Tar Quantification and Classification Based on Gasification Operating Condition of Downdraft Gasifier System Using Wood Pellet Feedstock

Dissertation

Tar Quantification and Classification Based on Gasification Operating Condition of Downdraft Gasifier System Using Wood Pellet Feedstock

木質ペレットを燃料とするダウンドラフト式ガス化装置における運転条件に準じたタールの定量分析と分類

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Date of Submission	: SEPTEMBER 2020

DISSERTATION APPROVAL

DISSERTATION TITTLE:

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Submitted in partial fulfillment of the requirements for
The Doctoral Degree in Engineering (Dr. Eng)
Division of Mechanical Science and Engineering
Graduate School of Natural Science and Technology
Kanazawa University
Japan 2020

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Kanazawa, September 2020
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ABSTRACT

Biomass gasification is a promising technology for improving the global green energy system. During, biomass gasification, tar formation generates a serious problem, creating high operational cost and reducing the system performance. There have been significant attempts to classify and interconnect all of tar components. In this present work, tar is examined as all organic contaminants with a molecular weight larger than benzene.

This research has produced a new tar classification for tar based on phenol molecular weight. Light tar have molecular weight lower than phenol. Otherwise, heavy tar have molecular weight more than molecular weight of phenol. Compared to heavy tar, the light tar was burn much better. More about heavy tar output leads to a large failure and valve link, which lower the biomass operating system efficiency.

Due to the fact that tar characteristics have many parameters including tar density, tar classification and tar quantification, those parameters that have commonly calculated beneficial for the optimal production. Tar quantification can be determined as quantification of tar for each tar compounds which calculated as a result of the GCMS in producer gas.

The aim of this research is to determine the optimal production of low tar density in producer gas using wood pellets feedstock in downdraft gasifier system. The experiments had been conducted under the variation of gasification operating conditions.

In order to ensure effective gasification performance and to contain the negative effect of the producer gas heating value, the balance of producer gas and energy conversion qualities should be lowered the moisture content at least 20 - 25 wt. % and the ignition becomes difficult in case the value of the moisture content is more than 8 wt. % in cedar wood pellet. Therefore, the effective value of moisture content for this research was chosen between 2 wt. % until 6 wt. %. The airflow rate is around 40 L/min, 60 L/min and 80 L/min to supply air in the gasifier system. The range of 40 L/min to 80 L/min was chosen to maintain the temperature inside the gasifier between 400 °C- 600 °C and optimize the system performance and avoid the “clinker” formation.

This experiment execute the result of Shimadzu GC-MS QP2010 Plus to identify the tar composition from tar sampling in 2 ml vial bottle as well as the existence of phenol, toluene, indene, naphthalene, biphenyl, fluorene, phenanthrene, fluoranthene, and pyrene. Furthermore, GC Postrun was used to analyzing data from GCMS to identify tar compound in the sample.

Gravimetric analysis is a technique using a tar sample to analyze and determine the density of a tar compound. The Tar density can be described by the total volume of tar in producer gas derived from the Gravimetric analysis. In these experiments, the acetone in the tar sample was evaporated to get pure mass of the tar compounds by IRIS OHYAMA (dryer-evaporation machine) and set to a temperature of 65 °C. Finally, with a tar-weight measuring machine (Chyo JL-200), the pure weight of the tar compounds was measured, and the sensitivity was 0.1 mg.

The result showed that the increase in the production of producer gas especially in CH_4 was linked to a decrease in the moisture content. The result of the experiments also showed that phenol and indene, were the majority and minority classes of the tar compounds, respectively in the tar quantification. The lowest amount of tar density was formed for the condition with highest airflow rate (80 L/min) and lowest moisture content (2 wt. %). Moreover, the increase in airflow rate significantly affected the PAH concentrations in classes 4 (Light polyaromatic hydrocarbon) and 5 (Heavy polyaromatic hydrocarbon) of the tar classification. In addition, the maximum amount of light tar on the tar classification was comprised from the lowest moisture content. The light tar quantity suggests that the gasifier is easy to ignite and his condition will eliminate the issue of equipment failure.

Key words: gasification operating condition; moisture content; airflow rate; tar classification; tar quantification; tar density; downdraft gasifier system; wood pellet; producer gas

ACKNOWLEDGMENTS

Thanks to the God, Allah SWT, Finally, I could finish for writing this dissertation. I also would like to express my sincere gratitude to my professor, Associate Professor Hiroshi Enomoto, for introducing and assisting me to the world of biomass and applied combustion research. It was only because of his guidance, enthusiasm, and support that I could complete my research and Ph.D. course.

I am very thankful to all the committee members, Associate Professor Hiroshi Enomoto, Professor Takahiro Kiwata, Associate Professor Yoshikazu Teraoka, Associate Professor Nobuyoshi Komatsu, and Assistant Professor Takaaki Kono, for reading my thesis and giving me valuable remarks and suggestions and also Research Associate Noburu Hieda for the helping research in the hard laboratory of applied combustion laboratory.

I also would like to express my gratitude to BUDI-LN scholarship from Indonesia Endowment Fund for Education (LPDP), Ministry of Finance Republic of Indonesia (KEMENKEU), Ministry of Education and Culture Republic of Indonesia (KEMENDIKBUD), and Ministry of Research and Technology of Republic Indonesia (KEMENRISTEK) for sponsoring my scholarship. Because of this scholarship, I was able to achieve my dream of studying as a Ph.D. student. In addition, I would like to thank you to my institution, Universitas Negeri Semarang, for permission to pursuing my Doctoral degree. I would like to thank Kanazawa University for providing me the opportunity to become a Ph.D. student. My deepest gratitude to all the staff of Kanazawa University who have helped me in my academic life in Kanazawa.

I would also like to thank my friends in the Applied Combustion Laboratory of Kanazawa University, for all the wonderful memories of working together and all the support. I would like to give my gratitude to my lab mates, Masahide Kobayashi, Mitsuhiro Maeda, Phung Minh Tung, Anh Vo Cong, Kazushi Fukadu, Zheng Zong, Shota Iwai, Yoshihide Ota, and Takuya Mino. Moreover, also thankful for all my friends here in Kanazawa, especially BUDI-LN 2016. I would like to thank my family, my beloved wife, Apri Nur Wulandari, my son, R. Prabuwardhana Rajasanagara Rizqi Naryaputra and my child in my pregnant, my mother, Sungkowati, my deceased father, Soenarjo, sisters, Agustien Naryaningsih and Diah Naryaningrum and my nephew, Afrilza Daffa Naryapramono, my brothers in law, Muhammad Khozin. I am grateful for their love, prayers, understanding, and encouragement.

Rizqi Fitri Naryanto

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

1.1. Background

Based on International Energy Outlook Project, more than 28 % world energy consumption will grow up between 2015 until 2040 for the world energy demand. The countries with strong economic grow in Asia need more than 60 % increase of world total energy consumption from 2015 through 2040. For this reason, many country define the new energy sources.

Figure 1 show the energy demand in every energy source, which are the highest is petroleum (36%) and the lowest is nuclear electric (8 %), and renewable energy in the 11 %. The other energy demand are natural gas (31 %) and coal (13%) from the world renewable energy demand, biomass have the highest portion in 45 % compare with other renewable energy sources such as geothermal (2 %), hydroelectric (25 %), wind energy (21 %) and solar energy (6 %) [1]. This condition can be show in the **Figure 2**.

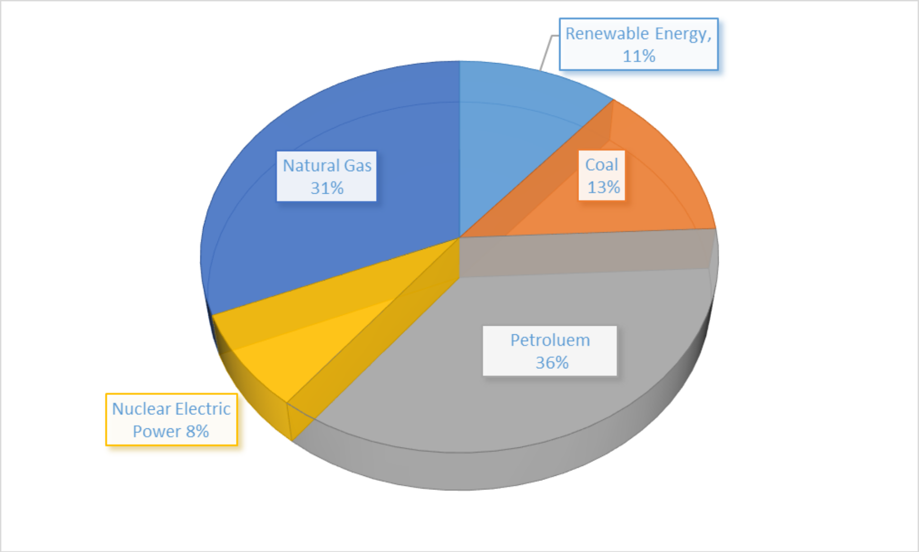

Figure 1. World Energy Demand

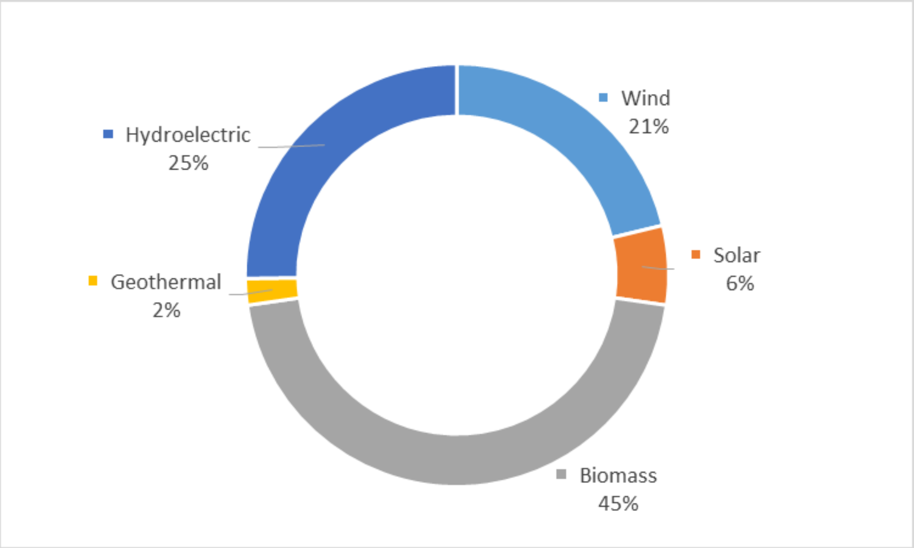

Figure 2. World Renewable Energy Demand

The increase of biomass energy demand increase in the future, from 2006 the energy demand of biomass is 49 % of total biomass energy demand, and in the 2010 the biomass energy demand increase in 53%, this condition give evidence, the biomass energy is the potential energy for the future, to overcome the energy need [2]. Biomass in the 2006 is 49% from total renewable energy demand in 6.659 quadrillion Btu, for the calculation of biomass in the 49% x 8.049 = 3.26 quadrillion Btu. The condition biomass in the 2010 is 53% from total renewable energy demand in 8.049 quadrillion Btu, and this condition is equivalent with biomass in the 53% x 8.049 = 4.26 quadrillion Btu. The condition of biomass in the 2019 was explain as biomass is 43% from total renewable energy demand in 11.4 quadrillion Btu, and this condition equal with Biomass in the 43% x 11.4 = 4.90 quadrillion Btu. **Figure 3**, **Figure 4** and **Figure 5** show the condition of biomass energy demand.

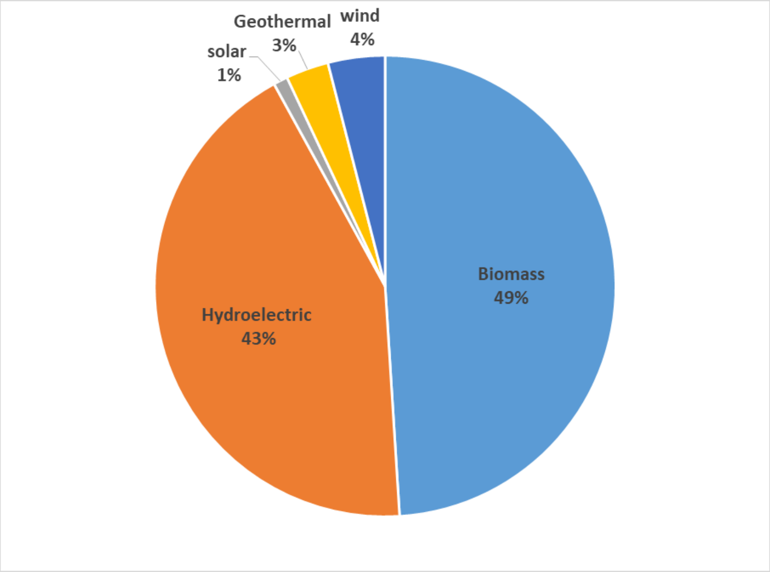

Figure 3. Biomass Energy Demand in 2006

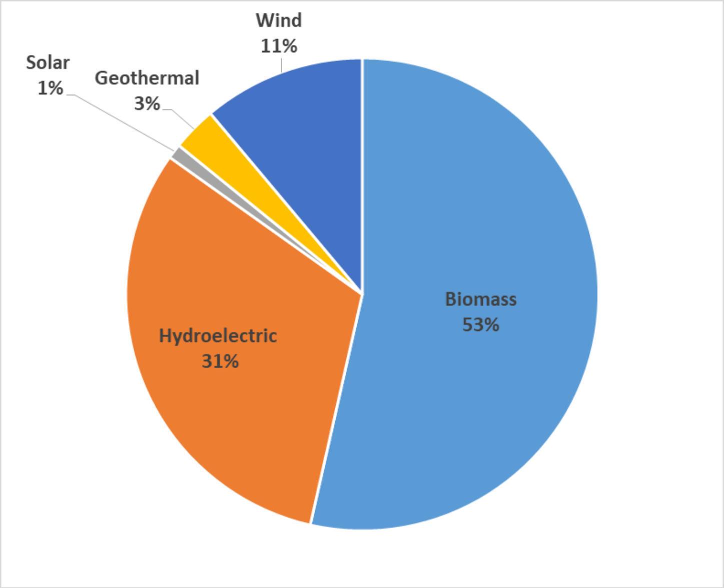

Figure 4. Biomass Energy Demand in 2010

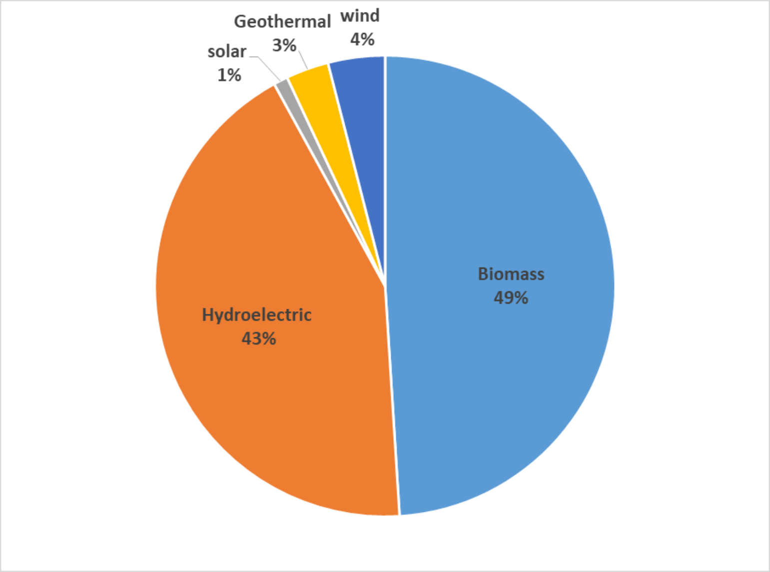

Figure 5. Biomass Energy Demand in 2019

From Comparison from **Figure 3**, **Figure 4**, and **Figure 5** biomass energy demand have the trend to increase, and this condition indicate that biomass is potential energy in the future. In order to reduce our current dependence of non-renewable energy sources, biomass gasification is a promising technology for improving the global green energy system. Biomass includes every organic material that has been produced from plants that is used in all organic substances produced from plants (including algae, trees, and crops) and includes all land and water-based veggies and all organic waste, trees and crops. The reaction of CO_2 through the photosynthesis in soil, water and solar energy results in the production of biomass-forming carbohydrates. The use of biomass as a source of energy was not much achieved. Biomass has contributed to environmental pollutants being used directly as fuel, without treatment because of its drawbacks, for example in boilers and direct combustion for household energy purposes.

Biomass is one of the renewable energy sources in addition of geothermal, micro hydro, solar, wind and biogas, can be one of the potential renewable energy sources to be created. Gasification process is a process by means of partial oxidation at 500 ^{o}C and more in the temperature to convert organic portion of the human life from animal, wood or fruit to methane and flammable gas. The primary production of the gasification system is producer gas or syngas, e.g. carbon monoxide (CO), methane (CH_4), hydrogen (H_2), carbon dioxide (CO_2), nitrogen (N_2). The product of syngas will be used to control and produce the energy for activating the engine and electricity.

The electricity supply is not available in a small area or village. In order to address this situation, the small power plant supported by biomass with knowledge of the area can be implemented. In Indonesia, for example, the Java Island as Indonesia's largest rice production, rice husk may be used as a power supplier. For Sumatera Island and Kalimantan Island as the world's largest palm oil production, all parts of the palms oil tree can be used in the production of electricity, although for the production of biomass it is possible to use in Japanese countries that have several trees, pellet wood or wood chips especially in cedar wood. The end use of biomass downdraft gasifier system is connected with Reciprocated Internal Combustion Engine (R-ICE) to generate electricity (less than 2 MW).

Biomass gasification is a thermal process in which solid fuel is transformed into a valuable gas using a number of gasifying agents, such as air and steam. In order to ensure effective gasification performance and to contain the negative effect of the producer gas heating value, the balance of producer gas and energy conversion qualities should be lowered the moisture content at least 20 - 25 wt. % and the ignition becomes difficult in case the value of the moisture content is more than 8 wt. % in cedar wood pellet [3]. Therefore, the effective value of moisture content for this research was chosen between 2 wt. % until 6 wt. %. The airflow rate is around 40 L/min, 60 L/min and 80 L/min to supply air in the gasifier system. The range of 40 L/min to 80 L/min was chosen to maintain the temperature inside the gasifier between 400 ºC- 600 ºC and optimize the system performance. Gasifier produces "clinker" in the more than 600 ºC temperature. Clinkering occurs in the biomass gasification process on inside of gasifier when ash melt and fuses into a hard and glassy slag. It also happens when ash is a noncombustible powder residue left over after wood pellet has burnt. This clinker sometimes blocks the feed movement and causes the discontinuity in the operation of gasifier [4,5].

During, biomass gasification, tar formation generates a serious problem, creating high operational cost and reducing the system performance. The biomass gasification process is carried out using wood pellet as feedstock in the production process of bio gasification. Tar is inevitable by-product for the process of biomass gasification during biomass gasification processes [6].

As a result, several organizations involved in biomass gasification have provided many definitions of biomass tars. As a 'historic' term tar is an operationally determined parameter, primarily based on organic gasification condensed in boiler, transfer and internal combustion engine (ICE) entry devices under operating conditions. In order to test the suitability for further downstream usage of the product gas, considering the formation of heavy carbons (tars), one of the key difficulties during the gasification process, determining the quality of the tar is highly significant. Tar is a generic term which describes a complex range of organic oxygenated constituents produced by the biomass feedstock's partial response. Such material is used as vaporized or persistent aerosols in the hot gas stream but typically condenses at cooler temperatures. There are three international organizations with the same definition of tar that defining tar as all materials from hydrocarbon with a molecular weight higher than benzene. Such tars contain various oxygenated aromas produced during the pyrolysis process. Tar has a description of a mixture of five-ring hydrocarbons, including aromatic compounds, oxygenated as Polycyclic Aromatic Hydrocarbon content (PAH). These tars include a variety of oxygenated aromatics formed in the pyrolysis step of the gasification process. Tar has a definition of a mixture of five-ring hydrocarbons, including aromatic compounds, oxygenated as Polycyclic Aromatic Hydrocarbon content (PAH). There are three international organizations with the same definition of tar that defining tar as all materials from hydrocarbon with a molecular weight higher than benzene.

Accordingly, there are some methods for quantitative measurement of Biomass Gasifier Tars. One of these methods was told by Carpenter [7] by using Molecular-Beam Mass Spectrometer. Other method which is suitable for analyzing heavy tar was by applying Gravimetric analysis. Gas Chromatography – Mass Spectrometry (GC-MS) is an analytical method that combines the features of gas-chromatography and mass spectrometry to identify different substances within a test sample.

For end-use applications such as fuel cells in which the compound 's existence becomes essential, GC-MS analysis is needed. The results of the gravimetric tar analyze indicate that numerous individual tar compounds are included, but not equal to the total tar mass as the light weight tar compounds that disappear during the evaporation process, depending on the evaporator conditions, used for determining gravimetric tar.

Additionally, there were three methods for analyzing tar, as follows: Solid Phase Adsorption (SPA), gravimetric method and Cold Solvent Trapping (CST). According to the SPA system, tar is measured by collecting it on a small amino-phase-sorbent in column.

On the other, gravimetric method is a technique which the amount of the tar being analyzed through the measurement of tar mass in tar density. In this research, we applied CST method which was sampled from the gasifier reactor. The trapper applied ethylene glycol as a solvent for this method. Samples were then analyzed using GC-MS [8]. Regarding from the analyzing tar, there are many parameters that commonly calculated. Those parameters are including tar density, tar classification and tar quantification, that generally calculated beneficial for the optimal production of syngas and minimizing of tar formation. In view of the formation of tar as one of the principal problems during the process of gasification, the optimal production of low-density tar-gas using pellets of wood as feedstock is therefore determined.

Different analysis methods have been proposed for solving the tar problem. The experiments had been conducted under the variation of gasification operating conditions. Therefore, the variation of moisture content are in the value of 2 wt. %, 4 wt. %, and 6 wt. % and the variation of air flow rate with the amount of 40 L/min, 60 L/min and 80 L/min.

1.2. Objectives

The main focus of this research is to investigate and to analyze the effect of gasification process in the downdraft gasifier in various gasification operating condition using wood pellet as feedstock with the tar characteristic specification. The specific objective of main purpose are:

1. To determine the effect of tar formation in the gasification process based on the variation of gasification operating condition in the form of moisture content and air flow rate on tar quantification with chemical compounds.
2. To analyze the consequence of tar generation in the gasification process based on the variation of gasification operating condition on tar classification based on the molecular weight with the division of heavy tar and light tar.
3. To evaluate the outcome of tar production in the gasification process based on the variation of gasification operating condition on tar density with the measurement from the Gravimetric Analysis
4. To investigate the effect of producer gas in the small R-ICE operation from a small downdraft gasification reactor.

