should be considered for the reduction of heat leakage. Combustion involves two steps which are moisture content reduction and the step of ignition, which gets both water and carbon dioxide.

2) Gasification

Gasification is a process of gas production from biomass. In the process, the control of air and oxygen needs to be considered. gases obtained from gasification are carbon monoxide, carbon dioxide, hydrogen, and methane, giving relatively low energy. [1]

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3) Pyrolysis

Pyrolysis is a process that gives heat to biomass without oxygen. Therefore, ignition does not happen in this case. An example of this process is producing charcoal which is a process that heats the feedstocks to 250°C to evaporate the moisture. The efficiency of energy conversion is up to 80%. Moreover, it allows biomass conversion to liquid and gas. For example, apply this process with organic substances by heating up until the temperature reaches 500-900 °C at atmospheric pressure and anaerobic condition; the product obtained is methanol. [1]

2.1.7 Gasification

1) Hearth zone or combustion zone

Solid fuel which contains carbon and hydrogen as the main component is combusted in this zone. As combustion occurs, carbon dioxide and water vapor are generated. The combustion temperature is about 1,450 °C.

2) Reduction zone or gasification zone

Flammable gas is synthesized in the reduction zone. Hot gas generated from combustion (i.e., Carbon dioxide, water vapor, and tar) flows to the reduction reaction. The gas products in this zone are carbon monoxide, hydrogen, and methane.

3) Distillation zone or pyrolysis zone

According to the heat transfer from the combustion zone, organic structure in the fuel is disintegrated to be volatile including methanol, acetic acid, crude oil, flammable gas, and inflammable gas. The temperature in this zone is approximately 280-500 °C. The residual from this process is carbon in the char.

4) Drying zone

As the temperature in this zone is insufficient to disintegrate the volatiles. Heat transfer from the pyrolysis vaporizes the moisture in the biomass in the form of water vapor. The temperature in this zone is 100-135°C. Efficiency can be increased by adding water vapor to the system. Water gas shift and water gas reaction occur as followed:

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$$CO + H_2O \leftrightarrow CO_2 + H_2$$ (Water gas shift reaction)

$$CO + H_2O \leftrightarrow CO + H_2$$ (Water gas reaction)

A water gas reaction is an endothermic reaction that decreases the temperature to 600-800°C. Carbon monoxide and hydrogen are formed afterward. If water vapor is excessive, it will react with carbon monoxide which causes carbon dioxide and hydrogen formation. The water gas shift reaction is shown in the equation. Both reactions increase the heating value of the fuel gas according to carbon monoxide and hydrogen formation. The efficiency of the gasifier is eventually increased. [1]

2.1.8 Biochar

Table 4: Properties of biochar that determine its efficiency in various applications.

Property	Description
Surface area	A higher surface area enables better adsorption of nutrients, water, and contaminants.
Porosity	Influences water-holding capacity, gas exchange, and nutrient availability.
Particle size	Affects surface area, porosity, and reactivity; smaller particles generally have higher surface areas.
pH	Impacts biochar's ability to buffer soil acidity or alkalinity.
Cation exchange capacity (CEC)	Indicates the ability to retain and exchange nutrients, such as potassium, calcium, and magnesium.
Fixed carbon content	Higher fixed carbon content implies longer-lasting carbon sequestration and a more stable amendment in the soil.
Elemental composition	Affects nutrient content and potential contributions to soil fertility.
Surface functional groups	Influence reactivity, adsorption capacity, and interactions with soil components.
Ash content	Impacts mineral content, alkalinity, combustion efficiency, and handling challenges.

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2.1.9 Combustion

A combustion reaction is an exothermic chemical reaction that happens when a substance (often fuel) combines with an oxidizing agent (typically oxygen) to produce heat and light energy. Combustion reactions are required for a variety of purposes such as power generation, heating, and transportation.

- In a complete combustion reaction, the fuel combines with oxygen to produce carbon dioxide (CO2) and water (H2O) as the primary products, along with the release of heat energy. For hydrocarbon fuels, such as gasoline, propane, or methane, the general equation for complete combustion is:

$$C_nH_m + (n + m/4)\ O_2 \longrightarrow nCO_2 + (m/2)\ H_2O$$

Here, C_nH_m represents the hydrocarbon fuel, where n and m are the number of carbon and hydrogen atoms, respectively.

- Incomplete combustion is a type of chemical reaction that occurs when a fuel does not burn completely, typically due to insufficient oxygen supply or other factors such as low temperature or poor mixing. Incomplete combustion is less efficient than complete combustion, as it does not fully convert the fuel's chemical energy into heat and often produces harmful byproducts., the general equation for complete combustion is:

$$C_nH_m + (x)\ O_2 \longrightarrow a\ CO_2 + b\ CO + c\ C + d\ H_2O + e\ C_nH_m$$

2.1.10 Calorific value

Calorific value, also known as heating value or energy content, is the amount of energy released when a specified quantity of a fuel is completely burned under controlled conditions. It is a measure of the fuel's capacity to produce heat and is typically expressed in units of energy per mass, such as joules per kilogram (J/kg) or British thermal units per pound (BTU/lb). There are two types of calorific values:

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1) Higher heating value (HHV) or gross calorific value

The HHV represents the total energy released when a fuel is burned, including the energy contained in the water vapor formed because of the combustion process. Since the water vapor condenses and releases the heat of vaporization, the HHV includes this latent heat. HHV is typically used when considering fuels with a significant moisture content or when the combustion products are cooled to recover the heat from the water vapor.

2) Lower heating value (LHV) or net calorific value

LHV represents the energy released when a fuel is burned, excluding the energy contained in the water vapor. In other words, it does not account for the latent heat of vaporization of the water vapor formed during combustion. LHV is typically used when the combustion products are not cooled enough to condense the water vapor, and the latent heat remains unrecovered.

Therefore, the calorific value of a fuel depends on its chemical composition and varies between different types of fuels. For example, coal, oil, and natural gas have different calorific values because they have different compositions and energy contents. Calorific value is an essential parameter in determining the efficiency and effectiveness of a fuel in producing heat or power and is used in engineering calculations for various applications, such as heating systems, power plants, and internal combustion engines.

2.1.11 Type of gasifier

a) Updraft (Counter-Current) gasifier

In an updraft gasifier, air enters from the bottom and moves upwards, countercurrent to the fuel flow. The produced gas exits at the top. Updraft gasifiers have a simple design and are suitable for producing low-quality gas with high tar content, which makes them less suitable for engine applications but appropriate for direct heating or firing kilns.

b) Downdraft (Co-Current) gasifier

Downdraft gasifiers have air entering at the top or side and moving downwards, co-current with the fuel flow. The gas is extracted from the bottom. These gasifiers are known for producing

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low-tar, higher-quality gas suitable for engine applications. However, they require well-sized fuel and are sensitive to fuel moisture content.

c) Crossdraft gasifier

Crossdraft gasifiers have air entering from the side and passing through the fuel bed horizontally. They are simpler in design compared to downdraft gasifiers and can produce medium-quality gas with moderate tar content. Crossdraft gasifiers are often used for direct heating applications and small-scale power generation.

d) Fluidized bed gasifier

Fluidized bed gasifiers suspend fuel particles in an upward-flowing stream of air, creating a fluid-like behavior. They provide excellent mixing of fuel and air, resulting in consistent temperature profiles and efficient conversion. Fluidized bed gasifiers can handle a wide range of fuel types and sizes but require more complex control systems.

The advantages and disadvantages in each gasifier type

Each type of gasifier has its advantages and disadvantages, making them more suitable for specific applications and feedstocks. It is crucial to consider factors such as the desired gas quality, fuel characteristics, and system complexity.

Table 5: The advantages and disadvantages in each gasifier type

Type of Gasifier	Advantages	Disadvantages
1. Updraft (Counter-Current)	- Simple design - Tolerance to fuel variability - Low particulate matter - Suitable for direct heating applications	- High tar content - Lower overall efficiency - Not ideal for engine applications
2. Downdraft (Co-Current)	- Low-tar, high-quality gas - Suitable for engine applications - Relatively simple design	- Sensitive to fuel properties - Requires well-sized fuel - Fuel moisture content sensitivity

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Type of Gasifier	Advantages	Disadvantages
3. Crossdraft	- Simple design - Moderate tar content - Suitable for direct heating and small-scale power generation	- Not ideal for high-quality gas requirements - Limited fuel variability handling
4. Fluidized Bed	- Excellent mixing of fuel and air - Consistent temperature profiles - Efficient conversion - Handles a wide range of fuel types and sizes	- More complex control systems - Higher capital and operational costs

2.2 Literature reviews

2.2.1 A design of a high-efficiency downdraft gasifier

Khosasaeng et al. design a high-efficiency downdraft gasifier by considering the height, throat diameter, and air pipe diameter of the gasifier, and controlling the amount of air. Additionally, a gasifier is designed with the steam generator system to increase its efficiency of the gasifier. According to the design, the 34kW gasifier with the raw material feed rate of 15 kilogram/hour generates steam at 13.84 kilogram/hour. Oxygen consumption is 2.68 m^3/h and air consumption are 13.99 m^3/h. The gasifier with the steam and oxygen addition to the system results in increased efficiency of 29.60% higher than the conventional gasifier. [2]

i. The design procedure

- Throat diameter

The throat diameter is calculated by specifying the fuel feed rate and determining the hearth load. The hearth cross-section area is 0.015 m^2 and the throat diameter is 0.138 meters.

- Gasifier diameter

The slope of the throat diameter from the gasifier wall and the throat has an angle of 45-60 degrees. The specific height is 22 centimeters which results in a 44 centimeters diameter. The proper angle of the slope is 45 degrees.

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- Gasifier height

Specific gasification rates, the density of fuel, and the resident time are needed to calculate the height of the reduction zone to the combustion area. The height is equal to 1.66 meters.

- Air or oxygen pipe diameter

The gasifier is designed with 4 air pipes. The total area of the air pipe is 0.000765 m^2 according to the calculation. Therefore, each pipe contains an area of 0.0001913 m^3 and the diameter is 1.56 centimeters.

- Oxygen feed rate

The properties of the fuel are analyzed by the Ultimate analysis to determine the carbon, oxygen, nitrogen, and sulfur content and the heating value of the fuel as shown in the table.

Table 6: Composition of municipal waste fuels

Fuel properties	**Value**
Moisture (wt%)	48.00
Proximate analysis (wt% dry basis)	
Fuel properties	**Value**
Volatile matter	46.15
Fixed carbon	7.70
Ash content	46.15
Ultimate analysis (wt% dry basis)	
C	30.77
H	4.62
O	17.30

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Fuel properties	Value
N	0.77
S	0.39
High heating value (kJ/kg)	13,076

Oxygen consumption of combustion can be calculated by the equation below:

$$M_{th} = \frac{32C}{12} + 8H + S - O$$

The gasification process consumes oxygen by 20-30% of the combustion process. As the ultimate analysis, oxygen is utilized for the combustion at 1.02 kg O2/kg fuel. Therefore, the gasification process consumes oxygen at 3.83 kg/h. [2]

ii. Size and efficiency of the gasifier

The conventional downdraft gasifier efficiency is 33% and the oxygen/steam gasifier efficiency is 62.60%. Oxygen/steam gasifiers have a higher efficiency of 29.60%.