1.3. Scope of Study

This study analyzed the effect of tar formation caused by the gasification operating condition for the tar characteristics as follows: tar quantification, tar classification and tar density. Besides, we investigated the effect of producer gas in the small R-ICE operation from a small downdraft gasification reactor. For these experiments, the variation of gasification operating condition were the variation of moisture content 2 wt. % to 6 wt. %, and variation of airflow rate from 40 L/min to 80 L/min using wood pellet as feedstock in downdraft gasifier and summarized in producer gas/syngas production.

Tar generally treated as hydrocarbon aggregate. There have been significant attempts to classify and interconnect all of the components of tar. A number of researchers tried to put tars into various groups and to observe their behavior. The literature includes various approaches for executing the classification. Corella et al. [9] had mentioned tars in two group, namely 'easy to destroy' that are more reactive tar species characterized and 'hard to destroy' the least reactive tar type. In this present work, tar is examined as all organic contaminants with a molecular weight larger than benzene. This tar classification system has been developed in cooperation with Energy research Center of The Netherlands (ECN), Toegepast Natuurwetenschappelijk Onderzoek (TNO) and University of Twente (UT) within the framework of the project 'Primary measures for the inhibition /reduction of tars in biomass fuelled fluidised-bed gasifiers', funded by the Dutch Agency for Research in Sustainable Energy (SDE). Instead of reactivities based on molecular weight, this classification is mainly based upon the solubility and condensability of various tar compounds. The classification of tar compounds based on class 1 (GC undetectable), class 2 (Heterocyclic aromatic compounds), class 3 (Light hydrocarbon aromatic compounds), class 4 (Light polyaromatic hydrocarbon) and class 5 (Heavy polyaromatic hydrocarbon).

This research has produced a new test for tar based on phenol molecular weight. If the compounds have a molecular weight lower than phenol, they are light tar. Otherwise, if the chemical compounds have a molecular weight more than that of phenol, they are comprised as heavy tar. This analysis was designed to divide the classification into two categories, including light tar and heavy tar. Light tar consist primarily of aromatic and phenolic compounds that are volatile and semi volatile, while heavy tar comprises nonvolatile polar compounds. Compared to heavy tar, the light tar was burn much better. More about heavy tar output leads to a large failure and valve link, which lower the biomass operating system efficiency.

The tar sample collection method used the "Method and Apparatus for Collecting Tar" developed by Hiroaki Ohara and Katsuaki Matsumura, which the Japan Patent Office had gave the patent number JP 2009-40885. The method uses three impingers bottles to freeze the producer gas which contains tar from the gasifier and catch the tar without liquid by surface contact method use glass beads, and this method can freeze the producer gas from 250 ºC into -20 ºC, from this condition we can get the total amount of tar sample. Tar sampling was taken in the position between the gasifier and soot remover equipment. The gasifier produces "clinker" in the more than 600 ºC temperature. For this reason, in this experiment used temperature at an average 400 ºC – 600 ºC. Clinkering occurs in the biomass gasification process inside the gasifier when ash melt and fuses into a hard and glassy slag. It also happens when ash is a noncombustible powder residue left over after the wood pellet has burnt. This clinker sometimes blocks the feed movement and causes a discontinuity in the operation of gasifier.

Moreover, these experiments were executed from the result of Gas Chromatography-Mass Spectrometry (GC-MS) for tar composition analysis, which was calibrated using standard reagents with high purity of 94% to 99%. Shimadzu GC-MS

QP2010 Plus was used to identify the tar sampling in 2 ml vial bottle as well as the existence of phenol, toluene, indene, naphthalene, biphenyl, fluorene, phenanthrene, fluoranthene, and pyrene. The total Ion Chromatogram (TIC) used nine standards, which were applied to quantify the product. The compound peaks with a similarity index higher than 70 were used to determine tar compounds. Furthermore, the data result of GC-MS was analyzed using GC Postrun software in order to identify the tar compound in the sample.

Additionally, Gravimetric analysis is a technique using a tar sample to analyze and determine the density of a tar compound. It is carried through the distillation and evaporation process to identify the pure mass of the compound. The Tar density can be described by the total volume of tar in producer gas derived from the Gravimetric analysis. This approach analyzes the pure mass compound to determine the total mass percentage. In this research, the tar sampling with moisture content 2 wt. % to 6 wt. %, and variation of airflow rate 40 L/min to 80 L/min were analyzed in the gravimetric method. It was carried out on the boiling point at 65 ºC to remove solvents mixed in tar sampling. In this case 3 grams of tar and acetone mixture is heated at 65 °C for 5 hours. Since the boiling point of acetone is 56 ºC, tar separates from other compounds, and all acetone evaporates. Only a pure mass of tar remains in the residue, a condition referred to as tar density. In these experiments, the acetone in the tar sample for pure mass of the tar compounds was evaporated by an IRIS OHYAMA (dryer-evaporation machine) set to a temperature of 65 °C. Finally, with a tar-weight measuring machine (Chyo JL-200), the pure weight of the tar compounds was measured, and the sensitivity was 0.1 mg.

Due to the fact that tar characteristics have many parameters including tar density, tar classification and tar quantification, those parameters that have commonly calculated beneficial for the optimal production. Tar quantification can be determined as quantification of tar for each tar compounds which calculated as a result of the GCMS result in producer gas.

1.4. Organization of Dissertation

The content of this dissertation consist of the research and publication as long as my study in Kanazawa University Japan. The three main part of this dissertation consist of gasification condition and tar compounds in downdraft gasification system. The structure as follow:

- Chapter 1 consisted of introduction, background, objectives, scope of study and organization of dissertation.
- Chapter 2 explained about the literature review of gasification system, tar compounds and Internal Combustion Engine theory and Palm Oil as Potential Biomass..
- Chapter 3 described about the materials and methods that were used in our research on Tar Quantification and Classification based on Gasification Operating Condition of Downdraft Gasifier System Using Wood Pellet Feedstock
- Chapter 4 consisted of Results and Discussion in the research of the effect of Gasification Operating Condition on Producer Gas Efficiency, Tar Quantification, Tar Classification, Heavy Tar and Light Tar Production, and Tar Density. Besides, we explains about the effect of moisture content on Gasification Efficiency and the effect of temperature on Tar concentration. Many parameters had been affected on the system of Reciprocating-Internal Combustion Engine (R-ICE).
- Finally, the chapter 5 explained of the summary and the suggestions for the future work for the improvement and better quality of this research.
- Additionally, the appendixes contained an additional information relating to various part of the dissertation.

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CHAPTER 2. LITERATURE REVIEW

2.1. Biomass

Biomass is organic and a renewable energy source, which is generated by animals and plants. Biomass contains energy from the sun stored in it. Plants absorb energy from the sun in a process known as photosynthesis. When biomass is burnt, the heat releases the chemical energy in biomass. Biomass can be directly burned or converted into liquid biofuels or biogas that can be combusted as fuels. Examples of the biomass and its energy uses:

- Burned waste for wood and wood processing in heating buildings, heat processing in industry, and electricity generation.
- Farm crops and wastes, which have been burned or transformed into liquid biofuels as fuel.
- Waste food, store and timber waste burned for electricity generation in power stations or converted into biogas at waste dumps.
- Animal waste and human urine that can be burned as a coal, converted to biogas.

In addition, solid biomass may be directly consumed to generate heat, such as wood and waste. Biomass can also be transformed in the gas known as biogas or in fluid biofuels like ethanol and biodiesel. Then energy can be consumed with these fuels. Biogas occurs as paper, food waste and yard waste in landfills decompose, and can be processed in special vessels known as digesters by treating sewage and animal manure. Ethanol is made from crops such as maize and sugar cane fermented for vehicle use to produce fuel ethanol. Biodiesel is made from vegetable oils and animal fats and can be used as heating oil for vehicles. In this process, biological biomass is called.

Figure 6 demonstrates the biological biomass system. Otherwise, heat in the process biomass, pyrolysis and gasification process is used for thermochemical biomass. Gasification is an oxidation process that often occurs at temperatures above 500 °C and converts a strong bio-substances into H_2 and CO [1]. This process transforms biomass into gaseous fuels, including hydrogen (H_2), methane (CH_4), and carbon monoxide (CO). As the oxidizing agent, the gas products are mixed together with atmospheric air to create an electrical / motor power plant combustion process. **Figure 7** demonstrates the network of thermochemical biomass.

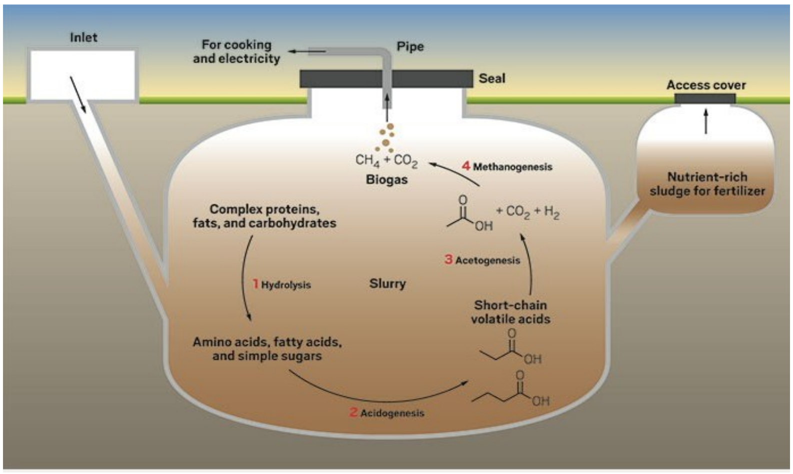

Figure 6. Biological Biomass System

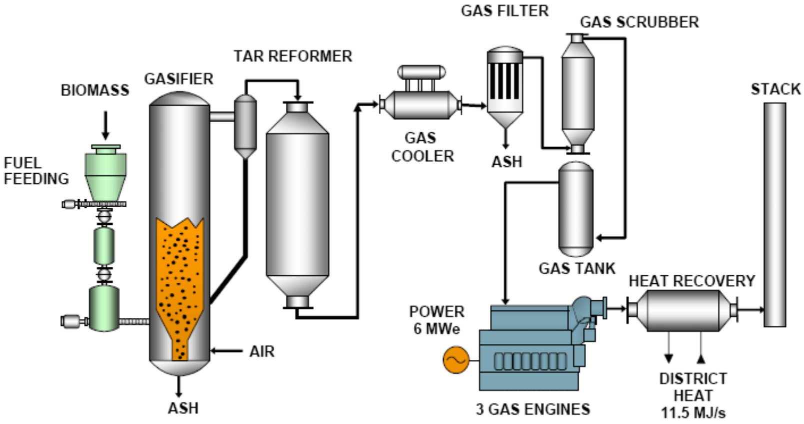

Figure 7. Thermochemical Biomass System

Biomass fuels therefore provided approximately 5 % of total United States primary energy use in 2017. Of these, 5%, about 47% were of biofuels (mostly ethanol), 44% were wood and wood-based bio-mass, and 10% were of municipal waste biomass. The researchers are trying to develop ways to use more biomass for fuel (the sum of proportions is greater than 100 percent due to independent rounding) [2].

In addition, biomass includes all plant-produced organic materials (including algae, trees and crops) and covers all land, water and organic waste. The CO_2 response by photosynthesis in air, water and sunlight results in the production of carbohydrates forming the biomass. Not much has been done about the use of biomass as an energy source. Biomass is used directly as an untreated fuel for the purposes of household energy such as heaters or direct combustion caused environmental problems. In addition to geothermal, micro-hydraulic, solar, wind and biogas, biomass is one of the potential renewable energy sources to be developed [3].

Likewise, biomass gasification is a thermal treatment that leads to high gas production and low levels of carbohydrate and ash. Gasification tends to occur at the high temp, with thermal decomposition of solid biomass to form gas-stage products typically H_2, CO, CO_2, CH_4, H_2O, hydrocarbons (CH_s), tars, char, and ash. Gasification is carried out at high temperatures [1,4]. It is also possible to use (downstream) this producer gas for generating heat and power as well as transport fuels. In recent years, Combined Heat and Power (CHP) had attracted significant attention. The use of the biomass gas producer directly in the gas turbines or in high-temperature fuel cells not only generates electricity, but also considerable heat. The bioelectricity efficiency of biomass gasifier / gas turbines is estimated to be between 40 and 45 percent, or more than twice as high as in Rankine systems. The thermal heat generated from the power generation cycle is collected and used for domestic use, for the production of additional electricity in steam turbines [5-7].

The definition of biomass includes complex organic and polymer combinations. Lignin and carbohydrates, like cellulose and hemicellulose, are the principal types of compounds, whose species-dependent ratios and resultant proponents. A complex polymer for phenyl propane units, Lignin is a cementing agent for cellulose. Cellulose is a polymer that consists of d(+)-glucose and is based upon hexose and pentose sugars. The hemicellulose polymer, the binding agent function of lignin in the gasification of biomass. Thermal gasification is the conversion of a carbonate feedstock such as biomass to a gaseous energy carrier by partial oxidation at elevated temperatures. This gas consists of carbon monoxide, carbon dioxide, hydrogen, methane, higher-carbon trace amounts, such as ethane, water, nitrogen and various other contaminants such as small char particles, ash, tars or oils. This gas contains carbon monoxide and oxide, hydrogen, and methane. Air, oxygen, steam or combination may be used for partial oxidation [8].

In several sequential phases, gasification takes place:

- **Drying** to evaporate the humidity.
- **Pyrolysis** to give gas, vaporized tars or oils and a solid char residue.
- **Gasification or partial oxidation** of the solid char, pyrolysis tars and pyrolysis gases.

There is therefore a pyrolysis to solid carbon, condensing hydrocarbons or tar and gases when a solid fuel is heated up to 300 °C – 450 °C when an oxidizer is not available. The relative outputs of gas, liquid and char mainly depend on the heating rate and final temperature. Pyrolysis typically proceeds much faster than gasification in the gasification phase, which is the rate control stage. The pyrolysis gas, liquid and solid products then react with the oxidizing agent (typically air, steam, nitrogen, carbon dioxide, oxygen, or any combination thereof) to give the permanent CO, CO_2, H_2 and small quantities of hydrocarbon gasses at high temperatures where gasification takes place. Char-gasification combines several gas-solid and gas-gas reactions in which solid carbon is oxidized into carbon monoxide and carbon dioxide, and hydrogen is produced through the reaction of the water-gas shift. Carbohydrate gas-solid reactions are the slowest and limit the total gasification process rate [8,9].

2.2. Biomass Gasification

Various types of gasses have been developed, divided into three main groups: induced flow gasifiers, bubbling / circulating fluidized gasifiers and flatbed gasifiers, with the final gasses divided into counter-current (updraft) and downdraft gasifiers. The key differences concern the movement inside the reactor of reactants and materials (in particular the movement of solid fuels and gasifying agents), the different gasifying agents employed (air, oxygen and/or Steam), and the resulting reaction conditions. The reactors may be used at or at higher pressure, but the latter can only be operated on bubbling or circulating fluidized bed reactors and on gasifiers for induced flow.

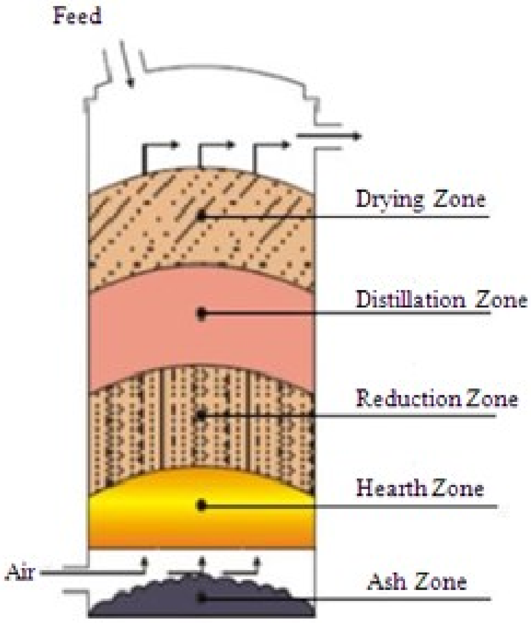

Figure 8. Updraft Gasifier or Counter-Current Gasifier in Biomass System

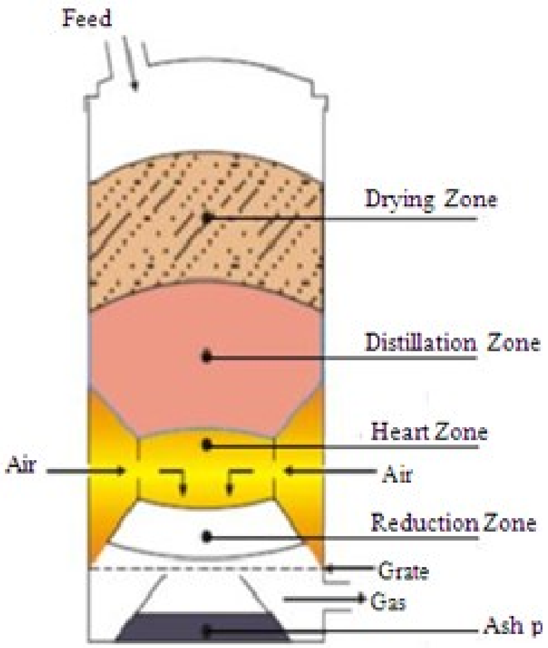

Figure 9. Downdraft Gasifier or Co-Current Gasifier in Biomass System

Reactor vessels in which the biomass content is either packing in or movement gradually as a plug involving fixed-bed gasifiers contain gases flowing between the partly [10]. Fixed bed gasifiers are typically fed from above the reactor and can be configured for updates or downdraft. **Figure 8** demonstrates the design of the updraft gasifier. The air or oxygen passes through a hot-reactive zone near the bottom of the gasifier in a way contrary to that from solid material flow with fixed-bed updraft gasifiers [11]. **Figure 9** displays the downdraft gasifier. They may be increased, but they provide a highly tar-friendly product gas. This tar will mainly be extracted from the gas, causing a gas purification problem. Downdraft gasifiers with fixed-beds are limited in scale, requiring a well-defined fuel to be fuel-flexible but produce less tar than Updraft. Downdraft gasifier also produces cleaner (low tar content) gas, which is preferable for the use of motors or for engine [12,13]. Entrained flow gasifiers require spent fuel and, as the temperatures above the ashes melting in biomass fuel, they are usually more suitable for coal than biomass gasification. On the other hand, fluid-free bed gasifiers (limited by the melting effect of the bed material) are usually operated at 1075-1275 K and cannot be used in the gasification of coal because higher temperatures are needed because of the lower reactivity of charcoal compared to biomass (> 1575K). The excellent mixing characteristics and high gas-solid contacting reaction rates are taken advantage of by fluidized-bed gasifiers [14].

The fluidized bed bubbling gasifier appears to create a tar-containing gas between the updraft and the downdraft gasifiers. Certain pyrolysis products are drawn from the fluidized bed by gasification products and then transformed in the Freeboard region by thermal cracking. A device in which the bed material circulates between the gasifier and a secondary level is used in the rotating fluidized gasifier. Fuel capacity higher than 10 MW is available with the fluidized gasifiers in circulation [15].

2.3. Wood Pellet Feedstock

Pellet energy based on wood biomass continues to be a popular commoditized feedstock based on solid biomass for the bioenergy industry. Its compact size and geometry have good volume properties and a relatively high energy density, as well as flexibility and appropriateness to existing handling and storage. Especially when pellet energy is focused on woody biomass, its low ash content, its high ash melting temperature and its unproblematic ash composition provide high feedstock quality. The combustion of wood pellets does not cause a significant deflection, decay, decomposition or even removal of nutrients from the biomass cultivation field. The feedstock supply was focused in the early days of production of energy pellets on residues of saw factories, such as scrubland or cuts in timber. Their processing into energy pellets has created an added income and value for a low cost or low price side product often at no cost. Sage and dry wood shavings are, however, an excellent input for the manufacture of wood pellets. These are still low in particle size and are already dry in the case of shavings. Due to the increasingly rising demand for energy pellets and the growing bioenergy sector in Japan in particular, a completely new industry in the production of power pellets is mainly generated from the side of demand and less from the side of supply. The production of these science mill residues like sawdust and shavings has already surpassed demand for wood pellets in many areas of the world. The wood pellet feedstock figure was shown in **Figure 10**.

Figure 10. Wood Pellet Feedstock

Wood pellet feedstock has been used in this analysis because it is readily available and corresponds to the operation of a laboratory gasification device. It was also picked because it had more lignin than other feedstock. The pellet is usually made of 21–31% lignin, 38–51% cellulose, 17–38% hemicellulose and 3% extractive pellet [16-18]. Lignin is an aromatic polymer mixed with cellulose fibers, which connects adjacent cells. It acts as a hydrocarbon bonding agent, resulting in the development of tar [19]. The wood pellet had a large density of 790 kg/m^3 and a diameter of 6 mm. Ultimate Analysis (UA) analyzes were carried out on the basis of the Japan Industrial Standard (JIS), UA and Proximate analysis (PA). **Table 1** and **Table 2** UA and PA have been shown, whereas in qualitative research natural feedstock materials like C, N, S, H, O were used. The PA provided a variety of parameters, such as fixed fuel, volatile moisture and ash [20].