Table 7: Characteristics of gasifier comparison between air gasification and oxygen/steam gasification

Characteristic	Air gasification	Oxygen/steam gasification
High heating value (kJ/kg)	20,540	20,540
Feed rate (kg/h, wet basis)	7.20	7.92
Air (Nm^3/h)	7.98	-
O2 (Nm^3/h)	-	2.00
Steam (kg/h)	-	3.20
Gas yield (Nm^3/h, wet basis)	0.94	1.32

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Characteristic	Air gasification	Oxygen/steam gasification
Lower heating value (MJ/Nm^3)	5.17	9.75

2.2.2 Experimental investigation of downdraft gasifier at various conditions

Kirsanovs et al. study the effect of fuel supply and fuel moisture on the gasification process performance. To examine the fuel supply effects, air flows are divided into primary and secondary airflow. Both are used as gasification agents. Primary airflow is strict into the oxidation zone and the secondary air flow varies from 0-15% into the pyrolysis zone. The experiment relies on the different thermal capacities and optimal operation processes. The downdraft gasifier is operated with a thermal capacity of 400 kW. Wood chips are the biomass in this experiment. As the moisture content in the biomass is excessive, therefore, heat from syngas is used to dry it before operating. Sensible heat that is removed from the syngas can be determined by the temperature in the pyrolysis, oxidation, and reduction zones. The gasifier thermal capacity and the amount of syngas produced can be determined by the mass and energy balance. Fuel supply varies from 75 kg/h to 136 kg/h and moisture content is in the range of 10% to 22%. The equivalence ratio is constant at 0.25. Experimental data show that the fuel moisture, fuel supply, and the primary/secondary air flow influence the gasifier performance. [3]

Table 8: Operation parameters effect on the gasification process performance

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Operation parameters						
Primary air flow, %	100	100	100	92.5	85	100
Secondary air flow, %	0	0	0	7.5	15	0
Thermal output, kW	366	381	397	403	401	224
Fuel moisture	21.1	16.2	12.0	12.8	10.9	12.4
Syngas parameter						

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	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
CO, %v, dry gas	13.6	17.9	21.3	19.2	20.4	20.6
H2, %v, dry gas	18.5	18.8	19.1	18.8	17.0	18.3
CH4, %v, dry gas	1.66	1.25	1.06	0.88	0.74	1.11
Syngas LHV, MJ Nm^{-3} (dry gas)	4.3	4.7	5.1	5.5	5.4	5.0
Gasification process characteristic						
Gasification temperature, °C	558	592	611	621	651	53.2
Cold-gas efficiency, %	45.6	51.4	57.0	61.9	59.8	58.7
Hot-gas efficiency, %	51.9	59.0	63.7	69.3	68.3	224

Regression models result in the effect of syngas calorific value, gasifier capacity, and cold and hot gas efficiency as a function of gasifier operation setup. The results determine that these factors are the function of the operating conditions. When the heat from syngas is increased, fuel moisture content decreases from 21.1% to 10.9%, and the hot gas efficiency increases by 17.4%. The optimized share of primary air is approximately 92.5%. Fuel supply influences thermal capacity and the gasification process efficiency. As the fuel supply decreases, the reduction of plant thermal capacity and efficiency takes place. [3]

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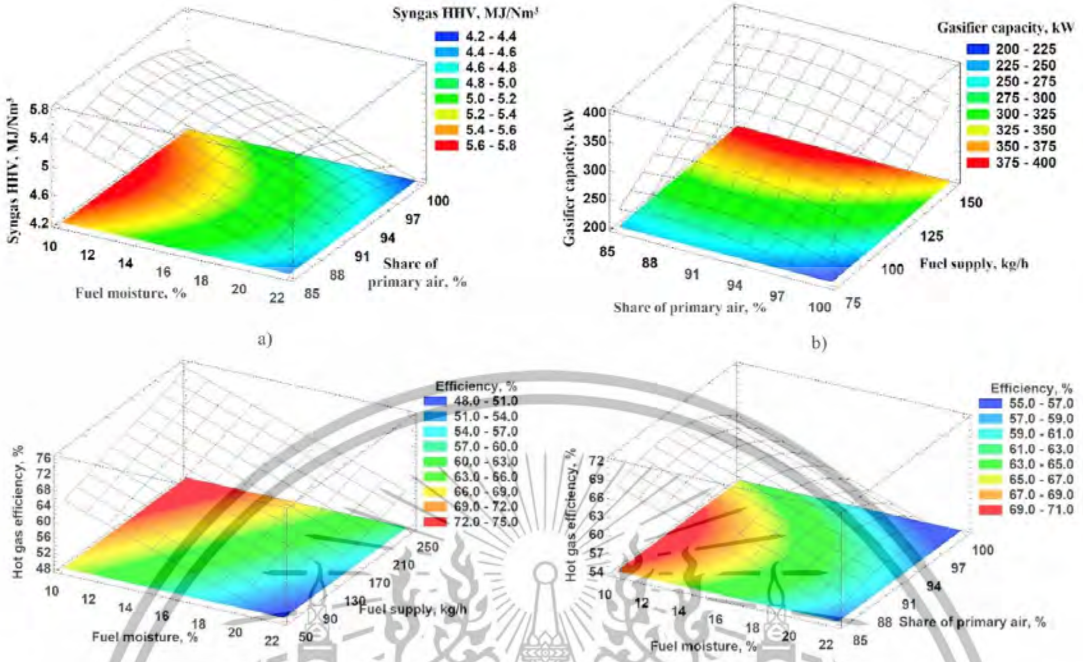

a) b)

c) d)

Figure 1 Influence of a) fuel moisture and share of primary air on the syngas calorific value; b) share of primary air and fuel supply on the gasifier capacity; c) fuel moisture and fuel supply on the hot gas efficiency; d) fuel moisture and share of primary air on the hot gas efficiency [3]

2.2.3 Design and develop downdraft gasifier to generate producer gas.

Ingle et al. develop a heating requirement for the gasifier by improving the generating producer gas. Wood blocks are used as feedstock of different sizes. Biomass briquettes are also studied to compare the results with wood blocks. The performance of the gasifier is observed with the usage of different air flow rates. The experimental setup consists of a hopper, reactor, grate, ash handling system, and air blower. The hopper has an outer diameter of 650 mm and an inside diameter of 500 mm. The material used is mild steel. The reactor is made up of stainless steel 304 with a cone cylinder shape. The temperature inside remains approximately 500-600°C. The grate is also made of stainless steel to hold the biomass. The ash pond is used to collect the ash produced from the process. Three air nozzles are set up at an angle of 120 degrees.

The results show a high impact on the grate design and spacing between the rods. The generation of gas depends on the sizing. Two gap designs are studied which are the 25 mm and

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12 mm grate gaps. The gap of 25 mm ensures that the ash produced from biochar production can go through the rods easily. The various types of wood feedstocks are wood pellets (100 mm-150 mm), biomass briquettes, and wood pieces (30-50mm). Wood pieces produce the highest content of CO and H_2, however, biomass briquettes produce the lowest CO and H_2.

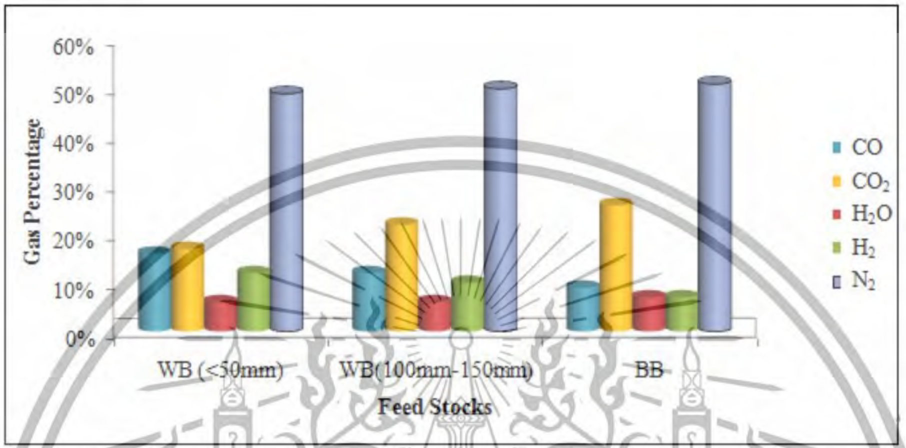

Figure 2 Gas composition of various feedstock [3]

Air velocity has a high impact on the CO content, and the calorific value of gas production is affected by the CO content. According to the graph, air velocity at 2.9 m/s results in the highest CO content. The highest possible air velocity to gasify is 3.88 m/s for this design. [3]

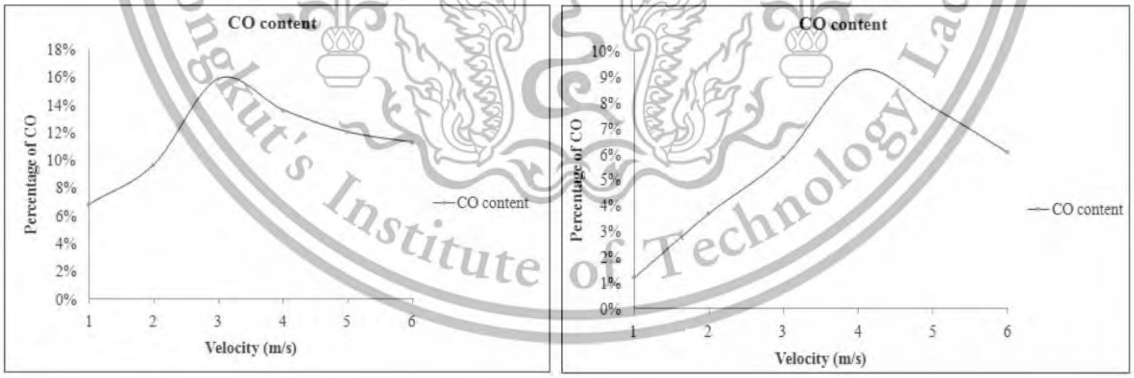

Figure 3 Effect of air velocity on CO content for wood and biomass [3]

Wood pieces with the size of 30-50 mm are the most suitable size for biochar production, and this biomass size provides the highest calorific value of 3.978 MJ/Nm^3. Both wood types are also better than the agricultural biomass briquettes in the way of calorific value due to their higher CO content.

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2.2.4 Modeling of a downdraft gasifier fed by agricultural residues.

Antonopoulos et al. study a non-stoichiometric model of a downdraft gasifier. The syngas composition and the moisture impact on the supplied fuel are examined. The gasifier is assumed to be 0.5 MW and the equivalence ratio is 0.45. Olive wood, miscanthus, and cardoon are the feedstock in this experiment. These are tested at temperatures of 800 and 1200°C. The gasifier contains an airflow rate of about 500 m^3/h. The reactor has the shape of a single throat. H_2 and CO_2 concentrations increase as the temperature increases. CO_2 is inversely proportional to the temperature. [4]

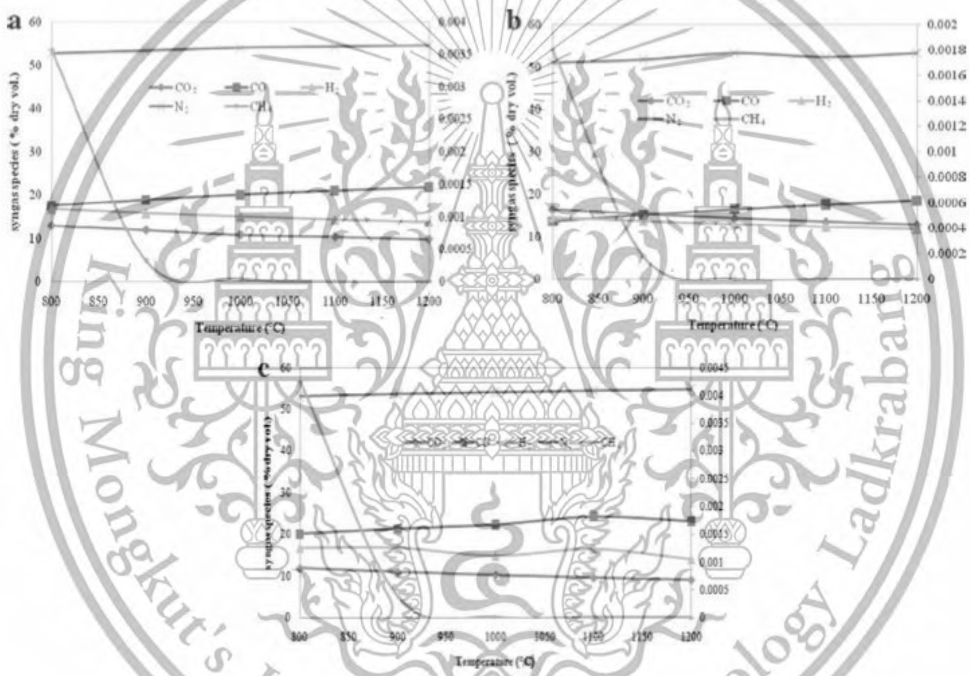

Figure 4 Effect of temperature on syngas species concentration: (a) miscanthus, (b) cardoon, and (c) olive wood[4]

The heating value of the synthesis gas is dependent on the temperature. As the equivalence ratio is constant in this experiment, LHV is increased when the temperature is increased. Moisture content and hydrogen concentration are reduced with the higher temperature, which affects the higher LHV. Moisture content also affected the LHV of syngas. The amount of air in the reactor causes an increase in moisture content. Heat conservation of the

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reactor temperature is not enough to gasify. However, if the airflow in the gasifier is not sufficient, the temperature is then observed to decrease.