Table 1. Wood Pellet Components (Ultimate Analysis)

Ultimate analysis (wt. %, dry ash-free) JIS M8813	
C (dry, ash-free)	50.02
N	0.09
S	0.09
H	6.43
O (balance)	43.37

Table 2. Wood Pellet Components (Proximate Analysis)

Proximate analysis (wt. %, dry basis) JIS M8812	
Fixed carbon	17.65
Volatile Matter (dry base)	81.82
Ash	0.53
Low heating value (LHV)	15.37 MJ/kg-dry

The first stage of the experiment is the preparation of feedstocks by a number of drying methods used (Akira Higashi Dryer TTM-440N, Japan). The sample's initial moisture was around 7 - 9 wt. %. The dry temperature is three different condition, including 70 °C, 60 °C, and 50 °C of their temperature. During drying, the moisture content should be reduced to 2 wt. %, 4 wt. %, and 6 wt. %. The analyzer of humidity / moisture content was used (AND MF-50, SHS inside Super Hybrid Sensor, with measurement accuracy 0.05% from A&D Company, Japan). In addition, the humidity measurement interval was performed in every 2 hours during 48 drying hours and was split into three sessions. The result is that in the first 12 hours, humidity changes substantially and gradually decreases to a stable percentage during the drying process. To get 6 wt. %, it took 1 hour to dry. The initial value is 7 ± 9 wt. %. Drying temperature at 70 ° C maximum. That the moisture content 7 wt. %, a maximum of 2 hours was required to 4 wt. %. A total of 6 hours drying time to 2 wt. %. For a drying temperature of 60 °C and 50 °C, this condition is not identical. In order to produce the same moisture performance, lower temperatures take a longer time. The drying state of the pellet feedstock is shown in **Figure 11.**

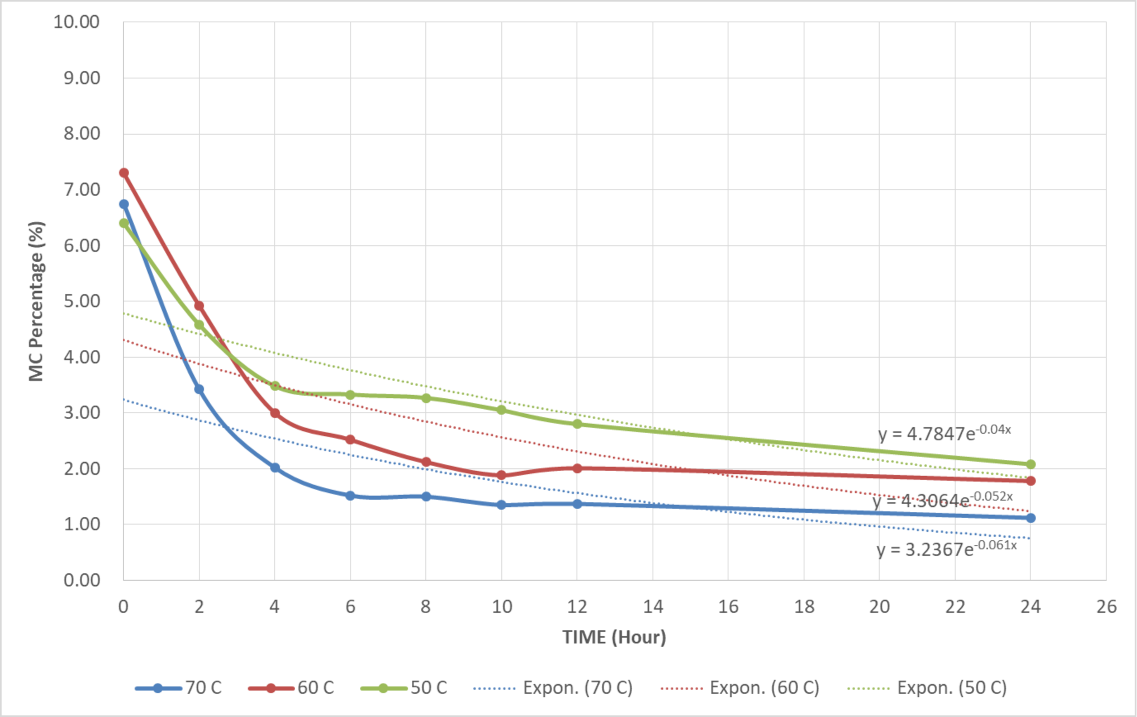

Figure 11. Drying of Wood Pellet Feedstock

2.4. Tar Biomass Gasification

The way in which tar are identified is one of the key issues with biomass gasification. Tar is a generic term which describes a complex range of organic oxygenated constituents produced by a biomass feedstock partial reaction. In the biomass gasification process, Tar is an unwanted by-product. The composition of the tar was split into two separately defined sections as well as heavy tar and light tar. Such materials are used as vaporized or persistent aerosols in the hot gas stream but typically condense at cooler temperatures. Such tars produce a large range in the pyrolysis stage of the gasification cycle of oxygenated aromas. In recent years, without a definitive resolution [21,22] the interpretation of the word 'tars' has been extensively debated. Some organizations working on biomass gasification have provided several definitions of biomass tars [23]:

- A combination of chemical compounds concentrated at room temperature on metal surfaces.
- The number of boiling point components above 150 °C.
- All synthetic contaminants weighing more than benzene with molecular weight

There does not exist, however, a general (uniform) description. Aside from the definition of "heavy tars," the definitions of "gravimetric tars" and "light tars" were given. In an analysis of bio gasifier tars, Milne et al. [24]. It has described it as organics derived from any organic material under the thermal or partial oxidation regimes, which are generally considered to be largely aromatic. In the gasification sense, the concept of tars is summarized for any aromatic and poly-aromatic hydrocarbon present in the manufacturer gas. Furthermore, since tar is often characterized in its activity by organic gassing products that condense boilers, pipes, and internal combustion engine (ICE) inlet devices under operating conditions, the variable production gas compositions required by a specific end-use application are the main reasons for diversity in the operating definitions of tars, and the way tars are collected and analyzed [24].

2.5. Tar Measurement Method

Tar measurement and characterization in biomass gasification producer gases is one of the most challenging tasks due to the complexity of the tar mixtures produced in the gasification process. The further use of the producer gas in downstream applications requires the analysis of the tar content, whose qualification and quantification is therefore of high importance in research and development. During the last years, several institutions and researchers have developed methods, which have been reported in the literature, for the sampling and analysis of tars. A short overview of these methods will be given in the following paragraphs of this section.

Conventional methods for tar sampling are mainly based on cold trapping using condensers and cooling traps combined with solvent absorption in impinger bottles. The tar protocol proposes the concept of a modular sampling train, which consists of four main modules and respective submodules. The main modules are: gas preconditioning, particle collection, tar collection and volume measurement, which are described in detail elsewhere [25-27]. The experimental setup of the sampling train based on tar protocol CEN/TS 143:2005 use pitot and probe is illustrated in the following **Figure 12.**

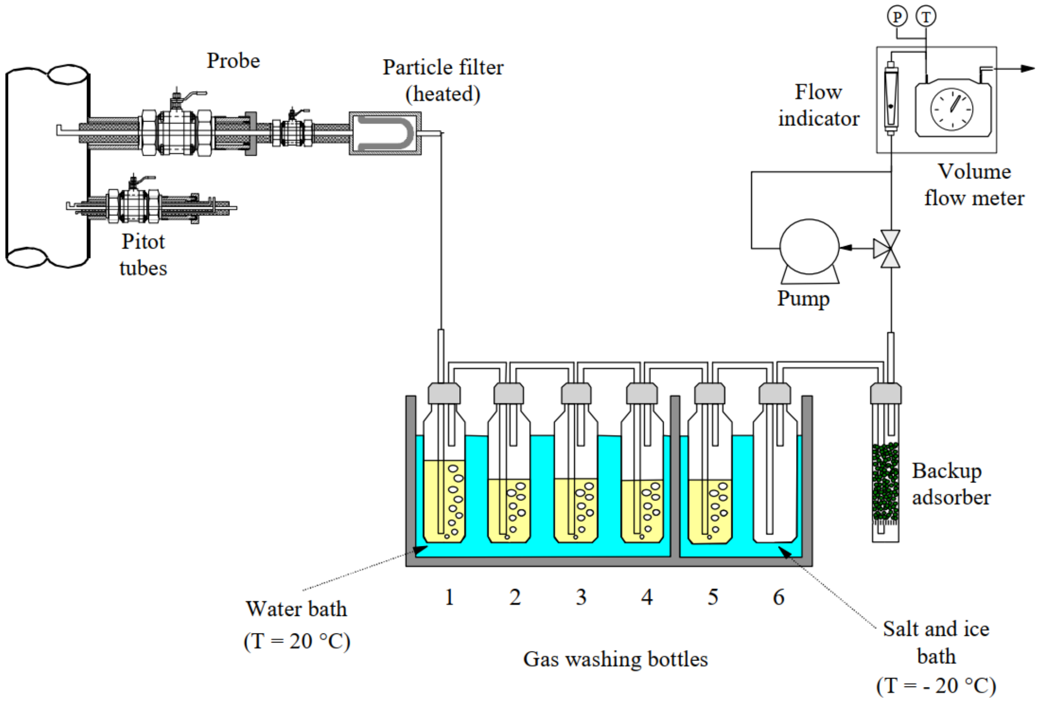

Figure 12. Modul of Sampling Train Based on Tar Protocol CEN/TS 143:2005 Use Pitot and Probe

The theory of measurement is based on the continuous sampling, under isokinetic or no isokinetic conditions, of a gas stream containing particles and organic compounds (Tars). Isokinetic sampling means that the speed at which the sample sample enters (nozzle) has to equate to the sampled gas' free stream rate. No isokinetic sampling is appropriate for the calculation of tar in compliance with the guideline [26,27]. It gives greater freedom to design the sample alignment with the gas flow and for building the sample dust form to prevent it from being stopped. The tar sampling system consists of a heated sample, heated particulate filter, condenser (a standard impinger bottle, or an internal liquid sampling device which uses Isopropanol as the fluid circulating), a series of impinger bottles containing tar absorber solvents and pressure and flow and measurement equipment. Within a temperature controlled bath, the impinger bottles are positioned so that the gas tested cooler. The gas is sampled for a specified amount of time during the process pressure (or pump) the flow rate will be maintained. Tar condensation is prevented from sampling lines including the filter. The first one serves as a moisture collector in which water and tar from the process gas are extracted by absorption into the most appropriate solvent, isopropanol. The gas passes through a series of four solvent impinger after the moisture collector and an empty final impinger bottles (collector). The device tests volume, temperature, pressure and gas flow, and eventually the gases are safely released to the atmosphere. The system is then washed with appropriate solvents (isopropanol) after the sampling process. The tar protocol specifies the total quantity of gravimetric tar but cannot include data on individual tar compounds. After re-evaporating the condensed tars, the concentration of the individual tar compounds can be measured with gas chromatography.

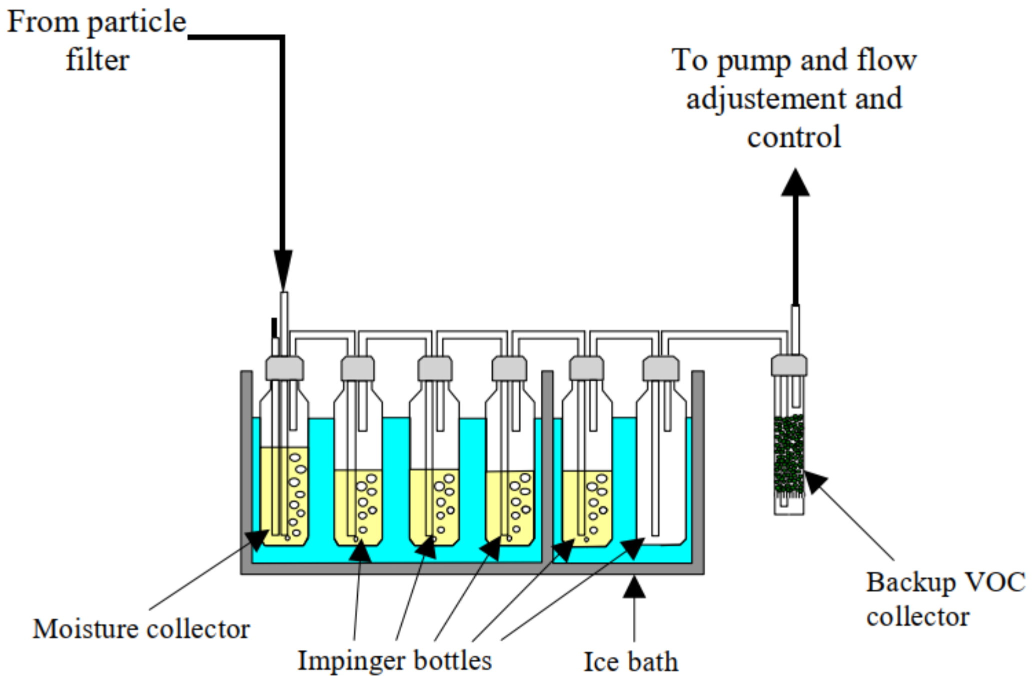

Figure 13. Modul of Sampling Train Based on Tar Protocol CEN/TS 143:2005 Use Liquid Tar Impingers Bottle

As a result of this, tar sampling with some modifying technique was carried out under the draft Tar Protocol CEN / TS 143:2005 [27,28]. The liquid quench method was carried out with circulating gas using the liquid tar impinger bottles in CEN / TS 143:2005. The liquid immediately injects into the gas sample, with a liquid stream rate of 10-500 ml / min being filtered out. This device can freeze from 250 °C to 50 °C and requires six flasks to collect tar. The bottles were split into two pieces, heated and cold. **Figure 13** displayed as a Sampling Train Board, using bottle of liquid tar impinger on Tar Protocol CEN / TS 143:2005. Evidently compared with the Hiroaki Ohara & Katsuaki Matsumura tar sampling equipment with patent No. JP 2009-40885 from the Japan Patent Office, the CEN / TS 143:2005 is more complicated [29]. The method is easier because only three impinger bottles are used to freeze the manufacturers' gas containing tar from gasifier by using glass beads to capture tar without the fluid by surface contact method and this method can contain the gas from 250 ºC to - 20 ºC.

The collection of tar was carried out using the equipment shown in **Figure 14** modification of tar sampling units. The product gas is heated to 250 °C in this equipment in order to remove impurities including ash, dust and soot until it is placed in the container. Three sample devices used to carry bottles with a length of 300 mm and a diameter of 24 mm are used for tar samples. All the bottles were packed to keep the tar in the gas of the producer with 30 ml glass beads (AS ONE BZ-2, µ1.5 to 2,5 mm). The glass beads are used to raise the contact surface of tar in the tar sampling impinging bottles. The tar sample inputs bottles then are mounted as an anti-freeze to -20 ° C into the Dewar vessel with ethylene glycol. For this analysis, the tar sample position between the gasifier and the soot remover was held at 8 L/min and 20 minutes during sampling time in a gasification system with producer gas flow.

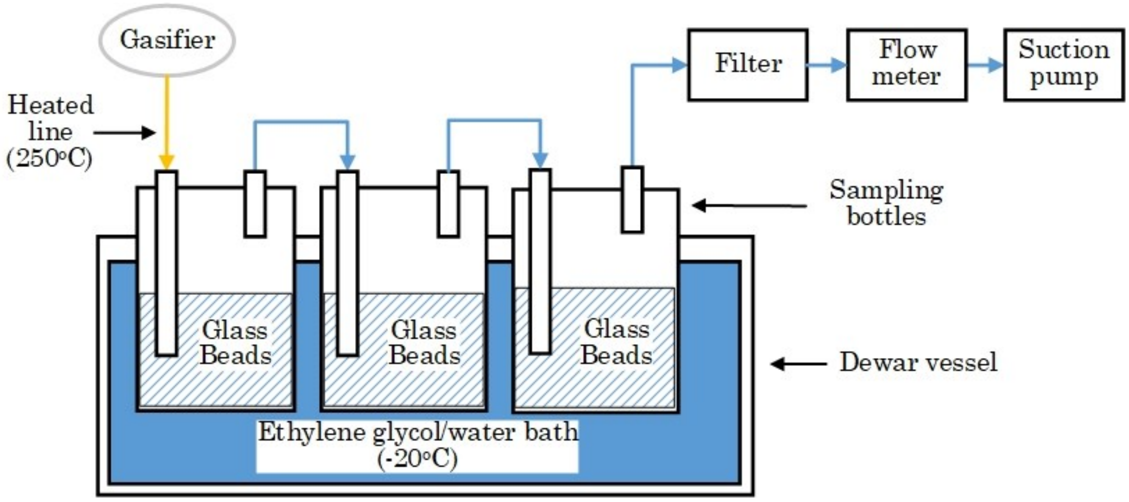

Figure 14. Tar Sampling Equipment Modification

Gas chromatography is one of the most widely used analytical methods for calculating gas mixture concentrations. The gas chromatographer can analyze each component in a mixture by using a narrow flow tube (column) with a specific (stationary) pillar filling process through which different gasses can be analyzed by using a carrier gas in a gas stream (mobile phase). The purpose of the column's stationary phase is to isolate the components, so that each component is separated at various times from its column (retention time). The GC (Gas Chromatography) offers both qualitative and quantitative analysis for even very complex mixtures through the assessment of the different rates of each compound. For testing and calculation of aromatic and polycyclic aromatic hydrocarbon blends, such as tars, gas chromatography was commonly used. The combination of a GC or FID (Flame Ionization Detector) with a Mass Spectrometer can be used to indicate the concentration of each tar compound in a tar mixture. The MS (Mass Spectrometer) can be connected to the FID [30].

A gas chromatograph may also be connected with a mass spectrometer serving as a detector. MS will isolate co-eluent compounds from GC, ensuring that each individual compound can be identified and quantified in a complex sample. MS can determine the identity of a wide range of unknown compounds by means of retention time and mass spectrum. GC-MS was employed by several scientists and has demonstrated its suitability to test both primary and secondary and tertiary tar compounds [31,32]. GC-MS techniques appear to be more expensive than other GC technologies, however, due to the difficulty of their process and the analysis of their data.

2.6. Analysis of Tar Sample

Biomass tar is a complex material made up of hundreds of compounds that vary widely from polarity to molecular weight. Carbon monoxide, carbon dioxide, hydrogen, and methane are the major thermal production materials for biomass. Nevertheless, small amounts of organic 'contaminants' form an undesirable by-product and it is widely considered that these toxic by-products can have a negative effect both on downstream plant treatment and power generation packages and on the local environment when released into the atmosphere. For the successful process development and economic operation of commercial gasifiers, a reliable sampling and analysis of these products from biomass gasification is essential. The free radical content of the gasifier during the tar formation cycle makes the tar mixture unstable and reactive. When the tar is isolated and polymerization and oxidation reactions will cool down, a high molecular content with complicated structures occurs. Upon collection, the tar analysis should be carried out within a period of one month, reducing the reactions from polymerization / oxidation. The condensed product is positively identified by using GC-MS as biomass tar for the identification of compounds in the tar. The presence of tar is usually suggested by the presence of PAH, phenols and BTX compounds (benzene, toluene and xylene) in the US-EPA suite. The GC-MS or GC-FID analysis can then be carried out using internal standards to quantitatively determine each compound. In order to enhance the gasification process, the process operator can need to measure those compounds in the tar and use them as markers. Due to the presence of high molecular weight material, not all tar components are subject to GC analysis. In most cases the GC analysis determines that the remaining is a high molecular weight of > 350 g / mol, which is over 80 percent of the tar. This fraction can only be significantly lower for updraft gasifier tars. The PAH compounds in the range naphthalene to indene (1,2,3 cd), pyrene, phenols, methyl phenols and dimethylphenols are the main compounds that are of interest to operators, particularly for gas turbines. **Figure 15** revealed this. Phase of the study of tar samples.

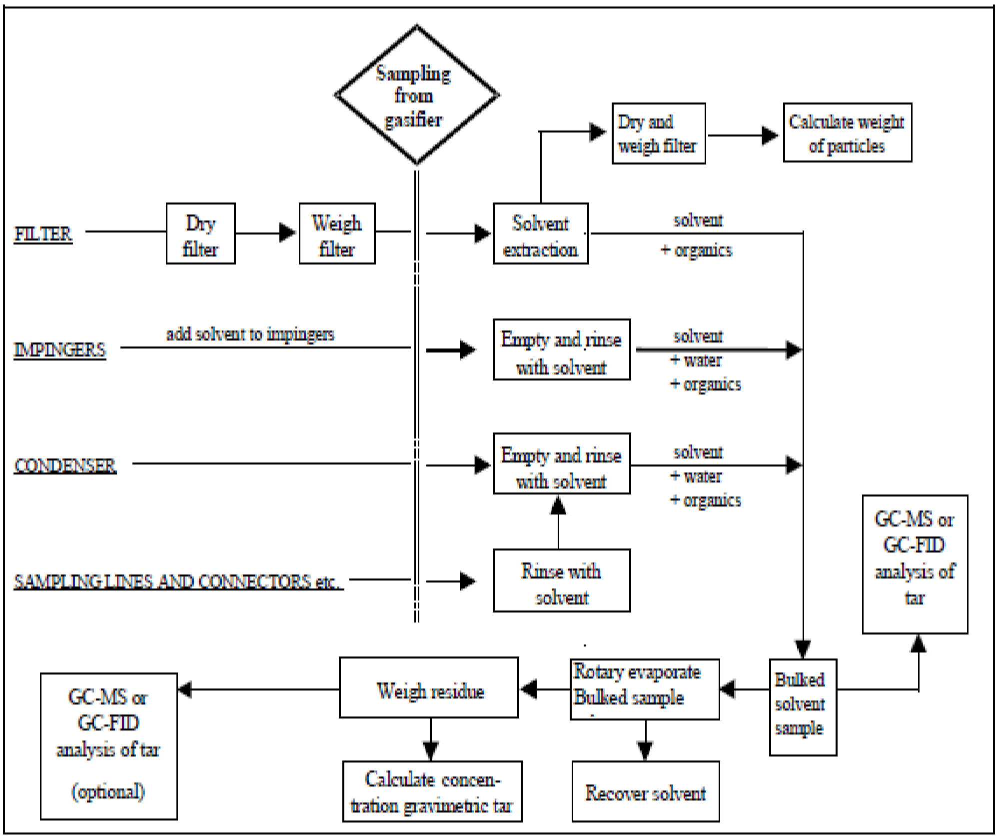

Figure 15. Step of Tar Sampling Analysis

In accordance with CEN / TS 143:2005, the tar sampling was conducted. This guideline allows the collection of tar in a series of bottles filled with 99 % purity isopropanol. Both containers with a fixed temperature of 20 °C and a temperature of 40 °C have to be separated from the two. The pyrolysis gas flows from a variety of cold hot impinger bottles and isopropanol is trapped within the volatile tars. Vakalis et al. are detailed in the sampling protocol [33-35]. The contents of the bottles (six in total) are merged and the total number of tars for analysis is represented. The use of a range of impinger minimizes the chance of tar losses that may in some cases leave the sample train along with gas, which is known as tar phenomenon.

2.7. Tar Classification

In different ways, tar can be classified. In the two groups of tars, 'easy to destroy' Perez et al. and Corella et al.[36,37] have mentioned that they are more reactive and harder to destroy tars of least reactivity. For example, tar can be divided according to its presence in primary, secondary and tertiary forms. Tar can also be classified in one of five groups, based on its molecular weight. Tar is known as all organic pollutants with a weight greater than benzene, in this current analysis. This tar classification system has been developed in cooperation with Energy research Center of The Netherlands (ECN), Toegepast Natuurwetenschappelijk Onderzoek (TNO) and University of Twente (UT) within the framework of the project "Primary measures to inhibit / cut tars in fluidized bed type of gasifier fueled by biomass", funded by the Dutch Agency for Research in Sustainable Energy (SDE). This classification is mainly based on the solubility and condensation of different tar compounds rather than reactivities based on molecular weight. Class 1 (GC undetectable), Class II (Heterocyclic Aromas) and Class III (Light hydrocarbon aromas), Class III (Light polyaromatic hydrocarbon), Class IV (Light polyaromatic hydrocarbon), and Class IV (Heavy polyaromatic hydrocarbon).

Table 3 displays 3 indicates the tar classification by its appearance. **Table 4** shows the tar classification by molecular weight. **Table 4** also shows these tar can be condensed and not condensed. Condensable tars can result in grave damage to various procedures like cleaning processes, power generators, etc., such as cracking in filter pores, the formation and plugging of coke or condensation in cold spots. Condensable tariffs are classified as pollutants from the producer gas [17].

Table 3. Classification of Tar Based on Its Appearance [38-40]

Tar Class	Property
Primary	Low molecular weight oxygenated hydrocarbons such as levoglucosan furfural and hydroxyacetaldehyde, produced at 400–700 ◦C
Secondary	Phenolic and olefin compounds such phenol, cresol, and xylene, produced at around 700–850 ◦C
Tertiary	Aromatic compounds such as benzene, naphthalene, pyrene, and toluene, produced at around 850–1000 ◦C

Table 4. Classification of Tar Based on Molecular Weight [38-40]

Tar Class	Property
Class 1	GC undetectable heaviest tars which condense at high temperature and very low concentration
Class 2	Heterocyclic aromatic compounds which are high water solubility such as pyridine, phenol, cresols, quinoline, isoquinoline, and dibenzophenol
Class 3	Light hydrocarbon aromatic compounds (1 ring) which do not cause a problem regarding condensability and solubility such as toluene, ethylbenzene, xylenes, stylene
Class 4	Light polyaromatic hydro carbon compounds (2–3 rings) which condense at low temperature even at very low concentration such as indene, naphthalene, methylnaphthalene, biphenyl, acenaphtalene, fluorine, phenanthrene, anthracene
Class 5	Heavy polyaromatic hydrocarbon compounds (4–7 rings) which condense at high temperature at low concentration such as fluoranthene, pyrene, chrysene, perylene, coronene

The study produced a new tar test based on molecular weight of phenol. If the compounds weigh less than phenol molecularly, they are light tar. Otherwise they are composed of heavy tar if the chemical compounds have a weight greater than that of phenol. The purpose of this study was to divide the distinction between light tar and heavy tar. Light tar consists mainly of volatile, semi-volatile, aromatic and phenolic compounds, while non-volatile polar compounds comprise heavy tar. The light tar was much better than heavy tar. More about heavy tar output leads to a large failure and valve connection that reduce the efficiency of the biomass operating system.

2.8. Internal Combustion Engine (ICE)

The electricity supply is not available in a small area or village. To overcome this case, a small power plant operating with biomass with local wisdom can be implemented. The Java Island, for instance, as Indonesia's greatest rice production, can utilize rice husk as power source. The case with Sumatera Island and Kalimantan Island as the world's largest palm oil output, on the contrary, can be used as the feedstock for power generation for all palm oil parts of the palm tree, whereas Japanese countries with many trees, wood pellets and wood chips can be used to gasify biomass [41,42]. Connected to a small biomass power plant, a reciprocal internal combustion engine (R-ICE) could produce electric power (less than 2 MW) and efficiency of up to 30% [43,44]. The reaction area, known as the gasification reactor, was poor in power and heat loss. This experiment consists of adjusting motor velocity and engine stop fluctuations in the R-ICE. In this analysis, the effects of variations on small R-ICE operations were indicated by a small downdraft gasification reactor. The major drivers of transport in today's society are internal combustion engines (ICE), which will potentially continue over the coming decades. In the 1800s, when Nicholas Otto, Rudolph Diesel and Jean Lenoir first conceived and demonstrated the idea for internal combustion heat engines.

While engines have improved considerably since then, including changes in performance and emissions, ICE's core operating principles have not changed significantly. The development and production of alternative fuel and combustion engine technology contributes to a long transition, but costs and integration and infrastructure requirements. Although the current emphasis is on improving engine performance, the sheer amount of transport energy consumption and oil dependence would require major changes to ICE without alternative fuels [45].

Basically, an internal combustion motor transforms the chemical energy that can be found in the fuel (conventionally based on petroleum) through combustion into thermal energy and converts thermal energy into mechanical work by expanding the working fluid by means of the crank-slider system converting lineal strength / work to a rotational torque / work to the outgoing shaft. The process takes place with operating fluids – air and fuel to combustion products – replaced in a closed chamber during a repetitive cycle. Different motor technologies with different applications are in use. Compression ignition (CI) engines, which typically use fuel-powered diesel and ignition (SI) engines which generally use gasoline, are two major engine technologies. Around 80 % of the total light-duty vehicles used by SI gasoline engines in the United States in 2008 (EIA 2010), and around 50 % of the light-duty vehicles used by SI gasoline engines in 2008 in Europe [46]. CI diesel engines are used for the majority of medium- and heavy-duty cars.

Two conventional cycles are run by internal combustion motors, a two-run and a 4-run operating cycle. The cycles differ based on the number and expansion or power of the crankshaft revolutions for each combustion event. Therefore, according to the engine size and other parameter, the number of cycles directly impacts the engine power output. The piston moves up or down the motor cylinder equivalent to 180 ° of crank-angle rotation during each operating pulse of the engine. In a two-stroke cycle, there is one rotation of the crankshaft for a power stroke ($360° = 2p$) and in the four-stroke cycle there are two rotations of the crankshaft ($720° = 4p$) for one power stroke. Therefore, this two-stroke cycle provides almost twice the energy density in this operating technique for a certain engine capacity.

2.9. Two Strokes Cycle of Internal Combustion Engine

The two stroke operating cycle includes a compression and power or expansion stroke, two strokes over one crank shaft revolution. The use of ports in the cylinder is a growing mechanism of two-way gas exchange in motors. The piston moves opens ports, as stated during the four-time process, to the regulation of exhaust and inlet flows, instead of using different intake and exhaust strokes. The inlet and exhaust ports are closed during the compression stroke, the cylinder charge is compressed and fresh air drawn into the crankcase. The piston moved to TDC, the mixture is compressed, and combustion begins and there is a power stroke, where the exothermic combustion of the fuel acts to force the piston downward. The pressure rise as the effect of the piston move to nears TDC, the exhaust port is exposed and a fatigue blow-down occurs, this condition occur because of the pressure differences between the combustion cycle and the atmosphere, the exhaust gas exits the cylinder. The piston continues to move down, the port of access is uncovered, allowing the new load to flow into the cylinder, which is compressed in the crankcase. Given that both the exhaust and inlet ports are being overlapped, the cylinder is designed to minimize fresh charge gas outlet flow through the exhaust port. The two times cycle operations of motor, outboard motors, chain saws and other devices that require high power density is used for certain motor, motors with low weight but high engine speed (RPM).

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a power stroke, where the exothermic combustion of the fuel acts to force the piston downward. The pressure rise as the effect of the piston move to nears TDC, the exhaust port is exposed and a fatigue blow-down occurs, this condition occur because of the pressure differences between the combustion cycle and the atmosphere, the exhaust gas exits the cylinder. The piston continues to move down, the port of access is uncovered, allowing the new load to flow into the cylinder, which is compressed in the crankcase. Given that both the exhaust and inlet ports are being overlapped, the cylinder is designed to minimize fresh charge gas outlet flow through the exhaust port. The two times cycle operations of motor, outboard motors, chain saws and other devices that require high power density is used for certain motor, motors with low weight but high engine speed (RPM).

2.10. Four Strokes Cycle of Internal Combustion Engine

Intake, compression, expanding / power and exhaust provide the four-time process period of ICE. **Figure 16** for the four-time cycle. Quadruple cycle (intake-compression-expansion / power-exhaust) motor cycle. With one power stroke, there are two crankshaft revolutions. The stroke includes moving the piston from TDC to BDC in order to induce the charge gas into the cylinder. When the engine is a CI engine, only air and potentially rubbish are induced, but a fuel-air mixture is induced into the cylinder for a SI engine fueled input port. The next stroke is the *compression* stroke with the piston moving from BDC to TDC, to compress the charge-gas (fuel and air mixture for SI engine, air and residuals for CI engine) to increase the temperature of the cylinder contents. Combustion occurs near TDC, with the next stroke being the *expansion* stroke or *power* stroke. In the power stroke, the piston moves from TDC to BDC, with the force of the high pressure products from combustion of the fuel–air mixture pushing the piston down. Of the four total strokes, this is the one stroke where work is extracted from the operational cycle of the engine. The last stroke is a stroke where the exhaust valve sets in and the piston sets out to push the combustion products out of the cylinder and back down the cylinders (BDC to TDC). After the exhaust stroke is finished, the intake stroke begins and defines the start of the following cycle.

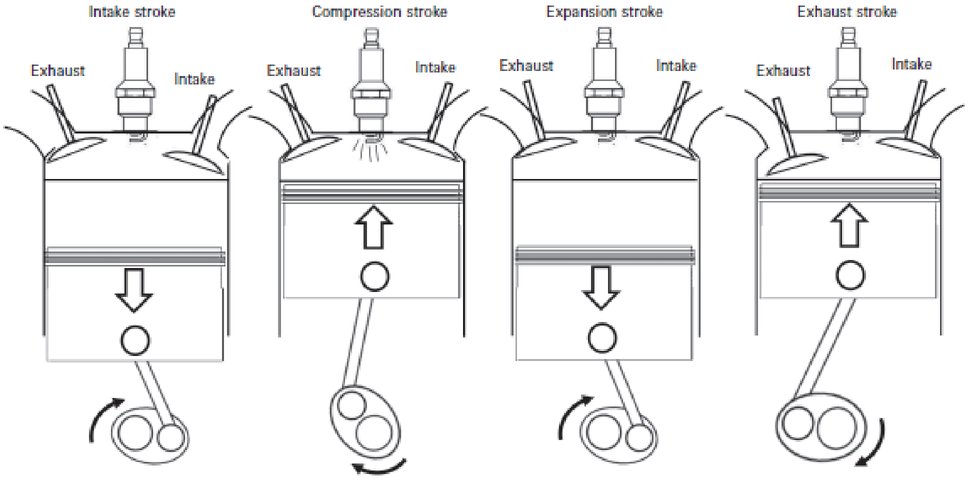


Figure 16. Four-Stroke Engine Cycle (*Intake* - *Compression* - *Expansion/Power* – *Exhaust)*

2.11. Alternative Engine Operating Cycle

In addition to the standard operating cycles of two-stroke and four-stroke motor, changes to them can be applied, as discussed. A variation of the traditional four-stroke motor cycle is the overextended cycle. In the standard cycle, the strokes for compression and expansion are symmetric, the expansion stroke is extended to increase the expansion ratio which increases the extraction of energy from combustion and, thus, improves engine performance. The expanded cycle is the general cycle that provides this expanded cycle. This cycle is based on cycle methods, including the Atkinson cycle and the Miller cycle. In addition, multiple cylinders are used to provide the motor with the operational cycle. The two paired cylinders are a common arrangement, the first for power and exhaust. The other for power and exhaust. The Scuderi division cycle and the Stirling division cycle are two different kinds of divided cycles.

Idealized thermodynamic heat addition, compression and expansion provide insight into factors that impact efficiencies and peak pressure. The above ideal cycles are based on However, it does not have practical efficiencies and we must investigate the two dominant engine technologies currently in use in order to address this further. Internal combustion engines (CI) or diesel engines are generally known as spark ignition engines (SI) or gasoline. These engines may use the same two- or four-hour-cycle (intake, compression, extension, exhaust) operating cycle techniques, but vary in how fuel is ignited and burned down. There are other variations in operating characteristics, type of fuel, emissions etc. The fuel and air are mixed with the spark- ignition engine, either on the intake manifest or now in a cylinder with direct injection techniques, before combustion with fuel is initiated. In any case, the combustible vaporizes and mixes to an ignitable mixture with the charge gases. A high-energy electrical (spark) discharge begins combustion and ignites before TDC of the compression stroke.

The fuel-air mixture forms a fire kernel which is converted into a spreading turbulent fire. The compression ratio is limited in order not to cause combustion to knock by the auto ignition of the air fuel mixture. Due to lower compression ratios, the maximum efficiency of SI engines is 35% [46]. For light-duty applications, the engine is normally operated at the stoichiometric air-to-fuel (exact fuel needed for all air combustion), allowing it to be able to meet strict emission requirements efficiently after treatment through a three-way catalyst. This means the engine is thrown at part load to control the air charge and thus the energy charging of the stoichiometric fuel to regulate the energy supply. This the volumetric efficiency (which determines how effectively the cylinders displaced are used).

The engine must pump the air from the input to the exhaust at lower intake pressure than atmospherically intake pressures (called pumping) that reduce output. By the process of valve timings and lifts to achieve excessive cycle activity with significant internal residuals, the pumping or throttling loss can be minimized or eliminated [47]. Recent developments in valve operation including variable cam phasing are physically achieving this process [48].

SI motors usually are fueled on diesel, the fuel dependent on the amount of octane. The number of octane determines the fuel's ability to minimize or knock auto-ignition, the greater the octane level, the higher the auto-ignition resistance. The number of octane in an engine is measured using two methods for the octane (RON), motor octane (MON), and an ASTM standard. SI engines can also use alternative fuels such as methanol, ethanol and their mixtures and natural gas and propane, in addition to petrol.

Only air or air plus residual gas fuel from the exhaust known as exhaust gas recirculation (EGR) will be inducted in a compression ignition engine and compressed during the intake stroke into the chamber. Oil is pumped into the cylinder directly by a high pressure fuel injector near the TDC of the compressive stroke. This fuel shall then mix with the already in the chamber compressed, heated, air and residuals to a limit of fuel and then auto-inflame a portion of the fuel – air mixture.

It is referred to as the time between the injection of the fuel and the first fuel ignition. After ignition part of the fuel is burned with the rest of the fuel combustion in the diffusion combustion mode in the premixed mode. The compression ratios of CI engines are higher as it is based on the auto ignition concept and is not limited to fuel-air-premixed fuel combustion in SI engines. CI motors achieve greater efficiencies than SI motors, peaking at around 45% [46]. The amount of fuel injected by the amount of charge of gas oxygen is regulated in the CI engine. In a locally rich story, but worldwide lean (excess air) CI diesel engines burn fuel to provide improvements in performance. Compression ignition motors usually run on diesel fuel. In order to reduce particulate pollution and enable the use of advanced lean after treatment equipment to reduce nitrogen oxides in line with emissions standards, diesel used in road uses from 2006 to 2010 has to be low in Sulphur.

Compressive ignition fuels are distinguished by their number with the lower auto ignition temperature and a shorter ignition delay providing the greater number of the other number. Alternative CI engine fuel include bio methyl diesel, which is made from vegetable oils and animal fats, multifunctional produced green diesel, and their blends all with varying advantages and disadvantages.

2.12. Palm Oil as Potential Biomass Source

2.12.1. Palm Oil Biomass as Feedstock for Biomass Production

Actually, palm oil is the most affordable vegetable oil on the global market. In terms of oil production per cultivated area the palm oil is commonly considered to be the most production crop. In the world's palm oil industry, more than 190 million tons of solid and liquid waste are made. Of that, only approximately 10 percent are commercially used for bio-fertilizers, such as value added products. Palm oil biomass has unique characteristics that make it suitable for biofuel production. The different types of the palm oil biomass, their characteristics and possible applications in the biofuel industry are discussed here in depth.

Biomass is defined as a renewable organic material that may be available on a constant basis as solid or liquid with examples of residues, forest and mill, agricultural waste, etc. Palm oil biomass includes all organic matter, whether edible or non-edible, fluid or solid that is produced during planting by the palm oil industry, palm oil friction, refining, palm kernel oil friction, etc. One of the largest producers of biomass is found in the palm oil industry, primarily in wastes. In 2011, Indonesia and Malaysia (being the largest producers of palm oil in the world) together generated nearly 182 million dry tons of palm oil solid biomass which is projected to increase to about 230 million tons by 2020.

Once, the palm oil produces about three times, seven times, ten times as much oil as cocoa and soybean [49]. The palm oil tree can yield between 4000 and 5000 kg of crude palm oil (CPO), and between 400 and 500 kg of Palm Kernel Oil per hectare of grown soil. As world population continues to grow and there is a rise in the demand for oils and fats for both food and energy, and as fossil fuels continue to grow. Palm oil may help to offset most of the challenges faced in this regard, as it may be important to produce minimum areas of soil for high quantities of fats and oils, the best candidate of which is palms oil tree. Consequently, palm oil biomass is seen as a major source of wealth for the bio-mass-use industries whose aim is to generate electricity.

A big problem for biofuel industry is the persistent scarcity of feedstock for biofuel manufacture. More than 95% of all the global biofuels used are currently being commercially manufactured from edible crops, such as sunflower, rapeseed oil, maize and other food crops. Nonetheless, palm oil tree is the world's most productive plant which produces enormous amounts of biomass in terms of food and waste that can be converted into biofuels other than those which cause catastrophes in the environment. The palm oil is planted over a total area of about 12.9 million in more than 45 countries worldwide.

Palm fruit oils (i.e. mesocarp oils and kernel oils) constitute the largest proportion of current consumption of edible oil in the world and its huge demand, especially mesocarp oil. This led to an international expansion of the palm oil industry, enabling the production of large quantities of palmitic oil waste. After harvesting and milling processes OPW are produced mainly from the plantation. Around 10% of the palm tree is made of mesocarp oil (palm oil) and palm kernel oil. The remainder of 90% contains the stems, leaves, trunk and roots, mostly waste. Oil palm produced annually nearly 70 tons of OPW on a hectare of cultivated land, representing around 184 million tons of OPW worldwide each year with an increase annually of around 5%.

In order to make the product more sustainable, several different forms of bioproducts, including biofuels can be produced both from palm oil and wastes. The biomass oil palm has good characteristics that make it highly suitable for the production of biofuels. All three types of biofuels can be generated from palm oil biomass, i.e. solid, liquid and gaseous biofuels. This chapter describes the forms, characteristics and the profile of palm oil biomass currently in use around the world.

2.12.2. The Palm Oil: History, Botany and Varieties

The palm oil is a widely cultivated oil bearing tropical palm tree which originated from West Africa (specifically the rain forest of Guinea) and initially illustrated by Nicholas Jacquin in 1763. In the late 1400s, the European visitors who were dwelling around the coast of Guinea discovered the palm oil trees. By 1508, palm groves had been recognized in nearby countries such as Liberia and Nigeria. Later, during the slave trade, palms oil tree spread from about 16 ° North of Senegal to 15 ° South of Angola through the east parts of Zanzibar and Madagascar through most of Africa [50]. While the environment is not suitable for palm cultivation in most parts of East and South Africa, few prosper at altitudes below 1000 meters near lakes or water bodies with significant rainfall. It was due to a local microclimate on the eastern shore of Madagascar but the crop could be affected in this area by the tornadoes. The royal palm belts in Cameroon, Ghana, Nigeria, Ivory Coast, Angola, Togo, Liberia, Sierra Leone and Republic of the Congo were initially found in Africa. This spread later between the 14th and 17th centuries to other areas of Africa, including Asia and South America [50]. In the botanical gardens of Bogor, Java was initially developed as ornamental plants for the first African palm oil brought by the Netherlands to Asia. However, intensive palm oil research and development (specifically, Deli Research Centre in Sumatera), in Singapore, Malaysia and Indonesia, created significant advantages since the start of the 1900s. The demand for palm oil as a lubricant for steam engines, machinery and as a major raw material for soap production grew globally at the end of the 19th century. The palm oil gained international recognition. The oil yields and quality of the palm oil grown in Asia are even higher than in other parts of the world.

The palm oil thrives very well with a topography of about 400 m above sea level and tropical climatic conditions at 70° north and south from equator in the high-precipitation areas of 1200 mm rain per year [49]. To date, palm oil industries have expanded with Indonesia and Malaysia as the world's largest palm oil producers in Africa, Asia and America. In 2010, Malaysia cultivated approximately 4.6 million hectares of palm oil that produced approximately 17.6 million tons of palm oil and approximately 0.7 million tons of Palm kernel oil.

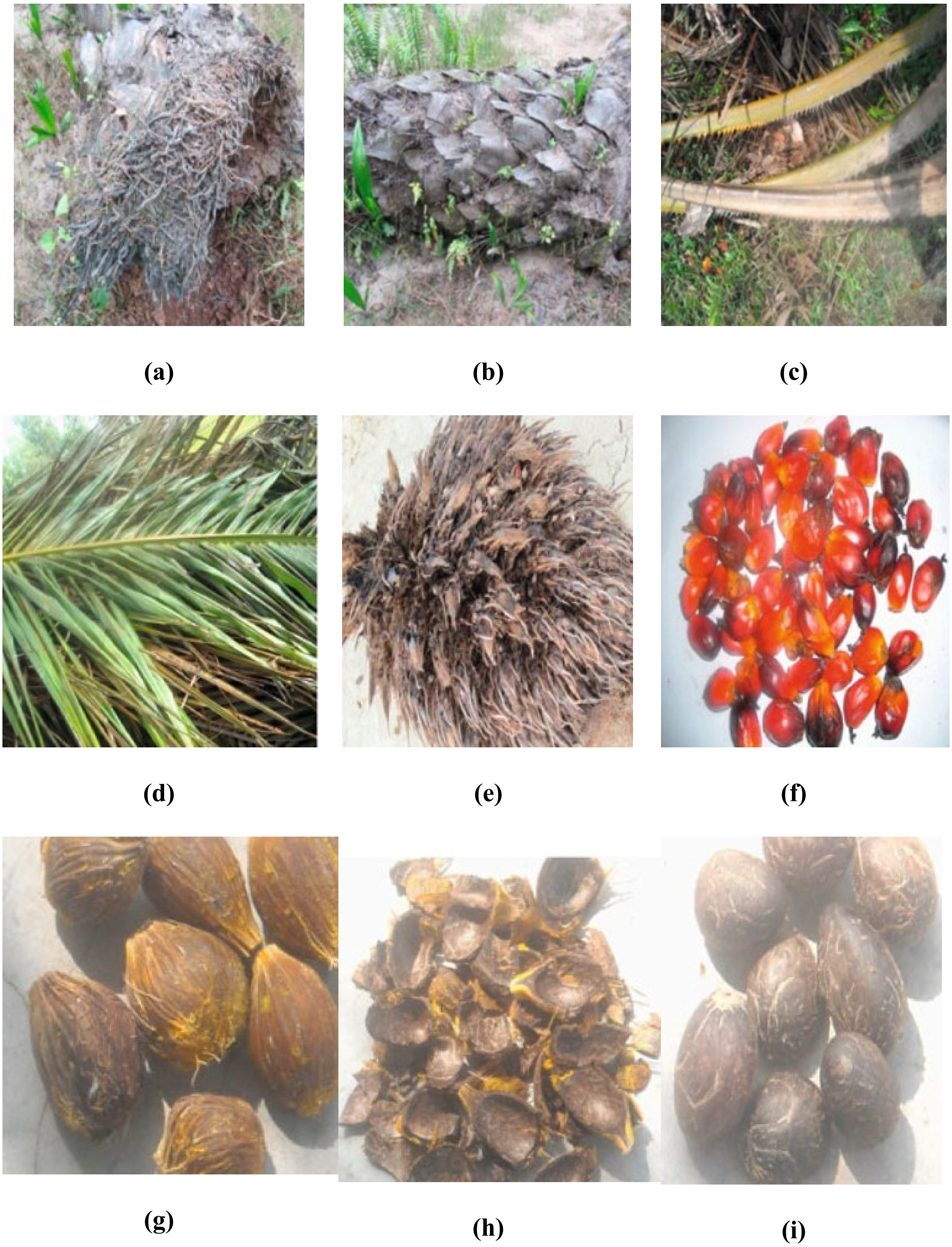
The palm oil cultivars are classified based primarily on the composition of the fruit and their return on market value. The palm oil is a perennial, annual, pollinated insect with seed plants (or tree), often from the weevil plant of Elaeidobius Kamerunicus. The anise-scented male flowers of the oil palm, most of which are pollinated. Modern preparation assists pollination to improve oil production. The natural distribution of the palm oil seeds does not germinate readily because the seasonal conditions are ideal for well-growing. In Western Africa they mostly remain sleeping in dry season and begin germinating for 80 days from the beginning of first rain from 6 to 10 weeks at temperatures between 30-40 °C [49].