Therefore, the air amount in the gasifier should be provided properly. The syngas composition is varied on the moisture content. The concentration of H_2 is increased from 16.9 to 17.8% as the moisture content increases from the range of 0-40%. The CO content is inversely proportional to the moisture content, while $CO_{.}$ concentration increases as the moisture content increases. [4]

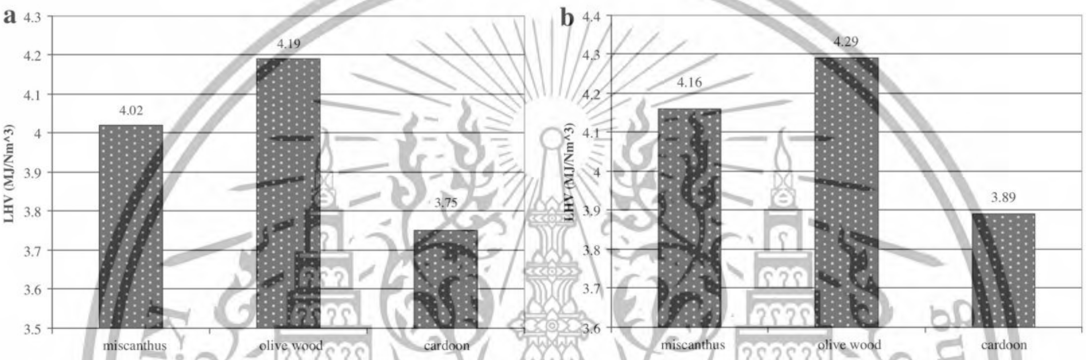

Figure 5 Effect of temperature on LHV of syngas (a)800°C and (b)1000°C [4]

2.2.5 Design and development of a laboratory-scale biomass gasifier

Ojolo et al. designed a gasifier with mechanical power of 4 kW and thermal power of 15 kW. The experiment is set up in natural downdraft and forced downdraft mode to determine the properties for the optimal performance of the gasifier. Wood shaving and palm kernel shells are used as feedstock. In the first experiment of the natural downdraft mode, the torch is used as an ignition source from the bottom. Air flows naturally to the reactor. In another experiment, the ignition starts in the throat and the fuel is inserted into the hearth area. A 3.5 kW blower is installed on the gasifier for the air inlet. Fuel is ignited in the throat area and loaded up to the throat level. [5]

Natural downdraft mode takes 35 minutes for gas combustion. It continues to show a blue flame, similar to butane gas, for another 10 minutes. Before the syngas production stops, the pressure of the gas at the outlet is low. The heat is controlled in the reduction area and the

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biomass is not combusted. There is no increase in the bed height during the process. As wood shaving is ignited at the throat, syngas is not generated, and the biomass does not gasify. Smoke is produced before combustion starts. Palm kernel shells are also not gasified. Ignition from the bottom is not sufficient to retain heat for biochar production. As the forced downdraft mode is operated, palm kernel shells take approximately 10 minutes. Combustible gases were stable generated. A lot of smoke and tar oil were produced after the fuel is loaded. [5]

2.2.6 The effect of biomass physical properties on top-lit updraft gasification of woodchips

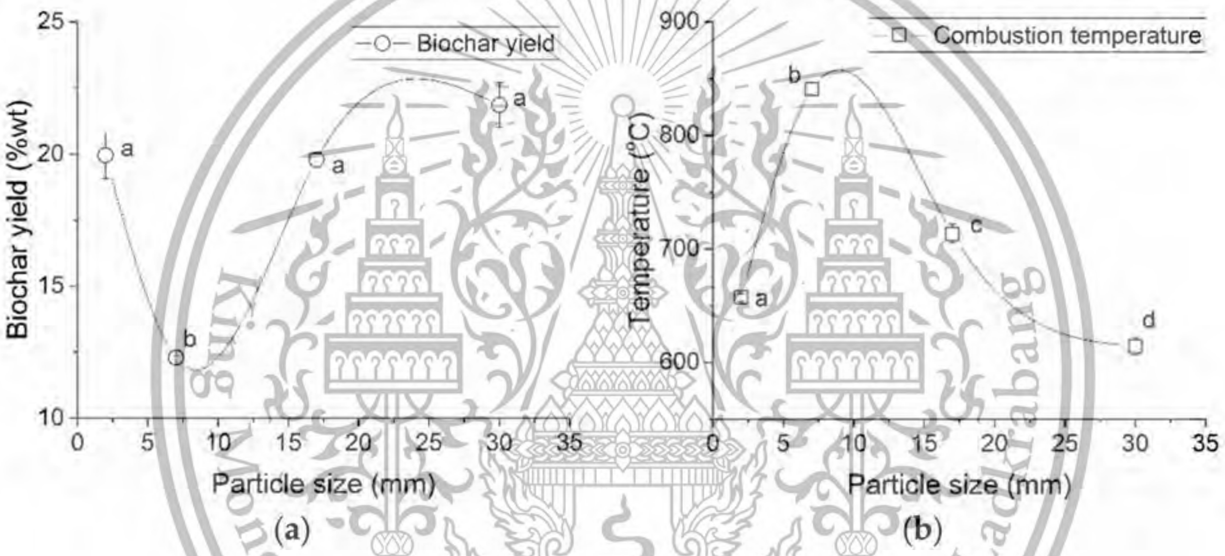

Figure 6 (a) The biochar yield and (b) combustion zone temperature of wood chips gasification at varying particles sizes

The particle sizes, moisture content, and biomass compactness of woodchips were studied. Evaluations were made on the combustion temperature, burning rate, biochar yield, syngas composition, and tar concentrations. The gasification was carried out in a steel gasifier column with an internal diameter of 10.1 cm and a height of 152 cm. 8.89 cm of Fiberglass insulation thick. Using screens with a 3-, 10-, 25-, and 35-mm mesh size, the typical particle size used in this work includes 2, 7, 17, and 30 mm. The biomass compactness and particle size were kept at 7 mm and 0, respectively, while four moisture contents were examined at 10%, 14%, 18%, and 22%.

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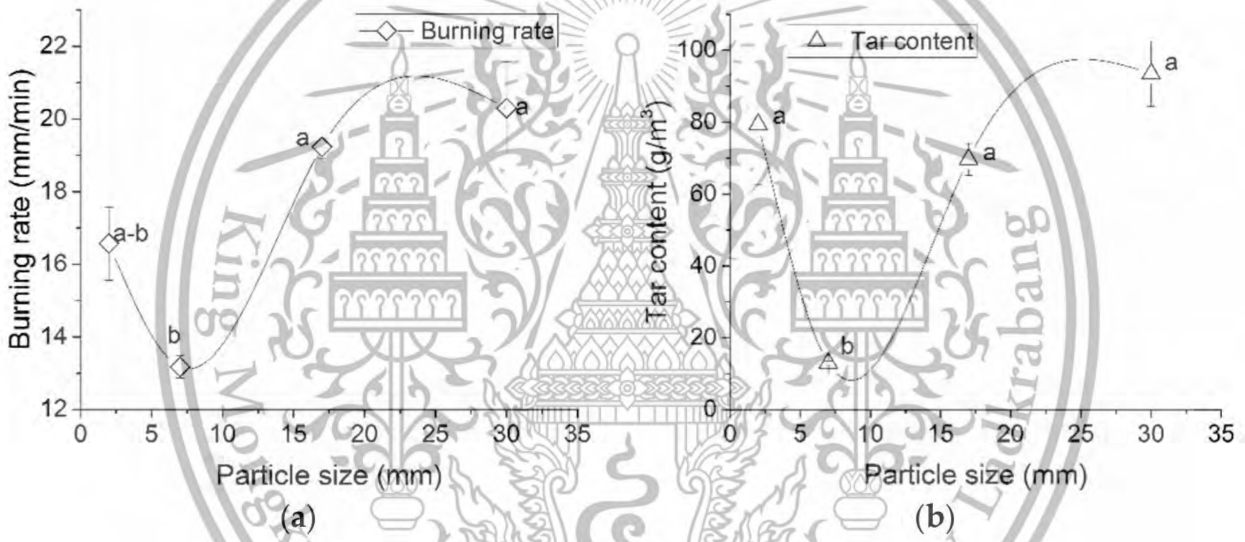
Figure 6a shows that the production of biochar dramatically decreased from 19% to 12% as particle size increased from an average size of 2 to 7 mm. However, the ฟyield of biochar started increasing from 12% to 19.8% as the particle size continued to increase, from 7 to 17 mm. Additionally, it did not differ significantly from the biochar yield (21.8%) obtained with a higher particle size of 30 mm. Figure 6b demonstrates that when the biomass particle size changed from 2 to 7, then 30 mm, the combustion temperature increased from 657°C to 840°C, then decreased to 614°C.

It was clear that the production of biochar correlated adversely with the temperature of the combustion zone.



(a) (b)

Figure 7 (a) Gasification burning rate and (b) tar content in syngas at varying particles sizes

The burning rate significantly decreased from 16.6 to 13.2 mm/min as the particle size increased from 2 to 7 mm, despite an increase in the combustion temperature shown in Figure 2b. But when the particle size was further enlarged (from 7 to 30 mm), the burning rate indicated an opposite tendency, rising from 13 to 20.3 mm/min, despite the temperature decrease that was observed as the particle size increased.

This implied that the burning rate dependent on particle size in addition to reaction temperature due to differences in biomass bulk density and its correlation with the burning rate. When the burning rate is compared to the bulk density of the biomass, a lower bulk density of biomass produced a higher burning rate; in contrast, denser biomass caused a lower burning rate.

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The yield of biochar increased as the moisture content increased from 10% to 22%. However, there were no significant changes in the combustion temperature as the moisture decreased from 12% to 9.9%. The reaction temperature can reduce biochar yield, as stated in the particle size analysis. As the moisture content increased from 10% to 22%, the burning rate decreased from 13 to 10 mm/min. The higher heat required to separate moisture from biomass with a higher moisture content resulted in a slower rate of combustion.

2.2.7 Performance analysis of updraft gasifier

The goal of this project is to create an updraft gasifier for mango pits and evaluate its effectiveness in comparison to coconut shell and gliricidea. A laboratory-scale updraft gasifier was developed. Results indicate the efficiency that mango pits are converted into producing gas. Gasification efficiency and rated thermal energy are initially assumed to be 70% and 25 kW, respectively. Fuel has a heating value of 18.5 MJ/kg. As this study only considers particle biomass, the reactor's specific gasification rate is 110 $kg/m^2 \cdot h$. The reactor's calculated diameter and height are 0.305 m and 1.25 m, respectively. Volume is 0.076 m^3. An entire batch takes 4 hours to complete. The lower and upper components of the reactor body are constructed from sheets of stainless steel and mild steel, each measuring 4 mm thick. The grate is made of stainless-steel sheet and has the same diameter as the reactor. Its surface has 10 mm-diameter circular holes for the removal of ash particles. The bottom of the reactor, above the ash chamber, has a fixed grate. Eight nuts and bolts secure the top cover plate at the feed point to the reactor. The plate is meant to be removed as the reactor is being fed with biomass. The reactor is coupled with a 274 mm high. Additionally, a 31.75 mm air supply pipe was installed below the grate. To reduce heat loss to the environment, fiber wool glass is used to insulate the reactor body. Heating value was measured by using bomb calorimeter while average density was calculated as 350 kg/m3. A bomb calorimeter indicated an average Higher Heating Value of 18.5 MJ/kg for all types of biomasses. In the combustion zone, the maximum temperature was measured at 1020°C. When the air flow rate increases, temperatures also increase.

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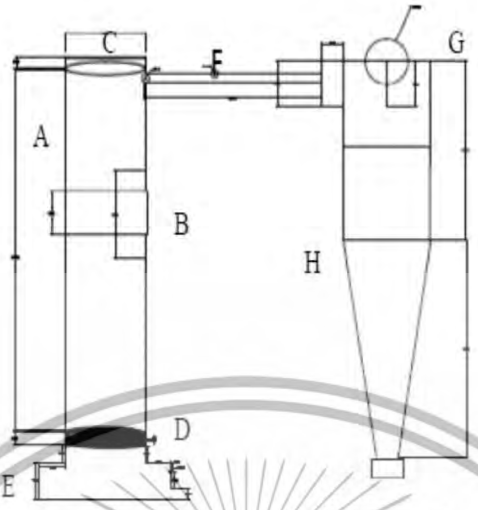

Figure 8 Model of updraft gasifier

The design, construction, and operation of an updraft gasifier unit for three different biomass feedstocks—coconut shells, gliricidia, and mango pit shells—was successful. Two equivalence ratio values were applied to analyze performance. The highest LHV is observed in both cases on coconut shells. Comparing mango pit to other types of biomasses, it has produced good results. Low LHV is a result of the mango pit's high moisture content, which also negatively affects the quality of the producing gas.