The seedlings are moved to nurseries or large polythene bags after 4-5 months, when they cultivate for 6-12 months before transplant in the main fields. The plants are transplanted for around 4-5 months. Depending on type of soil and climatic conditions, the density and distance used for the plantation is 128–148 palm seedlings/ha and the distance between palm oil tree is 9 m in the 9 area [49]. The normal frequency of harvesting is between 10 and 15 days. On average, the palm oil tree produces 12 Fresh Fruit Bunch (FFB) per year, with a bunch weighing around 15-25 kg, and containing 1000-1300 fruitlets, according to planting and planting processes. An average 35 tons of fresh fruit bunches (FFB) (from 148 palm trees) and 8.6 tons of palm oil per hectare can be produced in the oil palm plantation [49].

The palm oil of the kingdom is Plantae, Tracheobionta subkingdom, Spermatophyte control, Liliopsida tribe, the Arecidae group, Palmae family and the Elaeis genus. Guineensis and oleifera (or melanococca) are the main species of the palm oil. There are also several other species, including dura, deli, kamerunicus, macrocaria, pisifera, and tenera, which have evolved from these two principal species.

The most common palm oil variation with a generic average life of 150 years was Elaeis guineensis Jacq, a substantially high oil-to-bunch content (45-55% oil) over the other varieties Compared [49]. Dura and guineensis are the main species found in Central and Western Africa. The dura has a thick, 2–8 mm thick endo-carp that is approximately 25–55% of the fruit weight. With a medium mesocarp thickness of approximately 40% to 55% of its fruit weight, the dura is less productive The delight has a medium mesocarp thickness of about 35–65 percent, while the pisifera has very large mesocarp shells and tiny pea-like kernels in the fruit. Due to its premature existence, pisifera has no commercial interest as the flowers rapture before maturity. But for commercial use, hybrid varieties with high oil yield are worth cross-breeding. Tenera, a hybrid of the Dura and Pisifera, has approximately one–32% of the fruit weight, with a thin endocarp of approximately 60–95% of the fruit weight, with a medium to high mesocarp thickness, and their grains weigh about 3–15% of the fruit of the Dura and Pisifera [51]. Tenera is the most commercially important plant in contrast with others. The tenera has a higher number of bunches compared to dura, lower mean weight of the bunch and lower ratio of fruit to bunch [51]. Tennera and pisifera, however, produce much oil per hectare in comparison with other varieties. Tenera and guineensis are the common species found in Malaysia, Indonesia and parts of Asia. The oleifers and kamerunicus are primarily found in South America and the guineensis Jacq is scarcely visible. Higher levels of unsaturated fatty acids have been reported in Oleifera and are mostly utilized for production of interspecific guineensis hybrids. The macrocaria is an extreme or wild form of the dura and has an endocarp of about 6–8 mm thick [51]. It is commonly cultivated in Sierra Leone and Nigeria without any commercial value.

The palm oil industry focuses now on genetically modified methods for raising oil yield, tree height and disease resistance (such as nursery palm for the prolongation of the economic cultivation cycle). The palm oil is allogamated (i.e. cross-pollinated) and is propagated by plants, spanning 150 years generic life and 20-25 years economic life [49]. The genome size of the oil palm is 1.959 10^9 base pair with a haploid chromosome number of 16 as reported in the cytogenetic analysis. The palm oil is mounted on a perennial tree with a corona of around 35–60 pinate fronds. This has a single spike at the base of the coronation with heads and inflorescences. After the young palm is well known, flowering begins. Each primordial flora formed in the axil is a possible producer of inflorescence, male and female. Palm oil tree has both men's and women's (i.e., the monoecious) flowers, which are clustered in short inflorescences and produce approximately 1000 to 3000 fleshy fruits, approximately 2 to 3 cm in length and oblong-ovoid, also containing bunches of between ten to 30 kg in weight [49]. At the start of the leaflet, a primordial inflorescence is formed in the axil of each leaflet. Per palm oil tree, the number of inflorescences depends on the amount of the leaves produced and the amount of inflorescences reaching maturity without abortion. On the same palm oil tree men and women form inflorescences separately. A man's inflorescence produces about ten to forty gram of contamination. A female inflorescence is made up of a central stalk or a peduncle with leaf spikeles and coloured female flowers. In the course of inflorescence growth in the fruit system, the cycle from hybridization to flowering lasts about 24 to 26 months, and from flora to fruit, the time for the growth is about 40–42 months, with a span of 10 months from hybridization growth to flora and from 5-6 months. In the axil of the leaf of the palm the palm oil bunch is tightly wedged. There are around 1000–4000 fruit in a bunch of ripened palm oil fruits based on tree age and growth pattern. An erect single-stammed palm tree is a matured palm oil, around 25 to 30 meters high, with pinnate leaves 3–5 meters long [49]. The palm oil leaves are cultivated in a spiral succession from the meristem. Every month a leaf is produced, until the tree age is six months old. A palm tree's leaf size approximately in 400 mm. The curve comprises approximately 40–50 leaves which are opened in different stages of growth. The palm tree begins to bear the fruits after 24-30 months after planting, which are at first dark-green or almost black, but later become yellowish-red in shade with larger prunes in large bunches, when they are fully ripened. An palm oil bunch of fruit have weighs approximately in 15-50 kg at maturity. The palm oil fruitlet has four main element, they are: the exokarp, mesocarp, endocarp, and kernels seed. The exocarp is a yellow-red, outer coat of the fruitlet. The fibers are filled by palm oil in the mesocarp. The endocarp is essentially the outer layer of the kernel seed and if broken, the kernel containing the germ will be revealed. Kernel palm oil is extracted when broken and pressed from kernel seeds. The oil in pulp and the kernel amounts to approximately 50–60% and 45–55% [49]. **Figure 17** shows the picture of the various parts of the palm fruitlet and **Figure 18** display of palm oil fruitlets.



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 17. Varian Type of Palm Oil Used as Feedstock in The Biomass: **(a)** Palm Oil Roots **(b)** Palm Oil Trunks **(c)** Palm Oil Fronds **(d)** Palm Oil Leaves **(e)** Palm Oil Empty Fruit Bunch **(f)** Palm Oil Fresh Fruits **(g)** Palm Kernel Seeds **(h)** Palm Kernel Shells **(i)** Palm Kernels

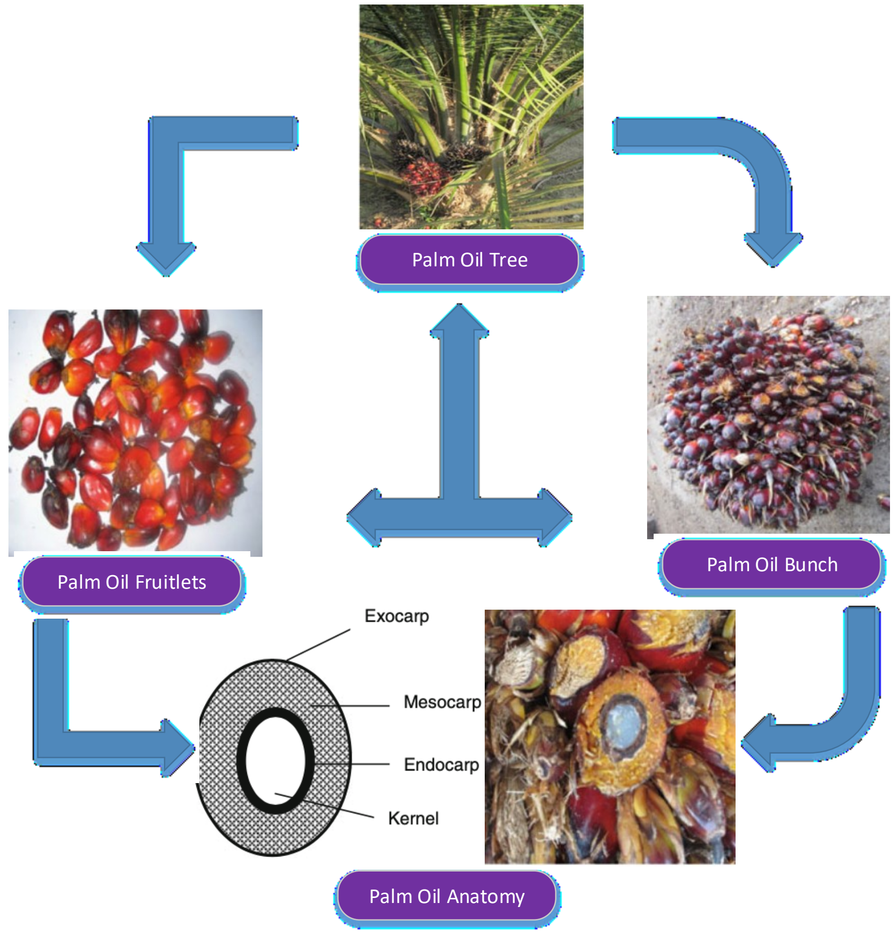


Figure 18. Palm Oil Fruitlet Diagram

The tree's roots grow from a hypocotyl’s cornerstone and then growth to its trunk's baseline bole. The primary roots are formed at the base of the trunk when the water surface is high. Within the top 15 cm from the land of the field, the majority of palm oil roots are found. Early seedling growth contributes to the development of a broad base of the stem. The apex of the oil palm tree reaches its maximum diameter after approximately 3 years, which creates an inverted cone that appears as the trunk. The trunk extension rate could range from 25 to 50 cm per annum depends largely on the environmental and hereditary factors~~.~~

2.12.3. Palm Oil Cultivation and Productivity

Palm oil cultivation involves various field work activities, such as seedling, crops planting, herbicides, pesticides and applications for fertilizers, processing, transportation to milling sites, and re-planting of soil preparations [49]. The planned field involving the Environmental Impact Assessment (EIA) and other steps for ensuring the sustainability of the palm oil planting are conducted prior to the land preparation of palm oil seedlings and their transplantation. In Indonesia, for example, before the nursery and subsequent planting procedures, the correct suitability of the proposed area must be approved by the respective acquisition bodies.

In essence, there are two kinds of nurseries of palm oil, i.e. single and double steps. The seedlings are raised in large polythene bags during a single-phase nursery until they are ready for transplantation on the main field. For a tree seedlings of palm oil which is used as double step, the seeds are planted with protective sun or shade in a small polythene bag (15 cm to 23 cm) up to 3-4 months of age and transferred back into a bigger polythene bag (30-38 cm to 38-45 cm) and then taken again to the planting area under direct solar light. They are transplanted in about 12–14 months to the appropriate plantation area, which is already in the process of properly creating roads and water drainage systems.

Palm oil seedlings are typically collected with the palm kernel seed, which could be preserved for more than a year, in polythene bags. Most of the fertilizer products are applied at this point to ensure adequate seedlings' growth with ample irrigation (e.g., 0.5 l and 1.5 – 2.5 l water per polythene bag per day, respectively, for small and large pool bags). Dithiocarbamate, which actually has negative environmental effects, is the main form of pesticide used in nurseries. One key attention during the clearing of oil palms (which may contribute to untenable farming) is the environmentally dangerous bush burning, which may lead to major biodiversity losses. In addition to soil nutrients and control soil erosion, oil palm is also interspersed with leguminous crops. This may not be enough, as it is important to use fertilizers in this planting stage.

If the trees ripen to some degree (not when they are harvested), maintenance practices such as cutting, control of pests and diseases as well as mulching are carried out (usually with pruned fronds and leaves). Depending on type of soil and climatic conditions, the density and distance used for the plantation is 128–148 palm seedlings / ha and 9 m distance per area palm oil tree [49]. The oil palm needs uniform distribution of precipitation between 1800 and 5000 mm / year. The typical harvest duration is 10 to 15 days.

The Fresh fruit Bunch (FFB) harvest depending on the soil's nutrient value and other factors, its will be sufficient after 24-60 months of transplantation. Drying of fruit gathered in performed by hand with levers such as wheelbarrow and faucet etc. The treatment of FFB after harvesting should be carried out in a manner that reduces the amount of freely fatty acid (FFA) in the oil. Furthermore, as the quality of the generated oil is dependent on the time period between harvest and sterilization, FFB must be transported immediately following harvest and the distance from a plantation to the milling site must be brief.

Actually, the palm oil-tree is cultivated over a total area of around 12.9 million hectares in more than 45 countries around the world. Palm oil tree is highly productive oil producers that require less land to produce oil than any other petroleum plant. Today, the palm oil tree is the world's largest producer of edible oil per unit area for all commercial vegetable oil crops. This means that the palm oil tree requires less land than all other oil crops to yield the same amount of oil. Nonetheless, the oil (palm oil and palm kernel oil), generated by only 10% of the palm oil tree, while the remaining 90%, generally, are regarded as waste consisting of empty fruit bunches, fronds, trunks, kernel shells, etc.

The palm oil tree produces an annual average of twelve bunches of fresh fruits which, depending on the planting practices used, weight of bunches between 15–25 kg/bunch of about 1000–1300 pigment/bunch. One hectare of palm oil tree could also yield nearly 148 palm oil trees [49] amounting to about 54 tonnes of fresh fruit bunches (FFB).

A FFB consists of approximately 25-26% mesocarp oil, 20-22% kernel noodles, 9-10% kernel shells, 28-30% palm empty fruit bunches (EFBs), 14-16% mesocarp fiber. The possible production of palm oil depends on the type of plant breeding used, according to several studies, of about 6.8-29 tonnes, of oil per hectare of cultivated land (with an estimated output of 17 ton oil / ha. **Figure 19** lists hectares of grown oil-field land corresponding to the amount of oil grown on the grown area.

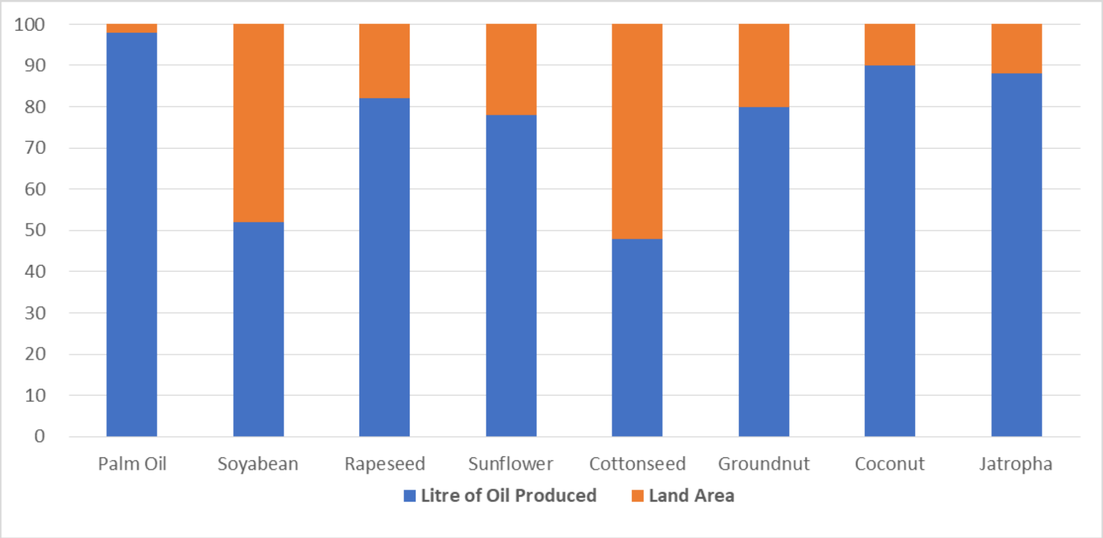


Figure 19. Palm Oil Efficiency Compared to Other Major Oil Crops

The selected location type, planting material type and volume for culture as well as agronomy and plantation management practices are other crucial factors that affect the productivity of the palm oil. Many researchers recorded that the management of fertilizer alone contributes to an increase in palm oil yield of around 29 percent. Such factors affect not only palm oil production, but also profitability and sustainability. In the palm oil plantation, most popular fertilizers are potassium mucus, sulphate, kieserite, rock Phosphate, etc., often transported to the field and hand-applied to the crops. The use of phosphorus-based or organophosphorus insecticides is also used for control of insects and weeds.

The palm oil industry is now focused to further improve its oil yield and tolerance of diseases and genetic approaches by plants for extending their economic cycle of cultivation. The field of testing for Ravigadevi et al. was high-productivity transgenic oleic acid palms. While the palm oil industry has not yet marketed genetically modified palms, they are likely to be launched in the next 15 – 40 years [52].

2.12.4. Production of Palm Oil Biofuels toward Sustainable Development

In comparison with other feedstock of first generation biofuel the palm oil provides a relatively beneficial source of feedstocks for the production of biofuels. The palm oil is one of the currently available and existing sources of feeding stocks for biofuel production in the world and it is the prime alternative that meets the sustainability requirements for high productivity, quality and competitive pricing discounts. Only when all supply chains from the production of palm oil to biofuels (even in production of raw materials and energy) fall within the appropriate production requirements for sustainable palm oil and biofuels growth are considered sustainable would organic fuel derived from palm oil biomass only be considered sustainable. Malaysia and Indonesia are currently enforcing strict sustainability standards through best practices, especially for the production of Palm Biocarburants, in order to fully meet the goals of sustainable palm oil biofuels production, in order to increase yield and reduce supply resources. This writing highlights some best practices in managing sustainable palm oil cultivation, palm oil milling, and processing projects globally embraced, as well as various development routes in manufacturing palm biofuel production.

While it was found that the manufacture and use of palm oil biofuels enhance economic growth and mitigates the effects of transport or industrial Green House Gas (GHG) pollution to some degree, they have a complex link with sustainable development. For example, the production of biomass of palm oil (mainly fresh palm fruit as a major source of palm feed) for biofuels can lead to loss of biodiversity, water, air, soil, and food health. In addition, oil palms are the most versatile of all the oil crops, as the tree can generate so many types of biomass that can be used on a variety of value-added biofuels. Nonetheless, if the entire supply chains are objectively assessed and ultimately scheduled for sustainable processing and consumption practices, then the positive effect of palm oil biofuels on sustainability will be achieved. Again, the processing of FFB for the production of biofuel provides enormous amounts of palm waste which are also high potential sources of second-generation palm biofuel. Integrating a palm biofuel network of first generation would lead to reducing waste emissions and rising the economic value of palm oil. Boost development of this biofuel of the second generation.

Palm oil biomass culture is an important development phase in the entire palm oil biomass production chain. The global focus on sustainable agriculture and biofuel production in the major producing countries has currently called for the palm oil sector to develop the potential sustainability norms for good manufacturing practices. While the palm oil has become the world’s most efficient fuel for a power plant that highly meets the requirements for sustainability, further research is still underway in order to meet the global norm for sustainable agriculture and energy production.

As already characterized palm-oil biomass is an economic source of biofuel, given that the palm-oil tree has a permanent and sustainable use in all types (both solid and liquid) over the entire life cycle. Large quantities of waste, including palm oil fronds (POF), leaves of palm oil (POL), palm oil trunks (POT), and POR (Palm oil) are produced with approximately 80% of waste which is not used on a commercial scale during planting and harvesting of FFB [53]. However, only about 40% of the palms' oil biomass generated in a palm oil mill is generated as waste for the production of biofuels in the plants such as empty fruit bunch (EFB), Palm Pressed mesocarp Fiber (PPF), Palm Oil Mill Effluent (POME), Palm Kernel Shells (PKS, PKC), Palm Cernel Distillate (PFAD), etc. Generally, about 80 percent of the biomass of palm oil is used in unregulated locations and does not sustainably cause environmental issues [53]. The abundance of palm oil waste available in the palm oil industry has nevertheless been a major step forward in reducing fossil fuel consumption and waste emissions both from the planting and from oil mills, which could ultimately reduce the cost of palm oil (CPO), crude Palm Kernel (CPKO) oil, and palm biofuels in general. During the course of the oil extraction processes, the solid residues like EFB, PPF, etc can also be used more sustainably for the production of biofuels.

Palm oil biomass for manufacture of all three main forms of bio fuel is currently utilized as feedstock. Biodiesel, bio alcohols and bio-oils, either from palm feedstocks of the first or second generation, are the widely produced and consumed forms of liquid palm biofuels. Bioethanol and bio methanol, albeit on base grounds, are currently the common types of bio alcohols produced from palm oil biomass worldwide. Biogas are also a major form of gassed biofuel (either biomethane or bio syngas) produced primarily through the anaerobic digestion of POME and/or EFBs and the gasification of EFBs, OPTs and OPFs. The solid components of the palm oil biomass have high potential for adding significantly to the global renewable energy mix as well as palm oil briquettes, pellets and other solid biofuels.

The manufacturing methods and the raw materials used in production must follow the sustainable development requirements in order for a supply chain to be sustainable. The "value" of an output resource must be greater than that of input resources that must be accepted as sustainable for a production process and product. The management practices of the production or farming of palm oil biomass and the subsequent production of palm bio-fuels will be essential prior to the production of bio-fuels because they largely affect the overall sustainability of the production process as well as the product.

However, the processing of palm oil biomass was criticized due to its negative environmental impacts. The contentious questions of palm oil bio-diesel sustainability once again focus on the potential for increased demand for extra-palm crops in the tropical rainforest, particularly within the two major palm-oil production countries, Malaysia and Indonesia, as a result of competition from palm oil for food and combustible. A number of meetings of different stakeholders, farmers, and NGOs, under the umbrella of the Roundtable or Sustainable Palm Oil (RSPO), were held to resolve this challenge related to the production of palm oil so as to enhance its growth towards sustainability for palm oil industry. In order to produce cost-effective, globally accepted, and environmentally friendly commodity (mainly palm oil), standards and requirements for sustainable production of palm oil aim at efficient production through best management practices. The environmental problems of palm oil production have included groups such as 'Restricting emissions from deforestation and forest destruction' (REDD+) and 'palm oil, timbers, carbon offset' (POTICO). Such organizations should create financial carbon values stored in the woods and provide incentives in the production of palm oil to minimize emissions of greenhouse gas (GHG) from palm oil.

Palm oil is the world oil from tree and have huge potential market with the most available and cheapest vegetable oils, meeting the environmental sustainability requirements fully, although there must be more environmental improvements. In this regard, palm oil as biodiesel, of course as candidate, at the top of the list if fossil fuel is to be replaced with biodiesel of the first generation. The enhancement of the processes at the production plant for palm oil biodiesel would contribute significantly to the overall sustainability of the palm oil sector.

2.12.4. Gasification of Palm Oil

In addition to palm oil used as biodiesel can also be used in the biomass gasification process. Even at temperatures of 700–1000ºC, the gasification temperature is normally considered, without a catalyst at 650–1200ºC. In the example case, a thin, 3 mm diameter empty fruit (EFB) bunch has up to two mm in length. **Table 5** shows the elemental feedstock.

Table 5. Elemental Pellet Feedstock of Biomass between Empty Fruit Bunches EFB and Cedar Wood

Elemental measurement (wt. %, dry basis)	C	N	H	O	Ash
Empty Fruit Bunch (EFB)	46.3	0.5	5.9	44.6	2.7
Cedar Wood	48.6	-	6.1	45.1	0.36

The EFB decomposes gradually with an increase of 340 ºC to a temperature of 800 ºC in the thermogravimetric test. In this experiment, the impact of processing gas, the total gas of EFB palm oil, is 67 to 75%, in particular in H_2 and CO, which is higher than the pellets of Japanese wood cedar.

Samson Mekbib et al. [54] stated that in the next stage pure palm oil was only obtained by 10% of the weight of the output of the palm oil trees. The final component is palm oil and kernel oil. What's 90% is waste and must be dumped. The other part of palm oil is like the empty fruit bunches (EFB), palm oil mill effluent (POME), oil palm fronds (OPF), kernel shells and trunks. The other part is also called palm oil. In this case, OPF, comprising 23% hemicellulose, 2,4% ash, 20,5% lignin and 49,8% cellulose, was applied as a feedstock to the gasification process. The next and final review is given for this OPF. The characteristic of proximate and ultimate analysis of oil palm frond (OPF) analysis is shown in **Table 6**. **Table 6** show the OPF feedstock measurement in 20 mm squarely, and 10 mm thickness. Customized cutting or chipping method for the gasification phase in the downdraft gasifier in the proximate and ultimate analysis.

Table 6. Proximate and Ultimate Analysis of Oil Palm Fronds (OPF)

Proximate analysis (wt. %, dry weight basis)	
Fixed carbon (FC)	11.5
Volatile matter (VM)	85.1
Ash	3.4
Ultimate analysis (wt. %, dry weight basis)	
C	42.4
N	3.6
H	5.8
O	48.2
LHV (MJ/kg)	15.72

2.12.5. Tar Production in Palm Oil Feedstock

The main benefit of the gasification process in biomass process if it is produce the lowest output of tar content. In three separate areas (cooler, drain and pipe) tar was recovering. Based on simple calculation, tar includes carbon and hydrogen (which is 94.3% of carbon and 6.3% of hydrogen). This was the case in the three-zone and the same finding is the gas chromatography and mass spectrometry. To classify tar compounds with 90 percent identical in total ionic carbon (TIC), six polycyclic aromatic compounds were used. Naphthalene, phenanthrene, acenaphthylene, fluoranthene, anthracene, pyrene are in the samples. An Empty Fruit Bunch (EFB) use as fuel during the gasification process, which results in the highest content of the naphthalene compound in tar compounds. In comparison, the level of tar in fluoranthene and pyrene is the lowest [54,55].

2.12.6. In Producer Gas Production

In terms of output and experimental results, Samson Mekbib et al. compares prediction for CO_2 , CO, N_2 and H_2 with an equal ration between 0.35 and 0.59 for producer gas production and equilibrium condition data [54]. This condition was based on the theoretical criteria on the gasification process of the Oil Palm Fronds (OPF) with minimum air-fuel ratio condition. This producer gas has a mean error value as a consequence of the experimental results. Depending on the amount of the square variance the estimate is determined. The findings have been shown as follows in **Table 7**.

Table 7. Comparison between Prediction and Experimental Producer Gas Production in The Different of Equivalent Ratio in The Oil Palm Fronds (OPF) **[56]**

Equivalent Ratio	N_2 % vol		H_2 % vol		CO % vol		CO_2 % vol	
	P	E	P	E	P	E	P	E
0.35	50.6	58.0	13.0	10.7	20.2	17.9	15.8	12.3
0.37	52.5	56.7	12.0	11.9	18.8	20.7	16.4	11.4
0.39	54.0	58.9	11.2	9.8	17.8	15.8	16.8	14.0
0.41	55.4	59.6	10.4	9.2	16.7	16.2	17.2	13.9
0.51	62.8	60.1	6.3	9.0	11.41	13.7	19.2	15.5
0.59	68.1	68.0	3.4	6.9	7.7	10.0	20.7	14.5

P = Prediction, E = Experimental

The test indicates a stronger result for the lower equivalent, in particular the equivalent ration 0.37. Furthermore, this figure has the most flammable gas (H_2 and CO) composition compared to the other, while the lowest quantity is the unflammable gas like N_2 and CO_2.

2.12.7. Consumption Rate between Palm Oil Pellet and Wood Pellet

The consumption of various feedstock and sizes is recorded by Catharina Erlich et al. [57]. The examples are the diameter 6 mm of wood pellet feedstock, 6 mm bagasse and 6 mm empty fruit bunch (EFB), with a diameter 6 and 8 mm of palm oil tree. **Table 8**. Shows many feedstocks with the different performance results.

Table 8. Several Performance Data of Various Feedstock in The Gasifier [57]

Several Pellet Feedstock diameter	Dry Gas production (m^3/h)	Fuel Consumption (kg/h)
Bagasse, 6 mm	4.8 – 6.1	1.6 – 1.8
Wood, 6 mm	5.2 – 6.8	2.0 – 2.1
Empty Fruit Bunch (EFB), 6 mm	5.0 – 6.2	1.8 – 2.1
Empty Fruit Bunch (EFB), 8 mm	5.0 – 5.6	2.1 – 2.5

Table 8 shows that wood pellets need increased consumption and highest gas output in the same condition as feedstock diameter. The diameter of this condition is 8 mm of empty fruit bunch (EFB). Consequently, the low condition's dry gas production is economically for the power plant consumption and power plant production.

2.12.8. Environmental Sustainability Assessment of Palm Oil Biomass

The emissions control from these systems becomes invincible in order to minimize dependence on fossil fuels while improving the economic viability and environmental performance of palm oil production for biomass. However, these hurdles can be overcome by best management practices and strict adherence to the basic principles of environmental sustainability.

The damage to one part of this ecosystem will impact directly on other sections because it is closed. Therefore, we need to promote environmental sustainability so that healthy living can have minimal adverse effects. Daly [58] describes environmental sustainability as the infinite rate for the accumulation of renewable resources, the management of emissions and the removal of non-renewable resources. This means that the world is more sustainable by providing "energy and facilities" of present and future generations without sacrificing the safety of the ecosystem. Again the amount of waste produced by the system should not surpass the input resources and wastes which the ecosystem will transport in order to be considered environmentally friendly. Normally, the program is accomplished by reducing non-renewable resources such as fossil fuel consumption. Without destroying biodiversity or exceeding ecosystem capacity for regeneration of critical products and services, human welfare is satisfied in an environmentally sustainable system. As a result, processes are conducted in an environmentally sustainable system with a consistent indefinite continuity and a minor environmental impact, thus making the system (or ecosystem) environment for future generations unchanged.

One of the environmental challenges facing a palm oil industry is the massive emissions caused by raw material production, the type of production technologies used; the quantity of input resources used for generating the products in their entirety; waste management practices; pollution management, etc. The cultivation of palm oil biomass will lead to waste, air, water and land contamination by damaging the environment if best sustainable production practices are not adhered. For example, the plantation contributes to loss of biodiversity and increased greenhouse gas (GHG) emissions due to the carbon combustion of fuel and decomposition of organic matter in peatlands, through the clearing of new forests and conversion of peatlands to palm oils cultivation. The environmental effect from the processing of palm oil will potentially increase the environmental contribution of the production systems of palm oil biomass. Consequently, environmental pollution from feedstock production units needs to be reduced more effectively. Efficient waste management of mills in Palm Oil Mill (POME), Empty Fruit Bunch (EFB), Palm Pressed Fibres (PPF), Palm Kernel Shells (PKS), Palm Kernel Cake (PKC) in palm oil factories is a prime concern. In this field of palm oil mills. This efficient administration is a unique challenge since only a few waste are used in electricity production for use in mills.

In order to guarantee the reduction of potential emissions such as greenhouse gas (GHG) of the palm oil industry, strategically identifying standards and requirements for sustainable palm oil production, the round table of sustainable palm oil and the national biofuel policies (in Indonesia and Malaysia) as well as the Kyoto protocol have become a critical point. The palm oil sector has been part of the UN Framework on Climate Change (UNFCC) for the purposes of reducing greenhouse gas (GHG) emissions from industry in Indonesia and Malaysia since 2004 under the Kyoto Protocol.

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CHAPTER 3. MATERIAL AND METHODS

3.1. Material: Wood Pellet Feedstock

This research used the wood pellet since it was readily available and corresponded to the laboratory scale gasification system application. It was also chosen because it contained more lignin compared to other feedstock. The wood pellet typically consists of 21 – 31% of lignin, 38 - 51% cellulose, 17 - 38% hemicellulose and 3% extractive [1-3]. The lignin is an aromatic polymer mixed with cellulose fibers to bind adjacent cells together. It functions as a bonding agent for hydrocarbon products, leading to tar production [4]. Lignin in the wood pellet acts as bonding agent for hydrocarbon products and it causes tar production. Additionally, wood pellet was chosen as feedstock because it contained lignin component compared to other kind of feedstock. In this experiment we used wood pellet with 6 mm diameter, 12-16 mm length, 0.4-0.6 grams weight and 790 kg/m^3 of bulk density. **Figure 20**, **Figure 21**, **Figure 22**, and **Figure 23** show the wood pellet specification as feedstock in biomass. On the other hand, the amount of wood pellet can be accommodated much more compared with a wood chip in the same reactor gasifier volume. Wood pellet has low of moisture content and has denser composition than wood chips. Moisture content that being used are around 2 wt. %, 4 wt. %, 6 wt. %, and air flow rate 40 L/min, 60 L/min and 80 L/min.

Figure 20. Wood Pellet Specification: Color of Wood Pellet Feedstock

Figure 21. Wood Pellet Specification: Diameter of Wood Pellet Feedstock

Figure 22. Wood Pellet Specification: Length of Wood Pellet Feedstock

Figure 23. Wood Pellet Specification: Weight of Wood Pellet Feedstock

The Ultimate Analysis (UA) and Proximate Analysis (PA) were conducted based on the Japan Industrial Standard (JIS). **Table 9** and **Table 10** shows UA and PA, while natural feedstock materials, such as C, N, S, H, O, were used in qualitative analysis. The PA produced several parameters, such as fixed carbon, quantitative moisture, volatile matter, and feedstock ash [5].

Table 9. Wood Pellet Components (Ultimate Analysis)

Ultimate analysis (wt. %, dry ash-free) JIS M8813	
C (dry, ash-free)	50.02
N	0.09
S	0.09
H	6.43
O (balance)	43.37

Table 10. Wood Pellet Components (Proximate Analysis)

Proximate analysis (wt. %, dry basis) JIS M8812	
Fixed carbon	17.65
Volatile Matter (dry base)	81.82
Ash	0.53
Low heating value (LHV)	15.37 MJ/kg-dry

The first step of the experiment involves preparing feedstock by drying through several methods used drying machine (Akira Higashi Dryer TTM-440N, Japan). The drying machine shown in **Figure 24**. The initial moisture content of the sample was around 7- 9 wt. %, which is dried in three different temperatures, including 70 °C, 60 °C, 50 °C. The drying is meant to reduce the moisture content from 7 – 9 wt. % to 2 wt. %, 4 wt. %, and 6 wt. % and then analyzed by the moisture analyzer (AND MF-50, SHS inside Super Hybrid Sensor, with measurement accuracy 0.05 % from A&D Company, Japan), the moisture analyzer was shown in **Figure 25 (a)** and **(b).** For the drying process the moisture content of wood pellet feedstock, the interval for moisture measurement was carried out in every 2 hours during 48 hours of drying time and the measurements were divided into three sessions. Based on the result, the moisture changes significantly in the first 12 hours and reduces gradually during the drying process to a stable percentage. It required 1 hour drying time to obtain 6 wt. % from the initial value of 7-9 wt. % at 70 ºC drying temperature. A maximum of 2 hours was needed to reduce the moisture content from 7-9 wt. % to 4 wt. % and a total of 6 hours to 2 wt. %. This condition is not the same for 60 ºC and 50 ºC drying temperature. Lower temperatures require a longer time to obtain the same result of moisture target. The drying time as shown in **Figure 26.**

Figure 24. Drying Machine (Akira Higashi Dryer TTM-440N, Japan)

(a)

(b)

Figure 25. Moisture Analyzer (AND MF-50, SHS inside Super Hybrid Sensor, with Measurement Accuracy 0.05% from A&D Company, Japan) **(a)** Open Position **(b)** Close Position

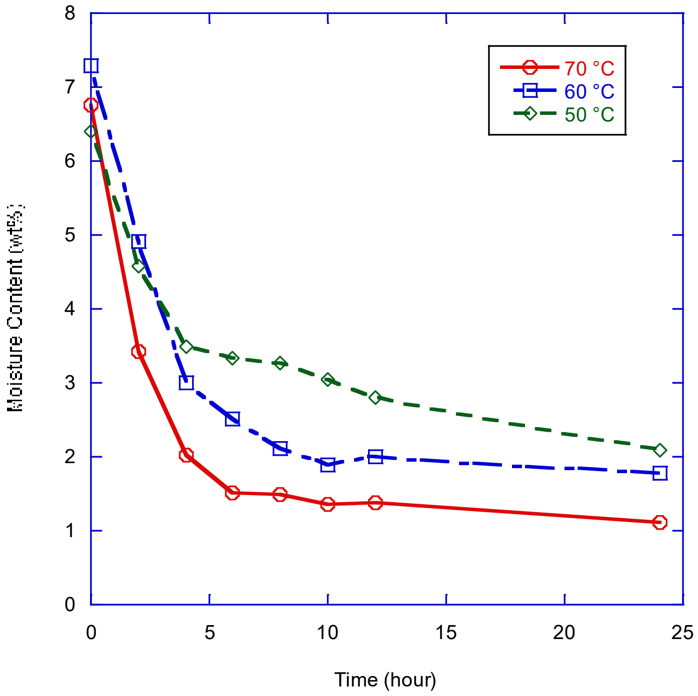

Figure 26. Drying Time Wood Pellet Feedstock

In this experiment, the environment temperature around 13 – 17 °C, we did not exactly measure the moisture content at the airflow rate (AFR) injected at the gasifier, only measure the environment temperature.

So far from the research, many researchers had conducted moisture content measurement on the fuel such as wood pellet or woodchip. Additionally moisture content analysis was difficult to be executed in the input area of airflow rate gasifier.

The high moisture content of the biomass strongly influences the combustion process through the use of biomass as fuel, such as lowering the flame temperature and/or boiler efficiency. Incomplete combustion and/or other operational problems may result from low fire temperature. Unless the combustion is lower, the results for syngas would worsen, leading to an increase in the production of tar. To solve the problem usually feedstock were dried before use in the gasifier to avoid the low temperature of gasification process [6].

On the other hand, the moisture content of the airflow rate does not have a significant effect, because of the changes moisture content in the air do not have big differences, for this condition the moisture content of airflow rate did not give the influence in the gasification process. In this experiment the humidity of air is around 55-60% and temperature of the environment around 13 – 17°C.

3.2. Methods: Gasifier System and Gasification Operating Condition

Figure 27 and **Figure 28** shows the real and the diagram of the downdraft gasifier system. The experiments used Reactor (Gasifier), Tar removal system (Soot Remover), Cooling system (Cooler), Suction Pump, Gas Chromatography-Mass Spectrometry (GC-MS), and Buffer tank. The downdraft gasifier type was made from stainless steel with dimension 500 mm length and 120.8 mm height. The tar enclosed in the producer gas cannot be eliminated only use activates charcoal in the gasifier. Therefore, the shoot removal installed in a gasifier system experiment equipment, with dimensions 1200 mm height and 320 mm inner diameter. The Reactor (Gasifier), removal system (Shoot removal) and Cooling system shown in **Figure 29**.

Figure 27. Real of Downdraft Gasifier System Equipment

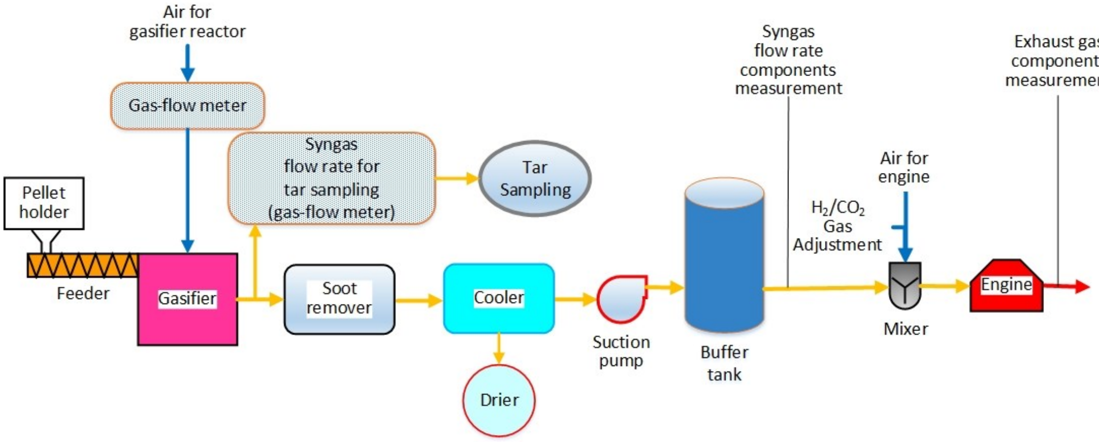

Figure 28. Diagram of Downdraft Gasifier System Equipment

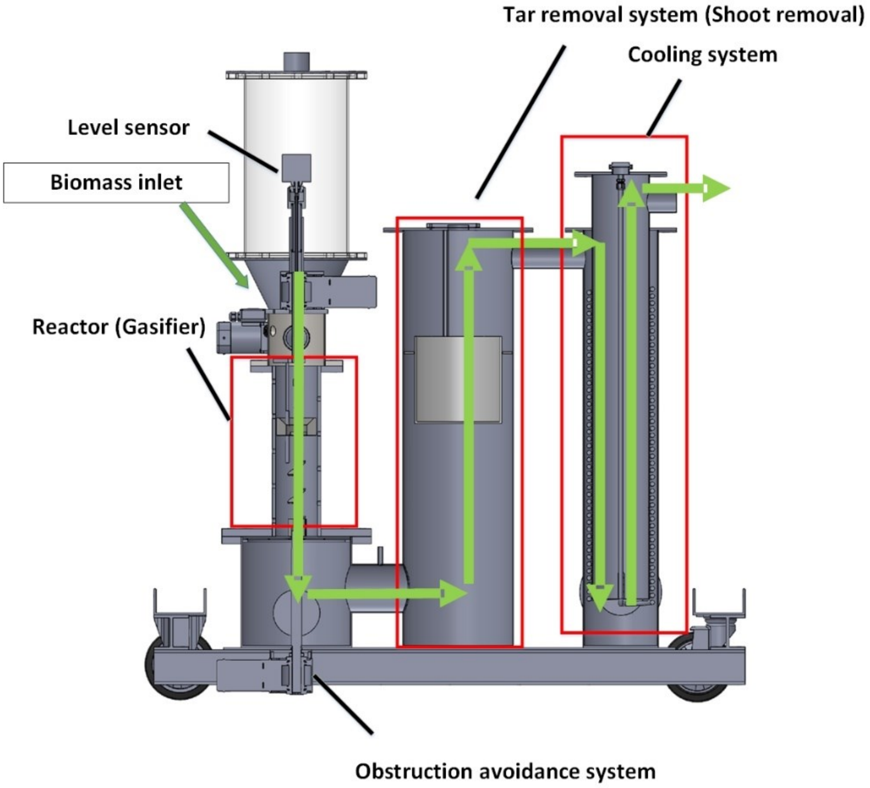

Figure 29. The Reactor (Gasifier), Removal System (Shoot Removal) and Cooling System

Seventeen K-type of thermocouples were installed to measure the temperature inside the gasifier. The thermocouple installs near the wall of gasifier to avoid interfere the wood pellet movement. In this experiment the operating temperature is 400 - 600 ºC and the measurement temperature of gasifier was record in Data Logger GL 820 (Data Instruments Inc., Ohio, USA). The thermocouple shown in **Figure 30**.

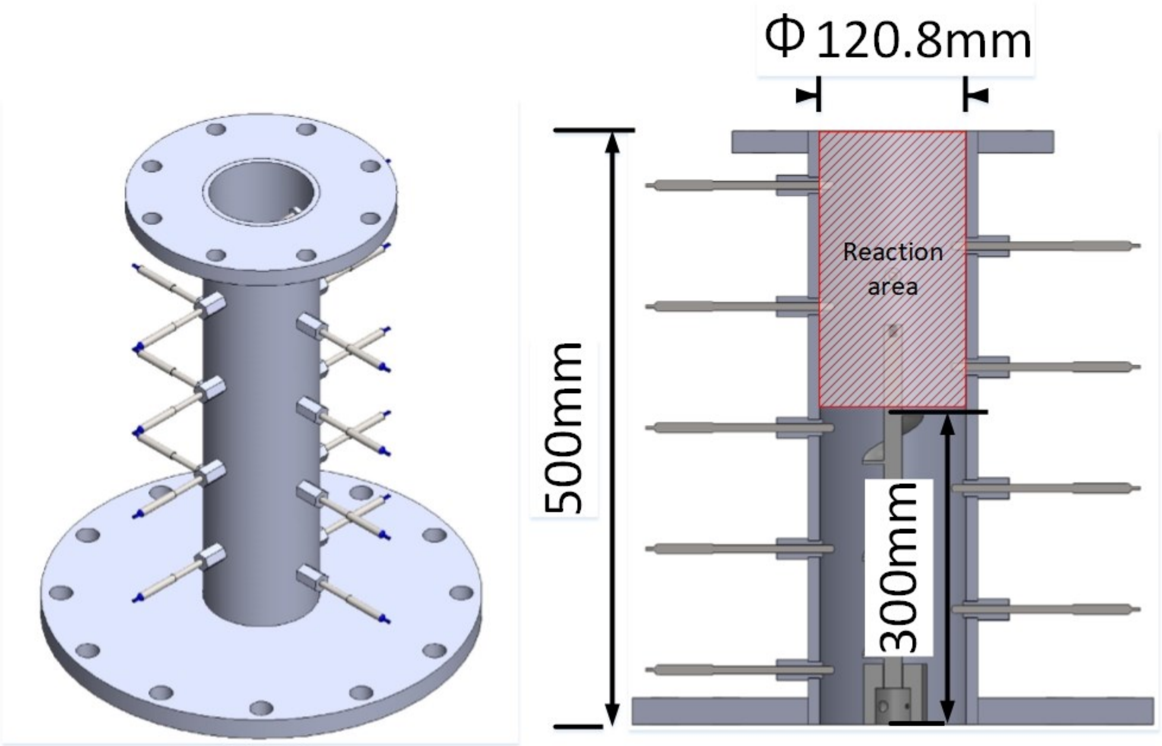

Figure 30. Thermocouple Installed in The Gasifier

The cooler was used to decrease the temperature of producer gas before being sucked by a suction pump to the buffer tank. The suction pump was used to absorb all the producer gas and collect it in the buffer tank. Gas Chromatography-Mass Spectrometry (GC-MS, Agilent, 490 Micro GC, TCD, Ar carrier) was used to identify and to quantify components in producer gas. A Buffer tank was utilized as storage before being used for other purposes, such as to drive the engine or generate electricity. This experiment using the gasification operating condition which was the variables of variation of moisture content on 2 wt. %, 4 wt. % and 6 wt. % and wide range of airflow rate on 40 L/min, 60 L/min and 80 L/min. The top of the gasifier supplied the air from the environment with variances value, starting from 40 L/min, 60 L/min and 80 L/min which were measured using a gas flow meter. Additionally, wood pellet with moisture content 2 wt. %, 4 wt. % and 6 wt. % was fed into the top position from the gasifier for the process. The woody biomass was fed intermittently and the average feed rate was 5 kg/h on dry basis using motor screw. The wood pellet feeding system shown in **Figure 31**.