Table 9: LHV and efficiency values of biomass

Biomass	ER	LHV (MJ/m^3)	η_g (%)
Coconut shell	0.16	4.40	58.23
	0.21	3.87	63.88
Gliricidia	015	4.20	64.85
	0.19	3.55	61.33
Mango pit	0.16	3.35	40.75
	0.21	3.09	47.06

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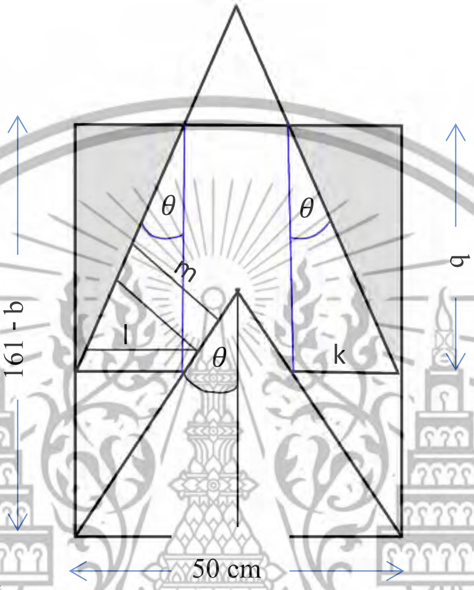
2.3 Dimension calculation

2.3.1 Gasifier height

$$H = \frac{m}{\rho A} \qquad (m) \qquad \text{---------} \; (1)$$

2.3.2 Gasifier dimension



$$\tan \theta = \frac{k}{m} \qquad \text{---------} \; (2)$$

$$m = 161\text{-}b \qquad \text{---------} \; (3)$$

$$k = (161\text{-}b)(\tan \theta) \qquad \text{---------} \; (4)$$

$$\cos \theta = \frac{1}{\sqrt{1+ \tan \theta}} \qquad \text{---------} \; (5)$$

2.4 Iodine number of biochar

The iodine number is a measure of the unsaturation level of a substance, which can be used to estimate the molecular weight, degree of branching, and the presence of double bonds in the substance. The iodine number is determined by the amount of iodine that is absorbed by a certain weight of the substance. The iodine number is commonly used to characterize the

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unsaturation level of fatty acids and their derivatives, such as oils, fats, and biodiesel. The test is based on the reaction between iodine and the carbon-carbon double bonds present in the unsaturated compounds.

In the iodine number test, a known weight of the sample is dissolved in a non-polar solvent, such as chloroform or carbon tetrachloride, and then reacted with a solution of iodine in the presence of potassium iodide. The iodine reacts with the carbon-carbon double bonds in the unsaturated compounds, forming an iodine addition product that can be titrated with a standard solution of sodium thiosulfate to determine the amount of unreacted iodine. The iodine number is calculated as the weight of iodine that is absorbed by the sample divided by the weight of the sample and is expressed in units of grams of iodine per 100 grams of sample (gI2/100g). A higher iodine number indicates a higher degree of unsaturation and a lower molecular weight of the substance.

The iodine number can be useful in determining the quality of oils and fats for use in various applications, such as food processing, fuel production, and industrial chemistry. However, it should be noted that the iodine number is just one of several properties that are relevant to the performance of these substances in different applications, and it may not provide a complete characterization of their behavior.

2.4.1 Calculation

There are two calculations required for the iodine number which are X/M and C. The standard iodine solution and filtrates must be specified to determine a carbon weight.

1) Sodium thiosulfate normality

$$N_1 = \frac{(P \cdot R)}{S} \qquad (6)$$

Where:

N_1 = Sodium thiosulfate, N

P = Potassium iodate, mL

R = Potassium iodate, N

S = Sodium thiosulfate, mL

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2) Iodine solution normality

$$N_2 = \frac{(S \cdot N_1)}{I} \qquad (7)$$

Where:

N_2 = Iodine, N

S = Sodium thiosulfate, mL

N_1 = Sodium thiosulfate, N

I = Iodine, mL

3) Calculation of X/M (Iodine absorbed per gram of carbon)

$$A = (N_2)(12693.0) \qquad (8)$$

$$B = (N_1)(126.93) \qquad (9)$$

$$DF = \frac{(1+H)}{F} \qquad (10)$$

Where:

DF = Dilution factor

I = iodine, mL

H = 5% hydrochloric acid used, mL

F = filtrate, mL

$$\frac{X}{M} = \frac{[A-(DF)(B)(S)]}{M} \qquad (11)$$

Where:

X/M = Iodine absorbed per gram of carbon, mg/g

S = Sodium thiosulfate, mL

M = Carbon used, g

4) Calculation of C (residual iodine)

$$C = \frac{(N_1 \cdot S)}{F} \qquad (12)$$

Where:

C = Residual filtrate, N

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$$M=\frac{\left[A-\left(DF\right)\left(C\right)\left(126.93\right)\left(50\right)\right]}{E} \quad (13)$$

Where:

M = Carbon, g

E = Estimated iodine number of the carbon

2.5 Ash content

Ash content refers to the inorganic residue that remains after a sample has been combusted or incinerated at high temperatures. Ash content is typically measured in organic materials such as biomass, coal, and waste materials and is an important parameter for assessing their quality and suitability for various industrial applications.

The ash content in a sample is the weight of the inorganic residue expressed as a percentage of the weight of the original sample. The inorganic residue consists of minerals and other inorganic compounds that were present in the sample or that were formed during the combustion process.

Table 10: Key Insights provided by ash content.

Aspect	Description
Fuel Quality	High ash content indicates lower fuel quality and reduced energy content.
Combustion Residues	Ash content gives an idea of the amount of combustion residues to be managed, affecting handling and disposal costs.
Emissions	Ash composition affects emissions, such as sulfur dioxide (SO2), nitrogen oxides (NOx), and heavy metals.
Ash fusion Temperature	Ash content and composition influence ash fusion temperature, affecting slagging and fouling in combustion equipment.
Potential Applications	Ash composition may offer alternative applications, such as construction materials, fertilizers, or valuable minerals.

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To measure the ash content in a sample, the sample is heated in a controlled environment, such as a furnace or muffle furnace, at a high temperature (typically around 550-600°C) to burn off the organic matter. The remaining residue is then weighed and expressed as a percentage of the original weight of the sample.

$$\%\text{Ash content} = \frac{\text{Weight of ash}}{\text{Weight of dry sample}} * 100$$

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CHAPTER III

RESEARCH METHODOLOGY

In fact, the design of machine or equipment can be designed from many programs, but here we use sketch up program to make gasifier in 3D and we use AutoCAD to make gasifier drawings because it is compatible with our computer and does not require High-Performance Computer Specifications to use. Before the design can be started, various dimensions must be calculated, followed by the selection of materials used to make.

3.1 Gasifier design

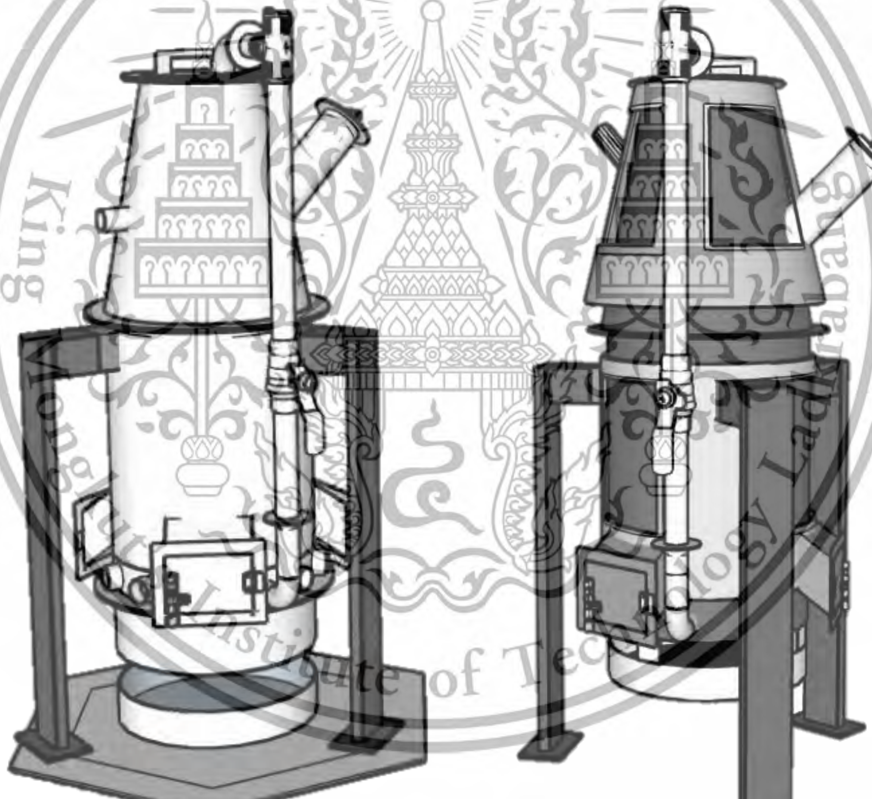
(a) (b)

Figure 9 Model of gasifier (a) without and (b) with insulation

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3.2 Biochar production

3.2.1 Feedstock preparation

Coconut shell and rice straw were prepared for the experiment in the package bags. Firewood is used as the fuel for all batches. All feedstocks are sun dried to minimize the moisture contents level as low as possible.

3.2.2 Experiment procedure

1) Open the top lid of the gasifier. Add the biomass either coconut shell or rice husk until it is full to the top of cylinder. Close the lid tightly.
2) Check the valve at the syngas pipe to be closed at the start.
3) Place the firewood in the grate at the bottom of the gasifier. Set the fire.
4) When the fire is already set up and the syngas has been produced, open the valve at the syngas pipe.
5) Add more firewood when the fuel at the bottom is decreased to control the temperature in the gasifier.
6) Record the temperature every 5 minutes for the first hour, and every 10 minutes for the rest.
7) When the syngas is not produced by observing at the combustion chamber from the syngas pipe, stop the process.
8) Cool down the gasifier.
9) Open the side lid to get the biochar out of the gasifier.

3.3 Biochar laboratory – Iodine number

3.3.1 Apparatus and reagents

1) Analytical balance, accuracy 0.0001 g
2) Burette, 10-mL capacity, or 5-mL precision burette
3) Flasks, Erlenmeyer 250-mL capacity with ground glass stoppers
4) Flasks, Erlenmeyer wide-mouthed, 250-mL capacity
5) Beakers, assorted sizes

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6) Bottles, amber, for storage of iodine and thiosulfate solutions
7) Funnels, 100-mm top inside diameter
8) Filter paper, 18.5-cm prefolded paper
9) Pipets, volumetric type, 5.0, 10.0, 25.0, 50.0 and 100.0-mL capacity
10) Volumetric flasks, 1 L
11) Graduated cylinders, 100 mL and 500 mL

3.3.2 Standardization of solutions

The preparation of solutions is identified as followed:

1) Hydrochloric acid solution

Add 70 mL of concentrated hydrochloric acid into 550 mL of distilled water for preparation the solution of 5% by weight.

2) Sodium Thiosulfate (0.100 N)

Dissolve 24.820 g. of sodium thiosulfate in approximately 75 ± 25 mL of fresh boiled distilled water. Then, add 0.10 ± 0.01 g. of sodium carbonate and dilute in the 1-L volumetric flask. Store the solution in an amber bottle.

3) Standard iodine solution (0.100 ± 0.001 N)

Weigh the 12.700 g. of iodine and 19.100 g of potassium iodide (KI) into a beaker. Add 2-5 mL of water and mix well. Continue adding water until the volume reaches 50-60 mL. Ensure the crystal is fully dissolved for approximately 4 hours. Then transfer to the 1-L volumetric flask. Store in the amber bottle.

4) Potassium iodate solution (0.100 N)

Dry 4 g. of primary standard grade potassium iodate (KIO_3) at 110±5 degree Celsius and cool down at room temperature. Then dissolve 3.5667 ± 0.1 mg in 100 mL of distilled water and dilute in 1-L volumetric flask. Store in a glass-stoppered bottle.

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5) Starch solution

Prepare the paste by mixing 1.0 ± 0.5 g. of starch with 5-10 mL of cold water and add 25 ± 5 mL more of water while stirring. Boil 1-L of water and pour the mixture while stirring.

3.3.3 Procedure

1) The procedure initiates with powdered activated carbon (able to pass through a 325-mesh screen).
2) Dry the ground carbon and then cool it to room temperature in a desiccator. The experiment is performed with three samples of the nearest milligram and transfers to the dry 250-mL Erlenmeyer flask with the glass stopper.
3) Pipet 10.0 mL into each flask and swirl until all the carbon is wetted. Place on a hot plate for 30±2 s to remove sulfur. As all flasks are done from the previous procedure, pipet 100.0 mL of 0.100 N iodine solution into the flask and shake for 30±1 s.
4) Filter by gravity through 1 sheet of folded filter paper. Then, add 2 mL of the starch indicator solution and use the standardized 0.100 N sodium thiosulfate solution to titrate until it turns pale yellow.
5) Record the volume of sodium thiosulfate used.

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CHAPTER IV

ANALYSIS RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the contents consist of the experiment results of the yield from the biochar production, heating rate at each temperature, temperature profile, temperature gradient, fuel rate, efficiency of the gasifier, and economic analysis.

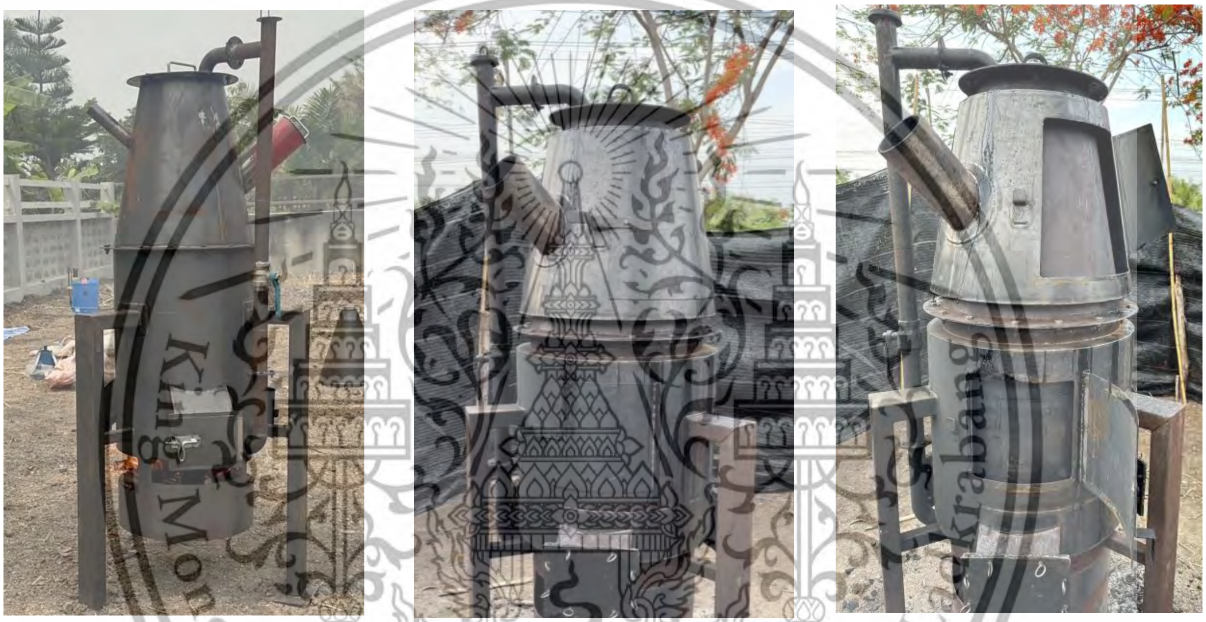

Figure 13: Gasifier

4.2 Batch condition

The experiment was held with 2 types of biomasses (coconut shell and rice straw), and 2-cone types inside the gasifier (large and small). Gasifier with insulation and without insulation were both studied.

Table 11: Condition of each batch for the gasifier without insulation

Batch No.	Condition	
	Biomass type	**Cone type**
Batch 1	Coconut shell	Large
Batch 2	Coconut shell	Large

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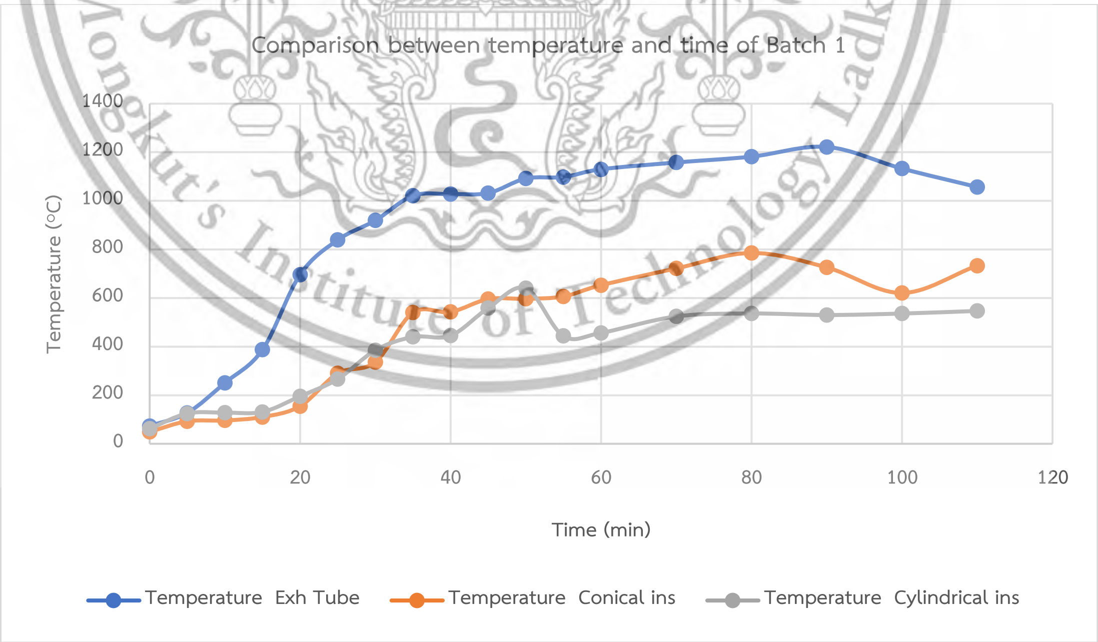
Batch No.	Condition	
	Biomass type	Cone type
Batch 3	Coconut shell	Large
Batch 4	Rice straw	Large

Table 12: Condition of each batch for the gasifier with insulation

Batch No.	Condition	
	Biomass type	Cone type
Batch 1	Coconut shell	Large
Batch 2	Coconut shell	Large
Batch 3	Coconut shell	Small
Batch 4	Coconut shell	Small
Batch 5	Rice straw	Small
Batch 6	Rice straw	Large

4.3 Temperature profile



(a)

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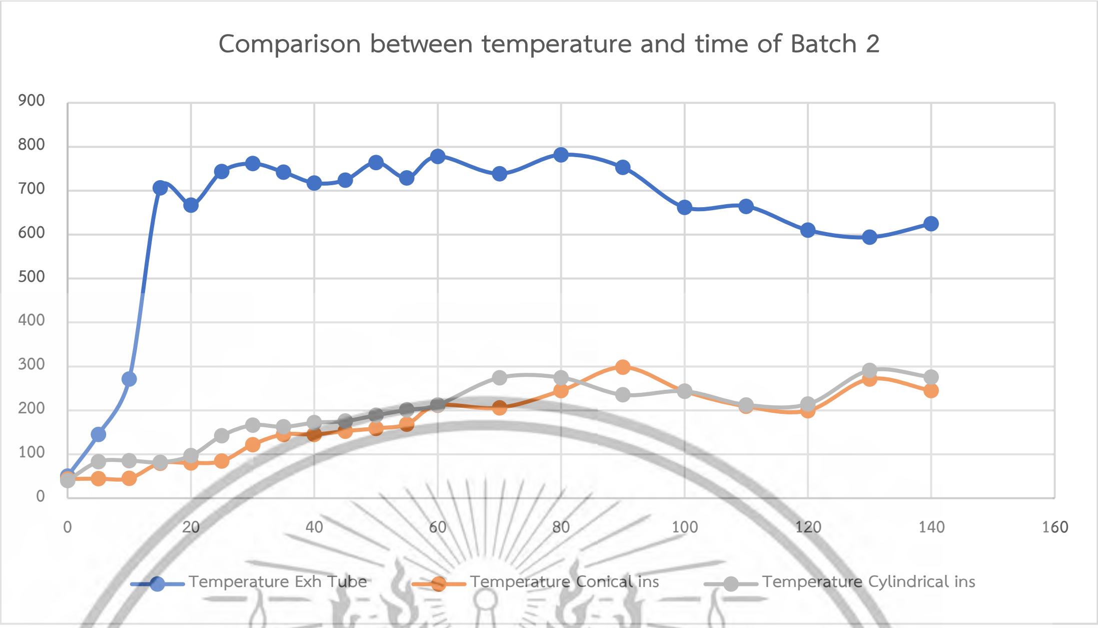

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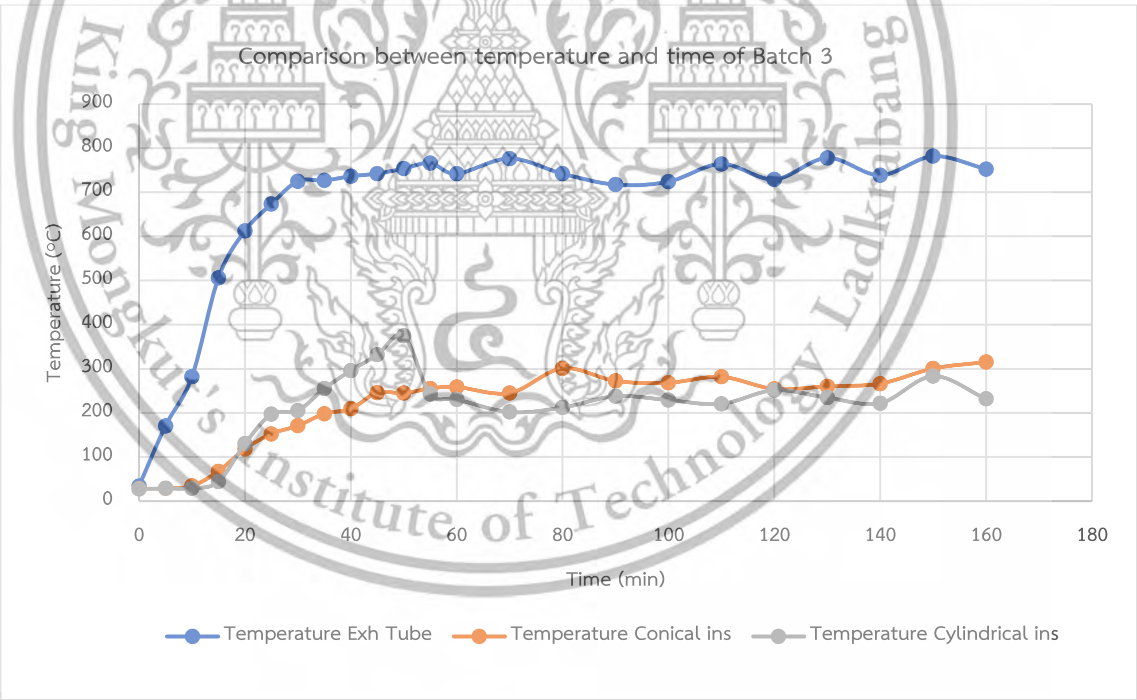