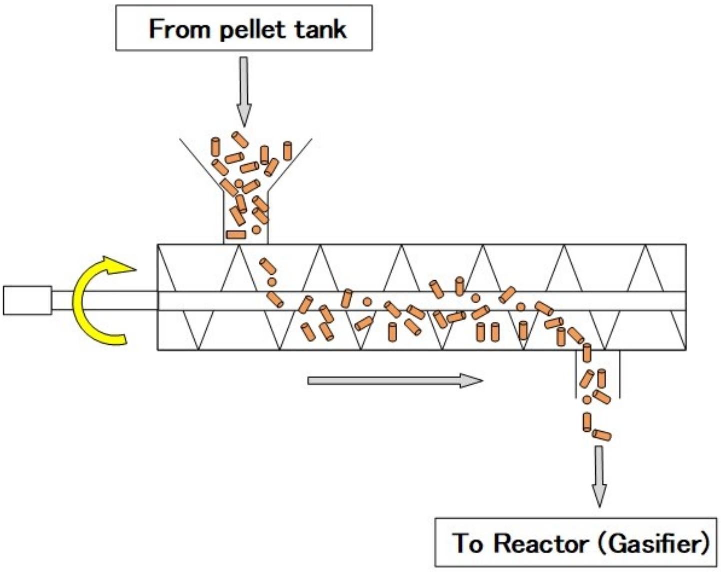

Figure 31. Feeding System of Gasifier

In order to ensure effective gasification performance and to contain the negative effect of the producer gas heating value, the balance of producer gas and energy conversion qualities should be lowered the moisture content at least 20 - 25 wt. % and the ignition becomes difficult in case the value of the moisture content is more than 8 wt. % in cedar wood pellet [7]. Therefore, in this experiment choose the effective value of moisture content for this research was chosen between 2 wt. % until 6 wt. % in gasification operating condition especially in the variation of moisture content. The other variation of gasification operating condition is variation of airflow rate. In this case the variation of airflow rate are around 40 L/min, 60 L/min and 80 L/min to supply air in the gasifier system. The range of 40 L/min to 80 L/min was chosen to maintain the temperature inside the gasifier between 400 °C - 600 °C and optimize the system performance. Gasifier produces "clinker" in the more than 600 °C temperature. Clinkering occurs in the biomass gasification process on inside of gasifier when ash melt and fuses into a hard and glassy slag. It also happens when ash is a noncombustible powder residue left over after wood pellet has burnt. This clinker sometimes blocks the feed movement and causes the discontinuity in the operation of gasifier [8,9]. Typically, some equipment melt in case there is high temperature conditions and long duration, especially where the Screw is inside the gasifier reactor.

3.3. Methods: Tar Sampling

This study used two methods to analyze tar, including Cold Solvent Trapping (CST) and Gravimetric. The CST was applied using the sample taken from the gasifier. The trapper used in this CST applied ethylene glycol as a solvent, and the samples were analyzed using GC-MS [10]. The gravimetric method is a technique used to analyze the amount of tar based on its density. This research used tar during gasification process.

Moisture content was simultaneously distinguished since the airflow rate was in various conditions, including 40 L/min, 60 L/min, and 80 L/min. The experiment was conducted at the moisture content between 2 wt. %, 4 wt. %, and 6 wt. %. Tar sampling was taken in the position between the gasifier and soot remover equipment. The temperature of the gasifier was operated in average as 400 °C – 600 °C, which generates increased amounts of light tar when compared to heavy tar [11]. Heavy tar caused damage to some gasification equipment and reduced the ability of gasification equipment compared to light tar.

As reported by the draft Tar Protocol CEN/TS 143:2005, tar sampling was executed with some modification technique [12]. In the CEN/TS 143:2005, the principle of liquid quench was executed with circulating gas. The liquid injects into the gas sample immediately, and the particle is filtered out with the liquid flow rate of 10-50 ml/min. This system could freeze sufficiently from 250 ºC to 50 ºC and needs six impingers bottles to collect tar. The bottles were divided into two sections, a heated and a cold bath. Evidently, the CEN/TS 143:2005 are more complicated compared to tar sampling equipment developed by Hiroaki Ohara and Katsuaki Matsumura, which has patent number JP 2009-40885 from Japan Patent Office [13]. The method is simpler because it only uses three impingers bottles to freeze the producer gas which contains tar from gasifier and catch the tar without liquid by surface contact method use glass beads, and this method can freeze the producer gas from 250 ºC into -20 ºC, from this condition we can get more total amount of tar sample.

The collection of tar was carried out using the equipment shown in **Figure 32**, **Figure 33**, and **Figure 34**. In this equipment, the producer gas is heated to 250 ºC to avoid impurities, such as ash, dust and soot before it is included in the tar sampling bottle. The equipment of tar sampling used three device of tar sampling bottles with 300 mm long and 24 mm in diameter. All bottles were filled with 30 ml glass beads (AS ONE BZ - 2, φ 1.5 - 2.5 mm) to hold the tar in producer gas. The glass beads are used in the tar sampling bottles to increase the contact surface of tar. The tar sampling bottle is then put in the dewar vessel with ethylene glycol as antifreeze to -20 ºC. In this experiment, the tar sampling position carried out between the after gasifier and soot remover in a gasification system with producer gas flow rate maintained at 8 L/min and 20 minutes sampling.

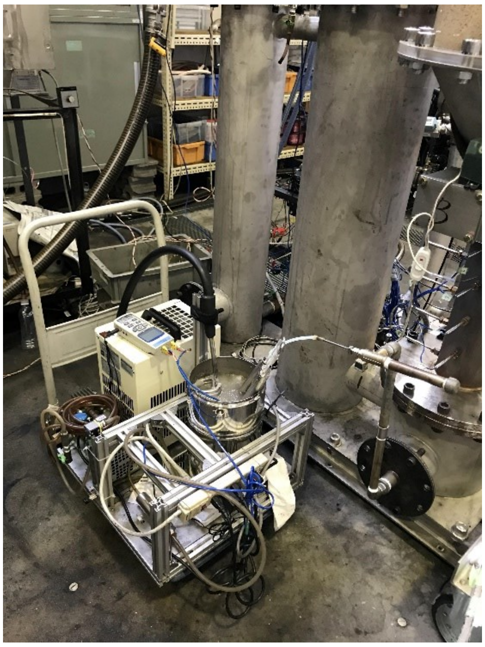

Figure 32. Real Tar Sampling Equipment Setting in The Gasifier Port

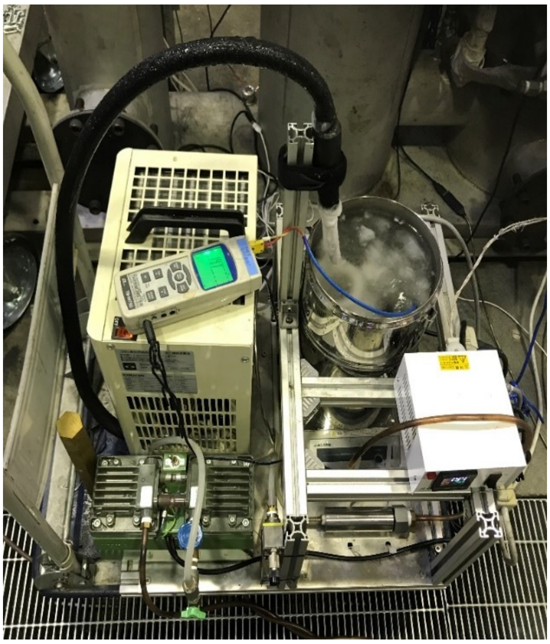

Figure 33. Real Tar Sampling Equipment Setting

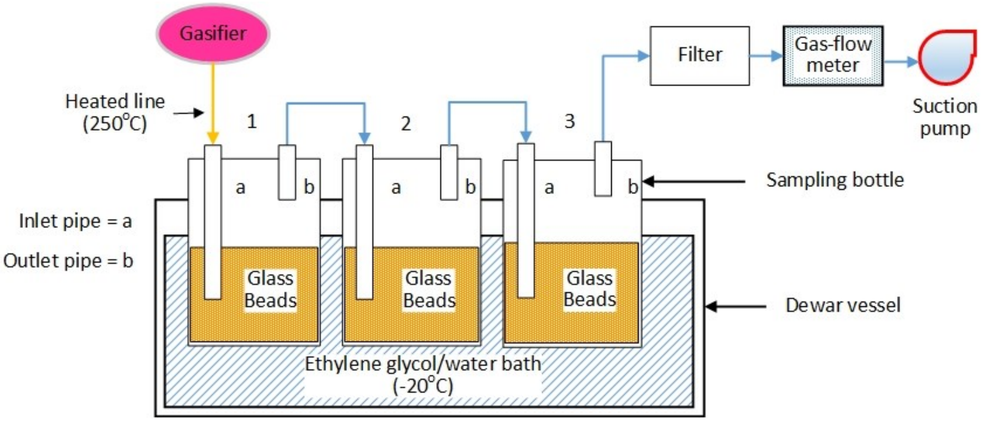

Figure 34. Diagram of Tar Sampling Equipment [14]

3.4. Methods: Extract Tar Sampling

Extract tar is the process separating tar from glass beads, which is using acetone as solvent. first step prepare 50 ml acetone as solvent and using syringe to inject in the impingers tar sampling bottles, and shake the impingers bottle until 30 times, the second step is open the cap of tar impingers tar sampling sampling and pour the mixing of acetone and tar in the stainless steel pan/stainless steel bowl, after that filtered the acetone and tar using nylon syringe filter (SIMPLEPURE, NY 0.45 µm) to avoided pure tar sample mixture from dust, shoot and many impurities. The next step is keep tar sampling in the bottle, and separate in 2 ml vial bottle and 50 ml bottle, respectively. The last is cleaning the impingers tar sampling bottle use fresh acetone, and cleaning the cap of tar sampling bottle use ultrasonic cleaning machine (AS ONE) in at least 10 minutes to make sure the all equipment clean from impurities. (The detail of tar extract in the appendix). The equipment of extract tar shown in **Figure 35**, **Figure 36**, **Figure 37**, **Figure 38**, **Figure 39**, and **Figure 40**.

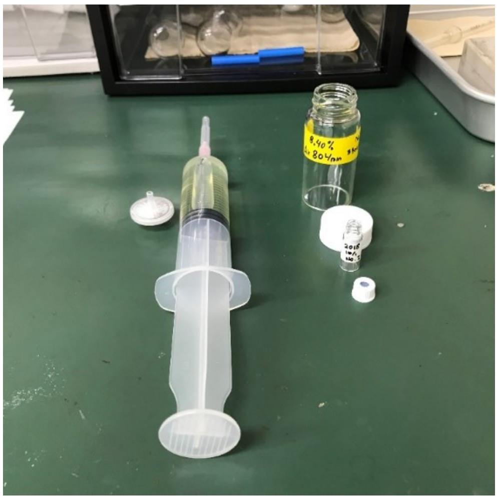

Figure 35. Equipment Extract Tar

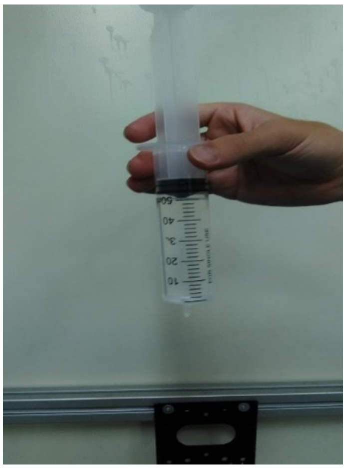

Figure 36. Syringe

Figure 37. Stainless Steel Pan/Stainless Steel Bowl

Figure 38. Nylon Syringe Filter

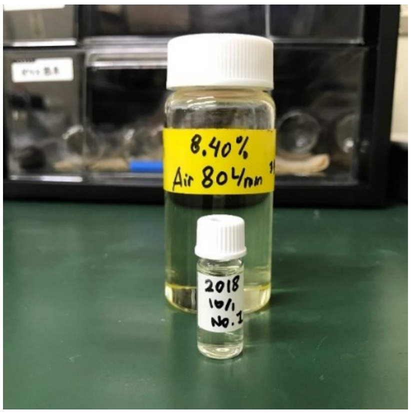

Figure 39. 2 ml Vial Bottle and 50 ml Bottle

Figure 40. Ultrasonic Cleaning Machine

3.5. Methods: Gas Chromatography- Mass Spectrometry (GC-MS)

This experiment used the result of Gas Chromatography-Mass Spectrometry (GC-MS) for tar composition analysis, which was calibrated using standard reagents with high purity of 94 % to 99 %. Shimadzu GC-MS QP2010 Plus was used to identify the tar sampling in 2 ml vial bottle as well as the existence of phenol, toluene, indene, naphthalene, biphenyl, fluorene, phenanthrene, fluoranthene, and pyrene. The total Ion Chromatogram (TIC) used nine standards, which were applied to quantify the product. This was based on the compound peaks with a similarity index that is higher than 70 [15,16]. Furthermore, the data result of GC-MS was analyzed using GC Postrun software in order to identify the tar compound in the sample. **Figure 41** shown the GC-MS apparatus.

Figure 41. The GC-MS Apparatus (Shimadzu GC-MS QP2010 Plus)

3.6. Methods: Gravimetric Analysis

Gravimetric analysis is a technique of using tar sample to analyze and determine the density of a tar compound. It is carried through the distillation and evaporation process to identify the pure mass of the compound. This approach analyzes the pure mass compound to determine the total mass percentage. In this research, the tar sampling with a variation of moisture content and airflow rate were analyzed in the gravimetric method. It was carried out on the boiling point at 65 ºC to remove solvents mixed in tar sampling. In this case, 3 grams mixture of tar sample and acetone is heated for 5 hours at the temperature of 65 ºC. Since the boiling point of acetone is 56 ºC, tar separates from other compounds, and all acetone evaporates. Only a pure mass of tar remains in the residue, a condition referred to as tar density. The last is measured the pure tar mass use Tar-weight measurement machine (Chyo JL-200) which have balance measurement precision and sensitivity until 0.1 mg. **Figure 42** and **Figure 43** shown the Gravimetric Analysis (GA) measurement.

Figure 42. Gravimetric Drying Machine (IRIS OHYAMA)

Figure 43. Tar-Weight Measurement Machine (Chyo JL-200)

3.7. Methods: Spark Ignition – Internal Combustion Engine

In Kanazawa University laboratory, we developed a device for producing bio-syngas with gasification of woody biomass. Our device is a downdraft gasifier system type. Then we use the bio-syngas which we produced, and drove the SI-ICE and generated electric power. Generally, the lean burn conditions lower the burning temperature and will improve the thermal efficiency but will also make the SI-ICE unstable at the same time. **Figure 44** and **Figure 45** apparent the real and diagram system of the gasifier manufactured in this experiment which is this apparatus was found in Kanazawa University Laboratory. The reactor, which is the main part of the gasifier, is a stainless steel tube with a total length of 500 mm and an inner diameter of 120.8 mm. Gas Chromatography-Mass Spectrometry (GC/MS) is an instrumental technique, comprising a gas chromatograph (GC) coupled to a mass spectrometer (MS), by which complex mixtures of chemicals may be separated, identified and quantified.

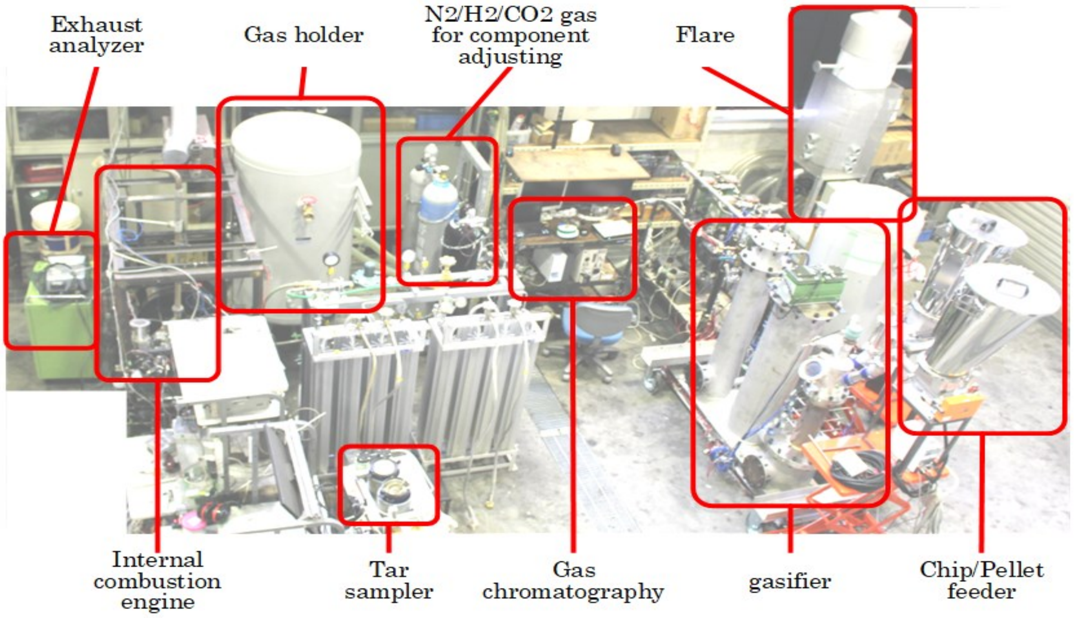

Figure 44. Real of Downdraft Gasifier System with R-ICE

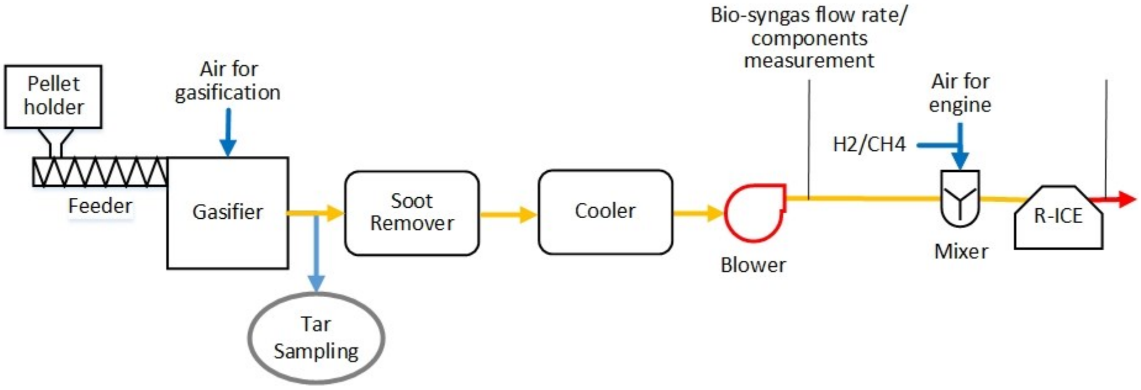

Figure 45. Diagram of Downdraft Gasifier System with R-ICE

In this experiment, the single cylinder Kawasaki FD750 with the specification 78 mm in the bore, 78 mm in stroke, using V-twin, and water-cooled engine, single overhead valve, and using spark ignition was modified becoming small Reciprocated Internal Combustion Engine (R-ICE). This research applied the main principle of combustion, including three parts of fuel, oxidizer, and heat source. It has been applied that the premixed combustion system, air as oxidizer was mixed with fuel using Venture type mixer with the brand of Heinzmann GM 50. Hence, the oxidizer intake to the combustion chamber was measured by a laminar flow meter executing by Sokken, LFE-25B. Pent roof type of combustion chamber was chosen because have advantages in faster burn time of the air and fuel mixing. The major specification of the engine test is shown in **Table 11**.

The experiment had identified that the Air Excess Rate (AER) was calculated from the intake airflow rate, and the gas fuelflow rate in the engine. So far, the precision of combusting timing was controlled by Altronic CD200D digital combusting system and was set up for 30 degrees- After Top Dead Centre (ATDC). In order to reduce the temperature of the engine by avoiding overheat the flow meter with the type TOFCO HF-GCT40-01-30-04 was used volume flow rate for cooling water.

The R-ICE load is measured with an eddy current type dynamometer on brand Tokyo meter, EWS-150-L. This type implemented 150 Nm in maximum torque, 0.5%-F.S. in torque accuracy and 1 rpm in engine speed accuracy. Another measurement of the pressure on the cylinder combustion chamber, a piezo type pressure sensor Kistler 6118CF type was used and combined with charge amplifier 5018A type production by Kistler. Finally, the data of pressure in the cylinder amounted on average one of 150 continuous cycles. **Figure 46** display of R-ICE engine.

Table 11. Engine Specification

Parameter	Kawasaki FD750
Bore (mm)	78.0
Stroke (mm)	78.0
Combustion chamber volume (mL)	49.0
Piston displacement (mL)	372.7
Cylinder number	1
Compression ratio	8.6
Combustion chamber	Pent roof type

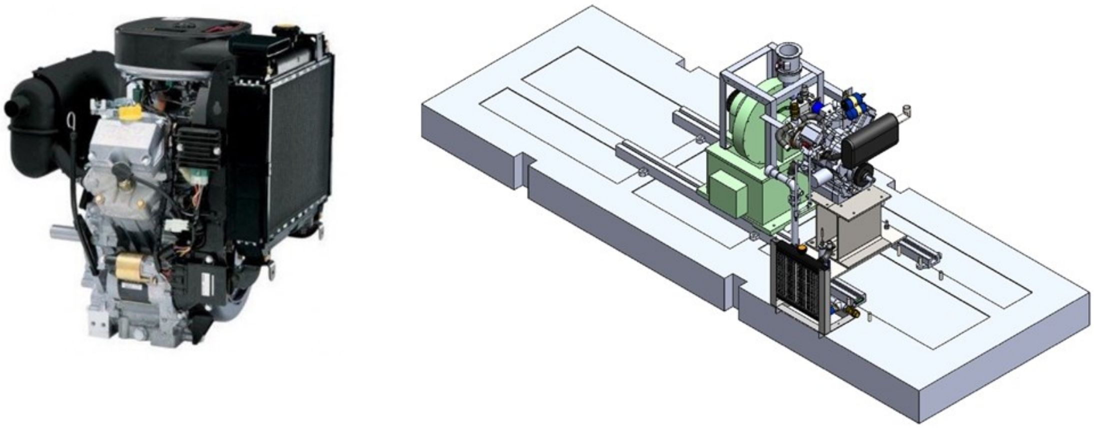

Figure 46. R-ICE Engine

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CHAPTER 4. RESULT AND DISCUSSION

This section explains about the result of many experiments that had been conducted on small downdraft gasifier system. Those experiments executed using wood pellet feedstock. Many variables had been investigated through the analysis which were applied on many samples. Here are the explaining effect of that many variables.