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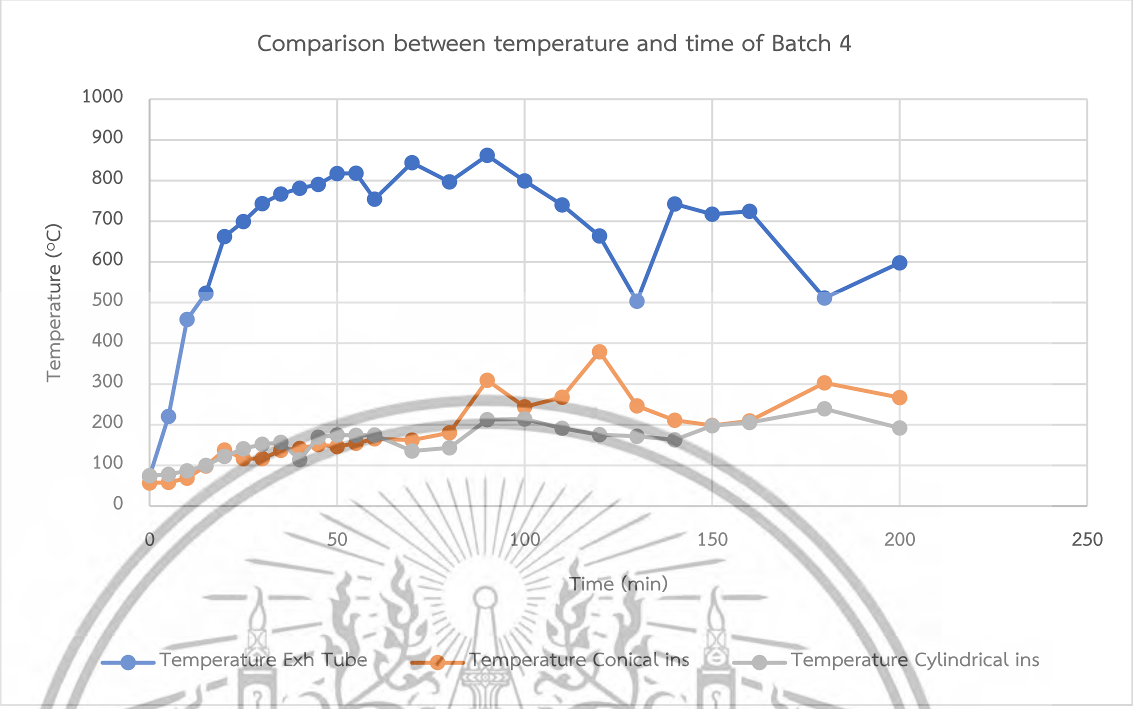

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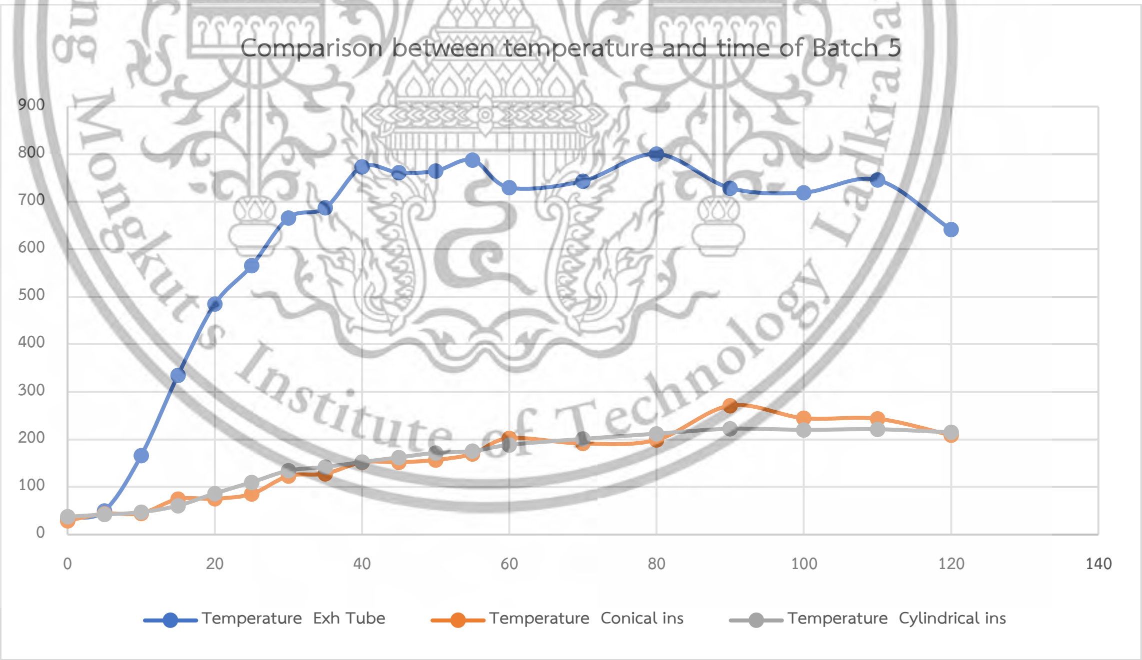

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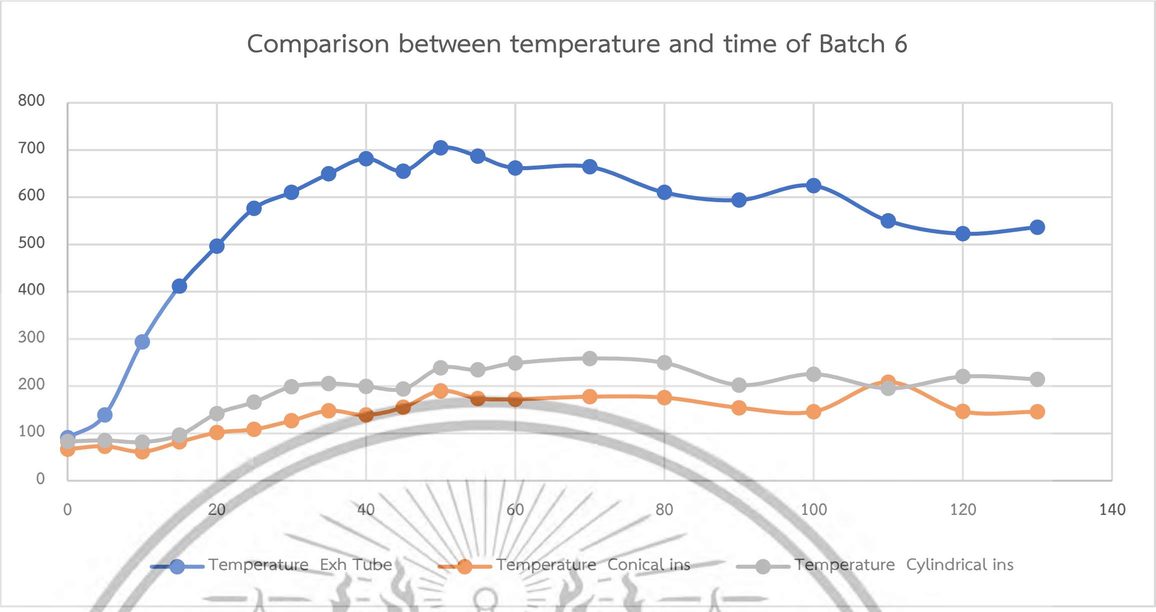

(f)

Figure 14: Temperature profile of the gasifier from (a) batch 1, (b) batch 2, (c) batch 3, (d) batch 4, (e) batch 5, (f) batch 6

4.4 Mass loss and yield

Table 13 shows the mass of raw material, biochar, and loss during the gasification. Biochar yield was observed to be better when the rice straw is used as a raw material. However, the amount of rice straw at the initial was quite low due to its density. The releases of volatiles present mass loss in biomass.

Table 13: Mass loss and yield of the different batches

Batch No.	Raw material (kg)	Biochar (kg)	Mass loss (kg)	Yield (%)
Batch 1	21.3	7.4	13.9	34.742
Batch 2	31.3	9.4	21.9	30.032
Batch 3	42.2	10.2	32	24.171
Batch 4	48	23.4	24.6	48.750
Batch 5	4.4	2.1	2.3	47.727
Batch 6	4	2	2	50.000

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4.5 Fuel rate

Since it is a gasifier that the electricity is not utilized, fuel is the main source to control the temperature of the process. From table 14, the batches that use the large cylinder type including batch 1, 2, 5 require more fuel rate for the biochar production. On the other hand, batch 3, 4, 5 that use the small cylinder inside the gasifier tend to require less fuel for heating up the chamber.

Table 14: Fuel rate of the different batches of the gasifier with insulation

Batch No.	Fuel consumption (kg)	Time (hr)	Fuel rate (kg/hr)
Batch 1	17.9	1.5	11.933
Batch 2	17.8	2.3	7.739
Batch 3	30	3.1	9.677
Batch 4	25	4.1	6.098
Batch 5	8.8	2.3	3.826
Batch 6	13.9	3	4.633

4.6 Effect of insulation on the temperature

Temperature was recorded at exhausted tube, cone, cylinder, and outside of insulation. As the insulation was provided, the temperature inside the chamber for both conical and cylindrical zones is higher due to less heat loss.

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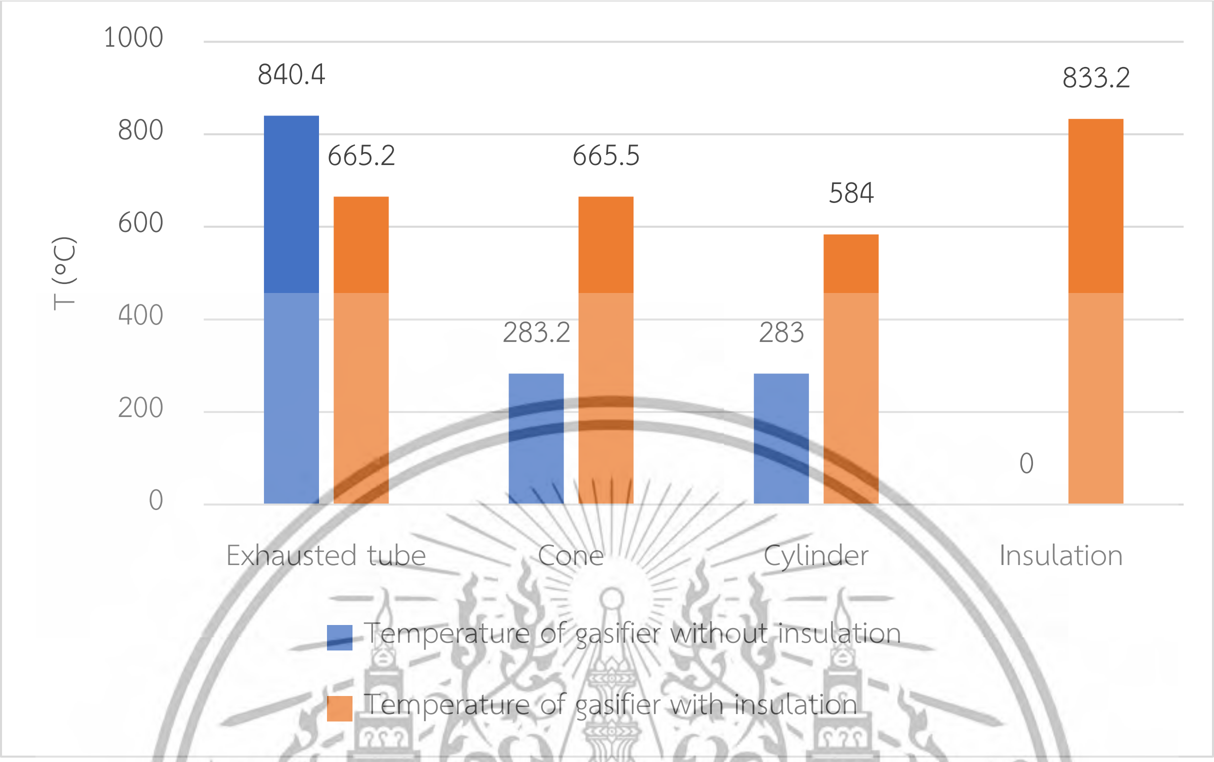
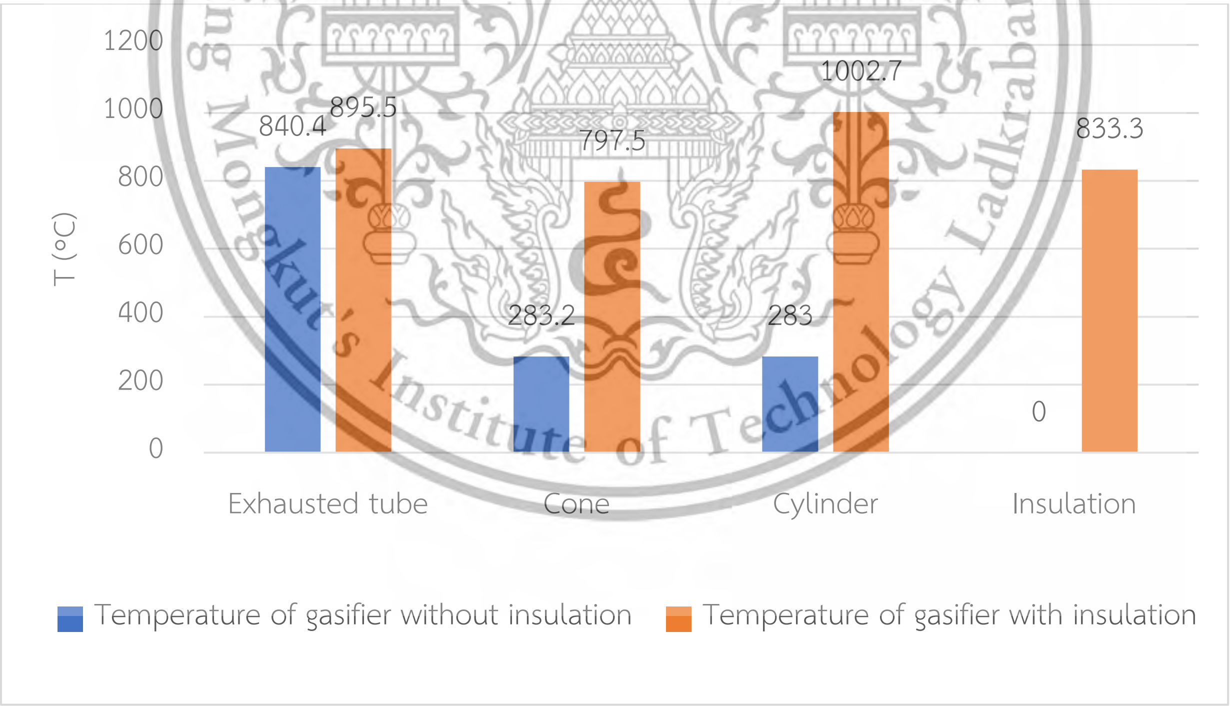


(a)



(b)

Figure 15: Temperature comparison of the gasifier with and without insulation from (a) batch 1 and (b) batch 2

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4.7 Efficiency

The syngas production was assumed to be recovered 100% to use as another source of fuel. The efficiency of the batch that coconut shells are used as raw materials (batch 1-4) are higher than the batch that rice straws are the biomasses. Batch 2 and 3 have relatively higher efficiency than other batches due to the high syngas production rate. Batch 2 has the highest efficiency due to the high ambient temperature which made the efficiency to be a little higher than batch 3.

Table 15: Efficiency of the gasifier

Batch No.	Syngas production (Assume 100% recovery) (kg)	M_g (m^3/hr)	Efficiency
Batch 1	13.4	9.404	53.669
Batch 2	21.9	10.023	88.206
Batch 3	32	10.866	76.472
Batch 4	24.6	6.316	70.546
Batch 5	2.3	1.053	18.738
Batch 6	2	0.702	10.316

4.8 Iodine number

Iodine number value is to determine the quality of biochar. From figure 16, the results show that the biochar produced from the large conical combustion chamber has higher iodine number value. The results are similar when the rice straw is used as a raw material. The average iodine number of the raw char was approximately 200 based on the range of iodine number obtained from analysis. Figure 16(a) is the iodine number value from the gasifier with insulation that uses coconut shell with the small cone type (S) and large cone type (L). Iodine number value from the experiments is all exceeded 200 which is acceptable. The coconut shell with the gasifier that has large conical combustion chamber has the highest value of iodine number of 342.315.

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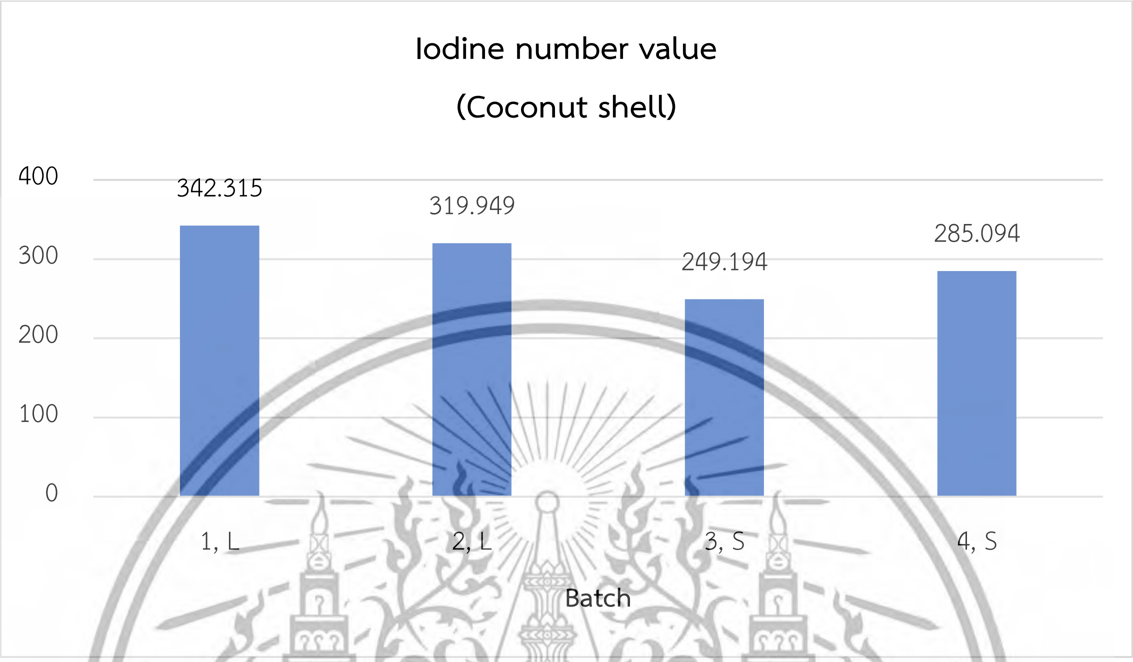
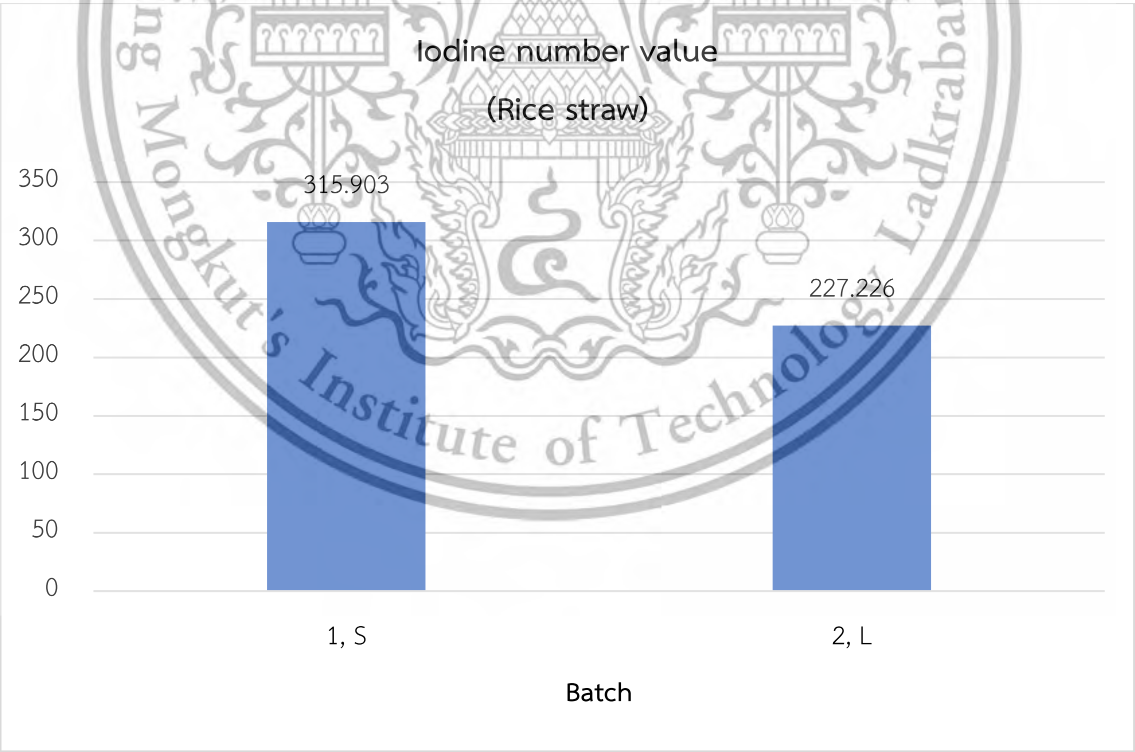


(a)



(b)

Figure 16 Iodine number value of the biochar from (a) coconut shell and (b) rice straw

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4.9 Reducing environmental impact

Table 16: Emission factor of rice straw compared with outdoor biochar burning

	CO_2	CO	NO_x	SO_2	TPM
Emission factor (g/kg_{bm})	1118.47	78.86	1.44	0.56	6.69
Emission per rice straw 4.2 kg (g)	2279.73	160.73	2.93	1.14	13.63
Emission per rice straw 4.2 kg (kg)	2.27	0.16	0.02	0.01	0.01

Table 17: Emission factor of coconut shell with outdoor biochar burning

	CO_2	CO	NO_x	SO_2	TPM
Emission factor (g/kg_{bm})	1118.47	78.86	1.44	0.56	6.69
Emission per coconut shell 23.7 kg (g)	12503.7	881.59	16.09	6.26	74.78
Emission per coconut shell 23.7 kg (kg)	12.50	0.88	0.02	0.01	0.07

4.10 Economic analysis

As the economic analysis was applied, the average amount of the feedstock was calculated for the total cost and profit gained from the biochar production. From table 16, coconut shell is more proper to be used as raw material since it gains more profit. According to the cost of feedstock and gasifier construction, payback period is at 198 days (operate the gasifier once a day).

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Table 16: Economic analysis of biochar production

Gasifier	**Cost**	43800	baht
Coconut shell	Cost/day	92	baht
	Income/day	315	baht
	Total profit/day	220	baht
	Payback period	198	day
Rice straw	Cost/day	42	baht
	Income/day	51	baht
	Total profit/day	8	baht
	Payback period	4977	day

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CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, the objective of the study is to design and develop a high-efficiency gasifier for biochar production. Based on the experimental work and limited period, the following conclusion has been pointed out.

The gasifier was designed with strength and durability for biochar production, integrating with the syngas recovery to utilize as another source of fuel. The conical combustion chamber was studied with different designs and sizes. Coconut shell and rice straw are the raw materials. The average biochar yield from coconut shell and rice straw is 34.632% and 48.864%, respectively. Due to the density of rice straw, the amount of initial mass of raw material is low. Fuel consumption of the gasifier that uses a large conical combustion chamber is higher than the small conical combustion. The fuel rate of the large cone type is 8.1 kg/h, while the small cone type results in 6.534 kg/h. The resident time to operate is approximately 2-3 hours depending on the conical combustion chamber type and the raw material selection. The resident time is proportional to the size of the conical combustion chamber. Providing insulation decreases heat loss to the environment, therefore, the temperature of the gasifier is increasing. The temperature of the gasifier is up to 840.4°C. The average efficiency of a gasifier that uses coconut shell as raw material is 72.2% while the efficiency of gasifier that uses rice straw as raw material is 14.53%. Iodine number of the biochar produced from coconut shell is up to 342.315 when the gasifier with insulation is operated. The average iodine number of all experiments is 289.94. Economic analysis shows the payback period of coconut shell of 198 days if the gasifier is operated once a day. Rice straw is not appropriate to use as a raw material due to its unworthy outcome.

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5.2 Recommendation

To extend the study and development more in research, the insulation of some parts in the gasifier should also be provided such as at the syngas pipe. The air flow of combustion chamber should be controlled to enhance the gasifier performance. More experiment should be provided for more accuracy.

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APPENDIX I

RAW DATA

1. Gasifier without insulation

Batch 1: 46.6 kg of coconut shell and 34.6 kg of fuel

Time (min)	Temperature at 0.24 emissivity (°C)
0	431.367368
10	390.492632
20	945.873158
30	781.778947
40	892.894737
50	949.246316
60	1140.52421
70	1142.90526
80	1289.73684
90	962.342105
100	1041.71053
110	1058.77474
120	1103.22105
130	1018.49526
140	645.463684
Avg	**919.655123**

Batch 2: 31.6 kg of coconut shell and 71.9 kg of fuel

Time (min)	Temperature at 0.24 emissivity (°C)
0	109.131579
5	317.473684
10	882.973684
15	1104.80842
20	1092.30789
25	1171.67632

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Time	Temperature at 0.24 emissivity (°C)
30	1174.85105
40	1105.80053
50	1133.18263
60	1126.03947
70	1157.98526
80	1133
100	1273
120	1282
Avg	**1004.58789**

Batch 3: 53.3 kg of coconut shell and 40.1 kg of fuel

Time (min)	Temperature at 0.24 emissivity (°C)
0	50.3
5	145.3
10	271.1
15	706.7
20	1247
25	1054
30	1245
35	1077
40	1201
45	1286
55	1350
65	1272
75	1164
85	989.7
95	974.4
105	1129
115	980.4

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Time	Temperature at 0.24 emissivity (°C)
Avg	**949.582353**

2. Gasifier with insulation

Batch 1: 20.8 kg of Coconut shell and 17.9 kg of fuel

Time	Temperature at 0.24 emissivity		
	Exh Tube	Conical ins	Cylindrical ins
0	73.4	49.4	62.3
5	127.2	92.7	124.7
10	250.8	96	128.3
15	387.3	110.3	131.3
20	696.5	155	195.6
25	839	290	266.4
30	919.5	336.5	385.1
35	1021	540	440
40	1028	542.6	445.1
45	1032	595.8	558.7
50	1092	596.6	640.4
55	1098	606.5	443.9
60	1130	652.7	456.4
70	1158	721.8	524.3
80	1182	785.5	536.3
90	1222	726	530.1
100	1133	620.9	536.2
110	1057	733.5	546.9
Avg	858.15	458.4333333	386.2222222

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Batch 2: 31.3 kg of Coconut shell and 17.8 kg of fuel

Time	Temperature at 0.24 emissivity (°C)		
	Exh Tube	Conical ins	Cylindrical ins
0	34.4	28.3	27.8
5	170.8	29	29
10	282.2	34.7	29.4
15	506.3	67.9	44.4
20	612.5	118.3	130.4
25	673.6	152.7	197.1
30	725	171.1	205.3
35	726.9	198.3	255.4
40	736.4	209.5	296
45	742.4	246.1	331.8
50	753.6	245	374.9
55	766.5	255.5	243.1
60	742.2	259.1	231
70	776.7	245.2	202.1
80	742.2	301.1	212.3
90	717.5	272.6	238.1
100	724.1	268.6	229.2
110	764.3	281.8	220.7
120	729.4	254.5	251.6
130	777.9	260.5	234.8
140	738.8	266.5	222.2
150	781.8	300.7	283.4
160	752.8	315.5	231.9
Avg	651.23043	207.9347826	205.3

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Batch 3: 42.2 kg of Coconut shell and 30 kg of fuel

Time	**Temperature at 0.24 emissivity (°C)**		
	Exh Tube	**Conical ins**	**Cylindrical ins**
0	73.3	56.9	74.7
5	220.1	58.4	78
10	458.5	68.5	86.2
15	523	98.7	100.2
20	662	137.5	121.9
25	699	116.4	141.1
30	743.4	116.7	151.5
35	767.1	136.8	156.6
40	781.1	141.7	114.3
45	790.5	151.3	168.8
50	817.3	146.4	174.3
55	818.1	154.3	174.1
60	754.2	165	174.5
70	844.1	162	135.3
80	797	180.2	143.4
90	861.7	309	212.5
100	799.2	243.8	214.1
110	740.2	267.3	190.8
120	664	379.5	175.7
130	503.3	246.5	171.8
140	742.2	211.2	162.5
150	717.5	198.3	197.1
160	724.1	209.5	205.3
180	511.3	302.6	238.8
200	597.8	266.8	192
Avg	664.4	181.012	158.22

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Batch 4: 48 kg of Coconut shell and 25 kg of fuel

Time	Temperature at 0.24 emissivity (°C)		
	Exh Tube	Conical ins	Cylindrical ins
0	73.3	56.9	74.7
5	220.1	58.4	78
10	458.5	68.5	86.2
15	523	98.7	100.2
20	662	137.5	121.9
25	699	116.4	141.1
30	743.4	116.7	151.5
35	767.1	136.8	156.6
40	781.1	141.7	114.3
45	790.5	151.3	168.8
50	817.3	146.4	174.3
55	818.1	154.3	174.1
60	754.2	165	174.5
70	844.1	162	135.3
80	797	180.2	143.4
90	861.7	309	212.5
100	799.2	243.8	214.1
110	740.2	267.3	190.8
120	664	379.5	175.7
130	503.3	246.5	171.8
140	742.2	211.2	162.5
150	717.5	198.3	197.1
160	724.1	209.5	205.3
180	511.3	302.6	238.8
200	597.8	266.8	192
Avg	664.4	181.012	158.22

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Batch 5: 4.4 kg of Rice straw and 8.8 kg of fuel

Time	Temperature at 0.24 emissivity (°C)		
	Exh Tube	Conical ins	Cylindrical ins
0	33.7	29.3	37.5
5	50.1	44	42.2
10	166.1	44.7	47
15	335.2	74.8	60.9
20	484.7	75.4	86.5
25	565.4	85.4	110
30	666.2	123.1	134.4
35	687.1	128.1	142.3
40	773.6	152.2	152.5
45	761.1	152.1	162.4
50	764.7	157	171.8
55	787.5	169.7	175.4
60	729.7	202.7	188.7
70	743.5	191.5	201.2
80	800.5	199.3	212.2
90	728.7	271.2	222.6
100	719.3	244.8	220.3
110	745.6	243.6	221.5
120	641.4	209.1	215.1
Avg	588.6368421	147.2631579	147.6052632

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Batch 6: 4 kg of Rice straw and 13.9 kg of fuel

Time	Temperature at 0.24 emissivity (°C)		
	Exh Tube	Conical ins	Cylindrical ins
0	90.9	66.8	83
5	139.2	73.1	85.4
10	294	61.3	81.8
15	411.8	82.1	96.7
20	496.8	101.8	142.3
25	576.6	108.7	166.3
30	610.6	127	199.1
35	649.6	148.2	205.9
40	682	139	199.9
45	655.5	155.3	194.3
50	704.6	190.1	239
55	687	174.2	234.7
60	662.2	172.5	248.9
70	664.5	177.9	258.9
80	610.2	175.9	249.5
90	594	154.5	202.6
100	624.6	146.2	225.6
110	550.1	208.8	195.5
120	522.8	146.7	220.5
130	536.6	145.9	214.8
Avg	538.18	137.8	187.235

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APPENDIX II

STANDARD AND IODINE NUMBER VALUE

1. Standardization of 0.100 N Sodium Thiosulphate

No.	KIO_3	KI (g)	HCl (ml)	$Na_2S_2O_3$ (ml)		
				START	END	TOTAL
1	25	2.0070	5	0.0	24.9	24.9
2	25	2.0014	5	24.9	50.0	25.1
3	25	2.0094	5	27.9	53.0	25.1
AVG	25	2.0059	5			25.0

No.	KIO_3	KI (g)	HCl (ml)	$Na_2S_2O_3$ (ml)		
				START	END	TOTAL
1	25	2.0045	5	0.0	24.8	24.8
2	25	2.0006	5	24.8	49.6	24.8
3	25	2.0056	5	17.2	42.9	25.7
AVG	25	2.0036	5			25.1

No.	KIO_3	KI (g)	HCl (ml)	$Na_2S_2O_3$ (ml)		
				START	END	TOTAL
1	25	2.0041	5	0.0	24.8	24.8
2	25	2.0021	5	24.8	49.7	24.9
3	25	2.0005	5	20.9	46.0	25.1
AVG	25	2.0022	5			24.9

Standardization of Sodium Thiosulphate is 0.100 N.

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2. Standardization of 0.100 ± 0.100 N Iodine solution

No.	**I_2 (ml)**	**$Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	25	0.0	24.9	24.9
2	25	24.9	49.9	25.0
3	25	0.0	25.0	25.0
AVG	25			25.0

Standardization of Iodine solution is 0.100 N.

No.	**I_2 (ml)**	**$Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	25	0.0	24.7	24.7
2	25	24.7	49.3	24.6
3	25	22.1	46.7	24.6
AVG	25			24.6

Standardization of Iodine solution is 0.099 N.

No.	**I_2 (ml)**	**$Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	25	0.0	24.5	24.5
2	25	24.5	48.8	24.3
3	25	15.5	39.7	24.2
AVG	25			24.3

Standardization of Iodine solution is 0.098 N.

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3. Iodine number value (Gasifier without insulation)

Batch 1: Coconut shell

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0095	0.0	39.7	39.7
2	1.0022	0.0	39.4	39.4
3	1.0058	0.0	40.4	40.4
AVG	1.005833333			39.9

Iodine number value is 224.9002 mg/g.

Batch 2: Coconut shell

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0021	0.0	39.5	39.5
2	1.0092	0.0	39.8	39.8
3	1.0073	0.0	39.6	39.6
AVG	1.0062			39.7

Iodine number value is 230.0062 mg/g.

Batch 3: Rice straw

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0058	0.0	40.2	40.2
2	1.0072	0.0	40.3	40.3
3	1.005	0.0	39.9	39.9
AVG	1.006			40.1

Iodine number value is 219.6741 mg/g.

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4. Iodine number value (Gasifier with insulation)

Batch 1: Coconut shell

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0082	0.0	32.9	32.9
2	1.0044	0.0	33.1	33.1
3	1.0057	0.0	32.0	32.0
AVG	1.0061			32.7

Iodine number value is 342.3153 mg/g.

Batch 2: Coconut shell

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.006	0.0	33.6	33.6
2	1.0021	0.0	33.2	33.2
3	1.003	0.0	33.7	33.7
AVG	1.0037			33.5

Iodine number value is 319.9491 mg/g.

Batch 3: Coconut shell

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0028	0.0	33.6	33.6
2	1.0032	0.0	35.6	35.6
3	1.0006	0.0	37.9	37.9
AVG	1.0022			35.7

Iodine number value is 249.1942 mg/g.

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Batch 4: Coconut shell

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0039	0.0	33.0	33.0
2	1.0011	0.0	36.6	36.6
3	1.0035	0.0	33.7	33.7
AVG	1.0028			34.4

Iodine number value is 285.093 mg/g.

Batch 5: Rice straw

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.0016	0.0	33.1	33.1
2	1.0042	0.0	33.9	33.9
3	1.0093	0.0	33.2	33.2
AVG	1.0050			33.4

Iodine number value is 315.903 mg/g.

Batch 6: Rice straw

No.	**Sample weight (g)**	**STANDARD $Na_2S_2O_3$ (ml)**		
		START	END	TOTAL
1	1.002	0.0	37.4	37.4
2	1.0065	0.0	36.3	36.3
3	1.0018	0.0	35.9	35.9
AVG	1.0034			36.5

Iodine number value is 227.226 mg/g.

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APPENDIX III

CALCULATIONS

Example of calculation: Iodine number of batch 1

1) **Sodium thiosulfate normality**

$$N_1 = \frac{(P \cdot R)}{S}$$

$$= \frac{25 \ * 0.12}{24.9}$$

$$= 0.100 \text{ N}$$

2) **Iodine solution normality**

$$N_2 = \frac{(S \cdot N_1)}{I}$$

$$= \frac{(24.6 \cdot 0.100)}{0.099}$$

$$= 0.099 \text{ N}$$

3) **Calculation of X/M (Iodine absorbed per gram of carbon)**

3.1) Sodium Thiosulfate normality (N)

$$A = (N_2)(12693.0)$$

$$= 0.099 * 12693.0$$

$$= 12566.07 \text{ N}$$

3.2) Iodine solution normality (N)

$$B = (N_1)(126.93)$$

$$= 0.100 * 126.93$$

$$= 12.693 \text{ N}$$

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3.3) Dilution factor

$$\mathrm{DF} = \frac{\mathrm{I+H}}{\mathrm{F}}$$

$$= \frac{100+50}{50}$$

$$= 2.2$$

3.4) Iodine absorbed per gram of carbon (mg/g)

$$\frac{X}{M} = \frac{[A-(DF)(B)(S)]}{M}$$

$$= \frac{[12566.07-(2.2)(12.693)(32.7)]}{1.0061}$$

$$= 342.3152 \text{ mg/g}$$

4) Biochar yield

- Initial mass of raw material: 20.8 kg
- Mass of biochar: 7.4 kg

$$\%\text{Yield} = \frac{\text{Mass of Biochar}}{\text{Mass of raw material}} \times 100$$

$$= \frac{7.4 \text{ kg}}{20.8 \text{ kg}} \times 100$$

$$= 34.742$$

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Example of calculation: Gasifier efficiency

$$\eta = \frac{Q_g M_g}{LHV_f M_f} \times 100$$

When Q_g is the heating value of syngas (MJ/kg)

M_g is the rate of syngas production (m^3/hr)

LHV_f is the lower heating value of fuel (MJ/kg)

M_f is the rate of fuel consumption (kg/hr)

- Q_g: 12.6 MJ/kg
- LHV_f: 18.5 MJ/kg
- M_g: 9.404 m^3/hr
- M_f: 11.933 kg/hr

$$\eta = \frac{12.6 \times 9.404}{18.5 \times 11.933} \times 100$$

$$= 53.669\ \%$$

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