4.1. Effect of Moisture Content Feedstock on Gasification Efficiency

The effect of moisture content on the tar production was analyzed for both feedstocks at three different moisture levels. The result of moisture content on pellet which is the condition on 70 degrees was shown in the **Figure 47**. Percentage of pellet moisture content decreased when the time was running out on value of 0h (hours), 2h, 4h, 6h, 8h, 10h, 12h, and 24h at the experiment. This drying use drying machine (Akira Higashi Dryer TTM-440N, Japan).

The initial moisture of the sample was around 7 wt. % ± 9 wt. %, which is dried in three different temperatures, including 70 °C, 60 °C, 50 °C. The drying is meant to reduce the moisture content from initial condition to 2 wt. %, 4 wt. %, and 6 wt. % and then analyzed by the moisture analyzer (AND MF-50, SHS inside Super Hybrid Sensor, with measurement accuracy 0.05% from A&D Company, Japan). The interval time of measurement moisture content was carried out in 2 hours as long as 48 hours. The result show the moisture changes significantly in the first 12 hours and reduces gradually during the drying process to a stable percentage. It required 1 hour drying time to obtain 6 wt. % from the initial value of 7 wt. % ± 9 wt. % at 70 °C drying temperature. A maximum of 2 hours was needed to reduce the moisture content from 7 wt. % to 4 wt. % and a total of 6 hours to 2 wt. %. This condition is not the same for 60 °C and 50 °C drying temperature. Lower temperatures require a longer time to obtain the same result of moisture target. In the 70 °C the value of moisture 6.75

wt. % (initial moisture content) reduce to 3.40 wt. % (2 hours), reduce to 2.02 wt. % (4 hours), reduce to 1.52 wt.% (6 hours), reduce to1.50 wt.% (8 hours), reduce to 1.37 wt.% (10 hours), reduce to 1.35 wt.% (12 hours) and finally reduce to 1.12 wt.% (24 hours).

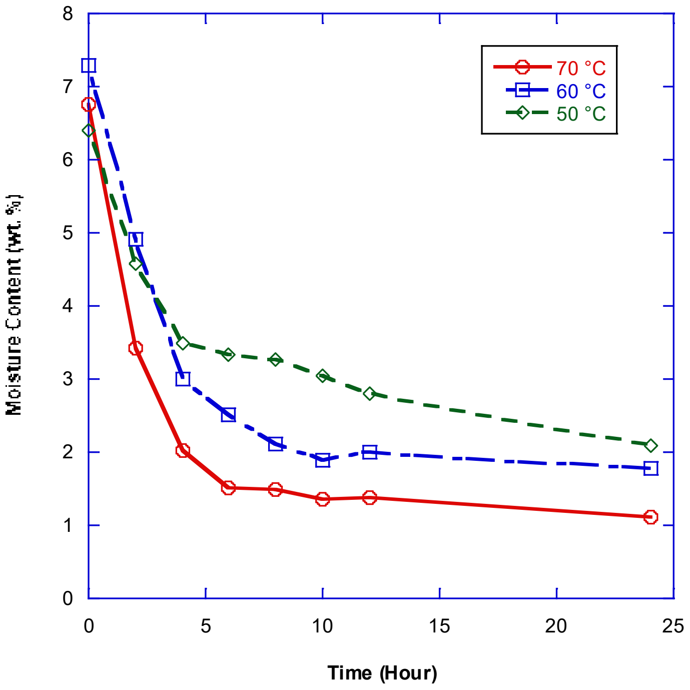

Figure 47. Wood Pellet Feedstock Drying

Cold gas efficiency can be defined as the ratio between the flow of energy in the producer gas and the energy contained with the fuel, and this condition can be define as parameter of gasification efficiency. The condition as shown in **Figure 48**. From the graph, it can be seen, cold gas efficiency decreases from 0.69 % in the moisture content 2 wt. % to be 0.65 % in moisture content 4 wt. % and gradually decrease to 0.64 % in the moisture content 6 wt. % of wood pellet feedstock. This condition indicated that wood pellet with low moisture content has a better value of fuel conversion and in the gasification efficiency. This condition happen because in the gaseous tar condensation, especially in the oxygenated hydrocarbons, e.g., acetic acid or phenol, it work as surfactant between oil in producer gas.

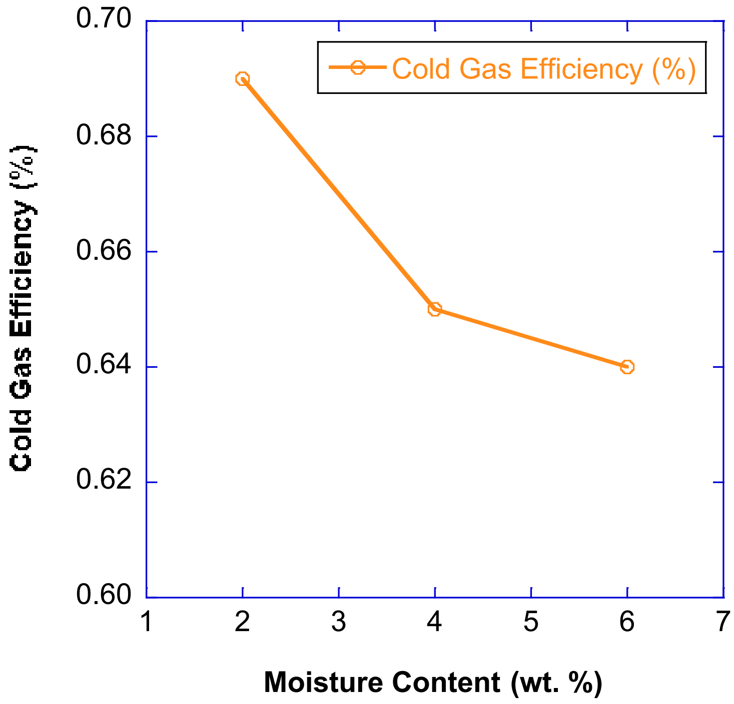

Figure 48. Cold Gas Efficiency Condition

This experiment conducted in the environment temperature at 13- 17 ºC with air humidity 55 – 60%. The moisture content is important point in the process of combustion on the gasification. The moisture content have influence in the combustion on gasification because moisture content have effect on the flame temperature in gasifier. If the moisture content high will make the flame temperature on low condition and this make incomplete combustion. In the incomplete combustion condition in the gasification will give the influence of consumption rate feedstock in feeding system. It's give the impact on the consumption rate of feedstock in gasification. **Table 12** show the consumption rate of wood pellet feedstock in variation of moisture content and variation of airflow rate.

Table 12. Consumption Rate of Feedstock

Wood	**Mater**	**Air**
Mass	Moisture Content (MC)	Airflow Rate (AFR)
5 kg/h	**2 wt. %**	**40 L/min**
	0.00002778 kg/s	0.00000480012 kg/s
	4 wt. %	**60 L/min**
	0.00005556 kg/s	0.00000720018 kg/s
	6 wt. %	**80 L/min**
	0.00008334 kg/s	0.00000960024 kg/s

From the table can be explain in one time process of gasification, the experiment need around 0.00002778 kg/s until 0.00008334 kg/s of wood pellet feedstock based on the variation of moisture content, and the consumption rate for the feedstock need 0.00000480012 kg/s to 0.00000960024 kg/s based on the variation of airflow rate in one time process of gasification. This table give the evidence that in low moisture content (2 wt. %) need the less amount of feedstock to get same total producer gas production in gasification process.

The other side to get the same amount of producer gas production, the lower airflow rate (40 L/min) has a consumption rate less than higher airflow rate, although this condition need longer time.

4.2. Effect of Gasification Operating Condition on Producer Gas

In order to ensure effective gasification performance and to contain the negative effect of the producer gas heating value, the balance of producer gas and energy conversion qualities should be lowered the moisture content at least 20 - 25 wt. % and the ignition becomes difficult in case the value of the moisture content is more than 8 wt. % in cedar wood pellet [1]. Therefore, in this experiment choose the effective value of moisture content for this research between 2 wt. % until 6 wt. % in gasification operating condition, especially in the variation of moisture content. The other variation of gasification operating condition is variation of airflow rate. In this case the variation of airflow rate are around 40 L/min, 60 L/min and 80 L/min to supply air in the gasifier system. The range of 40 L/min to 80 L/min was chosen to maintain the temperature inside the gasifier between 400 ºC - 600 ºC and optimize the system performance.

Gasifier produces "clinker" in the more than 600 ºC temperature. Clinkering occurs in the biomass gasification process on inside of gasifier when ash melt and fuses into a hard and glassy slag. It also happens when ash is a noncombustible powder residue left over after wood pellet has burnt. This clinker sometimes blocks the feed movement and causes the discontinuity in the operation of gasifier [2,3]. Typically, some equipment melt in case there is high temperature conditions and long duration, especially where the Screw is inside the gasifier reactor.

The method of gasification can be defined as incineration. It is a thermal recovery process aimed at the processing of chemical parts by gas and electricity [4]. The chemical reaction of biomass gasification and tar production is demonstrated during the process. In reaction R1, as shown in **Table 13,** homogenous and heterogenous reactions were shown. The distributed air in the oxidation zone moves with the feedstock to the inside of gasifier. All the products are driven to pass through the oxidation zone thus taking the effect of tar production. Importantly, the catalytic reforming reaction cleaves the C-C bonds of the carbohydrate backbone to generate a combination of H_2 and CO_2 (reaction R13 and R14). If H_2O is present, CO_2 may be produced through the reaction of the Water Gas Shift (WGS), which produces more H_2 (R10) producer gasses. According to **Table 13**, one of the tar reactions, specifically C_nH_m with H_2O, in the steam reforming process produces H_2 and CO from tar compounds (reaction R13). Steam reforms are needed at high temperatures where the increasing temperature drives the hydrocarbon endothermic reaction (R13). The temperature rises in the steam reforming cycle, increases tar removal and increases the concentration of H_2 and CO [5].

Table 13. Chemical Reactions Mechanism from Gasification [5]

Stoichiometry	**Standard Heat of Reaction (kJ/mol)**	**Name**	**Number**
Biomass $\rightarrow$ char + tar + H_2O + light gas ($CO + CO_2 + H_2 + CH_4 + C_2 + N_2 + \ldots$)	Endothermic	Biomass de-volatilization	R1
Char combustion			
$C + 1/2O_2 \rightarrow CO$	-111	Partial combustion	R2
$C + O_2 \rightarrow CO_2$	-394	Complete combustion	R3
Char gasification			
$C + CO_2 \rightarrow 2CO$	+173	Boudouard reaction	R4
$C + H_2O \rightarrow CO + H_2$	+131	Steam gasification	R5
$C + 2H_2 \rightarrow CH_4$	-75	Hydrogen gasification	R6
Homogeneous volatile oxidation			
$CO + 1/2O_2 \rightarrow CO_2$	-283	Carbon monoxide oxidation	R7

$H_2 + 1/2O_2 \rightarrow H_2O$	-242	Hydrogen oxidation	R8
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	-283	Methane oxidation	R9
$CO + H_2O \rightarrow CO_2 + H_2$	-41	Water gas-shift reaction	R10
$CO + 3H_2 \rightarrow CH_4 + H_2O$	-206	Methanation	R11
Tar reaction (tar assumed C_nH_m)			
$C_nH_m + (n/2)O_2 \rightarrow nCO + (m/2)H_2$	Endothermic (except R12) (200–300)	Partial oxidation	R12
$C_nH_m + nH_2O \rightarrow (m/2 + n)H_2 + nCO$		Steam reforming	R13
$C_nH_m + nCO_2 \rightarrow 2nCO + (m/2)H_2$		Dry reforming	R14
$C_nH_m + (2n-m/2)H_2 \rightarrow nCH_4$		Hydrogenation	R15
$C_nH_m \rightarrow (m/4)CH4 + (n-m/4)C$		Thermal cracking	R16

From the reaction R12 until R16, tar was produce in gasification process, tar is unavoidable product and will reduce the performance of gasification system.

In general tar reaction mechanism in tar mainly happen occurs due to tar formation, in the steam reforming, dry reforming and thermal cracking. In steam reforming reaction mechanism (reaction R13) the high temperature and H_2O needed to crack the tar (C_nH_m) and will produce the syngas in H_2 and CO. In the Dry reforming mechanism reaction which is reaction with CO_2 (reaction R14) make the increasing of production CO and H_2 in the process of gasification. Additionally, in the Hydrogen and Thermal Cracking reaction mechanism (reaction R15 and R16) the tar (C_nH_m) will produce methane (CH_4) in the high temperature.

Gasification is the process of the heating of solid or liquid carbonate material (feedstock) with some gasifiers to produce gaseous fuels that often referred to as “producer gas". This producer gas production can be characterized regarding the variations in the volumetric concentration of H_2, CH_4 and CO. The combustion was significantly influenced by the variation in the inert components of producer gas (N_2 and CO_2). In general, fuel moisture content affects the producer gas composition and gasification process [6]. It is one of the essential fuel properties. Fuel with moisture content 40 wt. % on a dry basis and more can be used for the gasification process. Besides, the value of moisture content higher than 30 wt. % makes the ignition is difficult. For ensuring the effective gasification performance and the negative effect of the syngas heating value, the balance of producer gas quality and energy conversion quality made the condition of moisture content should be lowered at least 20-25 wt. % [1].

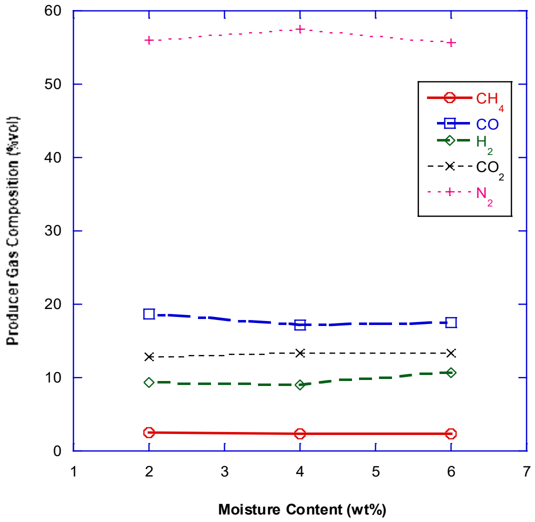

Figure 49. Producer Gas Composition in Airflow Rate 40 L/min with Variation Moisture Content 2 wt. %, 4 wt. %, and 6 wt. %

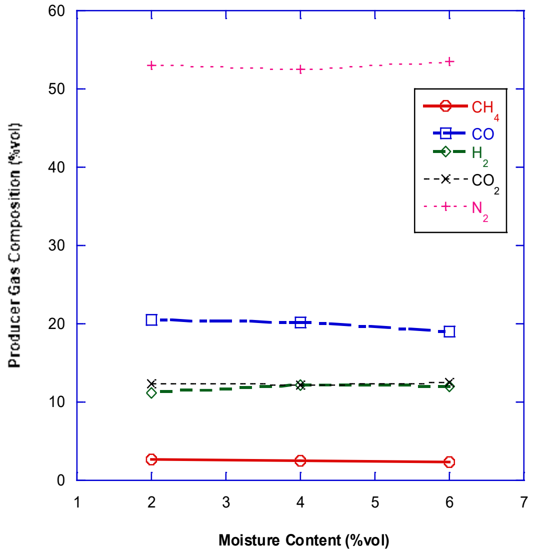

Figure 50. Producer Gas Composition in Airflow Rate 60 L/min with Variation Moisture Content 2 wt. %, 4 wt. %, and 6 wt. %

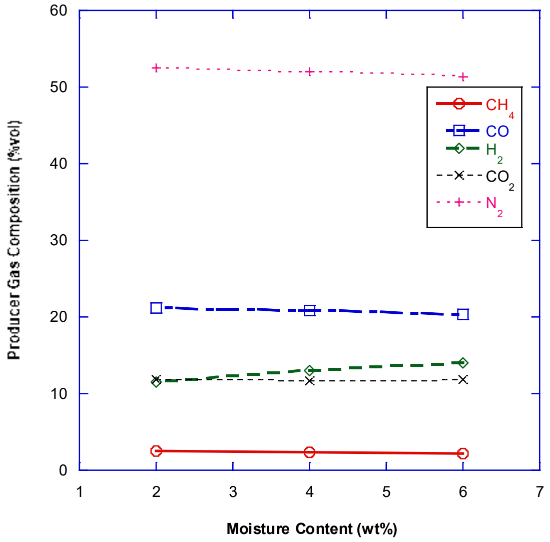

Figure 51. Producer Gas Composition in Airflow Rate 80 L/min with Variation Moisture Content 2 wt. %, 4 wt. %, and 6 wt. %

The producer gas, according to the variation of air flow rate and moisture content was shown in **Figure 49**, **Figure 50**, and **Figure 51**. Producer gas in variation of airflow rate 40

L/min, 60 L/min and 80 L/min with variation moisture content 2 wt. %, 4 wt. %, and 6 wt. %. **Figure 49** presents the air flow rate 40 L/min the composition of Hydrogen (H_2) increasing from 9.30 %vol in moisture content 2 wt. % (MC 2 wt. %) to 10.60 %vol in moisture content 6 wt. % (MC 6 wt. %), the composition of methane (CH_4) decrease from 2.50 %vol (MC 2 wt. %) to 2.30 %vol (MC 6 wt. %), the composition of carbon monoxide (CO) decrease from 18.70 %vol (MC 2 wt. %) to 17.50 %vol (MC 6wt. %), the composition of carbon dioxide (CO_2) have rises from 12.80 %vol (MC 2 wt. %) to 13.30 %vol (MC 6 wt. %), and the composition of Nitrogen (N_2) decline from 56.00 %vol (MC 2 wt. %) to 55.70 %vol (MC 6 wt. %). In **Figure 50** the air flow rate 60 L/min the composition of Hydrogen (H_2) increase from 11.16 %vol (MC 2 wt. %) to 12.03 %vol (MC 6 wt. %), the composition of methane (CH_4) decrease from 2.68 %vol (MC 2 wt. %) to 2.31 %vol (MC 6 wt. %), the composition of carbon monoxide (CO) goes down from 20.54 %vol (MC 2 wt%) to 19.02 %vol (MC 6 wt. %), the composition of carbon dioxide (CO_2) increase from 12.30 %vol (MC 2 wt. %) to 12.59 %vol (MC 6 wt. %), and the composition of Nitrogen (N_2) increase from 52.98 %vol (MC 2 wt. %) to 53.57 %vol (MC 6 wt. %).

In **Figure 51** the air flow rate 80 L/min the composition of Hydrogen (H_2) increase from 11.59 %vol (MC 2 wt. %) to 14.00 %vol (MC 6 wt. %), the composition of methane (CH_4) decrease from 2.57 %vol (MC 2 wt. %) to 2.12 %vol (MC 6 wt. %), the composition of carbon monoxide (CO) decrease from 21.19 %vol (MC 2 wt. %) to 20.38 %vol (MC 6 wt. %), the composition of carbon dioxide (CO_2) increase from 11.87 %vol (MC 2 wt. %) to 11.90 %vol (MC 6 wt. %), and the composition of Nitrogen (N_2) decrease from 52.52 %vol (MC 2 wt. %) to 51.32 %vol (MC 6 wt. %).

In the moisture content 2 wt. % have result the amount of flammable gas such as CH_4 and CO in producer gas production much more than in the moisture content 4 wt. % and 6 wt. %, however H_2 gas in the decrease condition and this gas will get much more in the moisture content 6 wt. %, this condition applies the same result in every air flow rate and the huge amount of flammable gas will get on air flow rate 80 L/min compare with 60 L/min and 40 L/min. This condition happen because in the higher air flow rate will be obtained higher temperature in the gasifier and this condition will affect much more chemical compounds react. Which is producer gas are hydrogen (H_2), methane (CH_4) and carbon monoxide (CO_2) used as parameter of inflammable gas, The other side, carbon monoxide (CO_2) and nitrogen (N_2) used to identify unflammable gas. H_2 was increasing in all conditions of airflow rate, hence the highest rising in airflow rate 80 L/min with increasing significantly by 20.79 %, from initial 11.59 %vol in moisture content 2 wt. % to 14.00 %vol in moisture content 6 wt. %. High CH_4 content was found in moisture content 2 wt. %, including in airflow rate 60 L/min and 80 L/min with 2.68 %vol and 2.57 %vol, respectively. The highest CO was found in air flow rate 80 L/min with 21.19 %vol. The lowest CO_2 as unflammable gas was found in airflow rate 80 L/min and moisture content 2 wt. % with value 11.87 %vol. The lowest N_2 was found in airflow rate 80 L/min and moisture content 6 wt. % with value 51.32 %vol.

Based on the experiment on biomass gasification using wood pellet and the downdraft gasifier method, the volume percentage of N_2 achieved 50 – 55 %vol. Producer gas had a high nitrogen content and cannot be eliminated with a justifiable cost. Therefore, it is not suitable as an economical producer gas. Besides, the amount of inflammable gas was found in the producer gas as follows CH_4, CO and H_2 with the result around 2-3 %vol, 17-22 %vol, 12-20 %vol, respectively. This result is in accordance with the statement of S.C Bhatia [7].

The increasing moisture content yielded a decreasing effect of biomass consumption rate because the energy produced in the gasification system was implemented for drying the wood pellet feedstock. This condition reduced the gasification performance of biomass. As a result, the differences in moisture content affected both operations in the gasification process and the quality of gas composition in producer gas [8].

Gasification operating conditions influenced the yield of producer gas, with the parameter of moisture content and airflow rate. It revealed that the decrease of moisture content affected the increasing of combustible gas production (H_2, CO and CH_4) and the decrease of carbon dioxide (CO_2). The effective value of airflow rate was achieved on the number of 80 L/min and this value reached the highest concentration of the total combustible gas of producer gas production.

4.3. Effect of Temperature on Tar Concentration

The composition of the producer gas was affected by the temperature which occurred inside the reactor gasifier. Hence, the observation on the temperature also needs to be evaluated. For this purpose, we installed a thermocouple to measure temperature inside gasifier. Seventeen thermocouple was set in the wall of gasifier with interval 25 mm. **Figure 52**, **Figure 53**, and **Figure 54** display the relation between the heights of gasifier with the temperature inside the gasifier. **Figure 52** shows the experiment was conducted on the air flow rate 40 L/min and the lowest temperature reached up 310 ºC. The position of the thermocouple was at 150 mm in the gasifier with the moisture content of 4 wt. %. In addition, the highest temperature gained at 576 ºC when the position of the thermocouple was at 425 mm in the gasifier in almost all moisture content variations value of 2 wt. %, 4 wt. %, and 6 wt. %.

Figure 53 presents that the experiment had executed with an airflow rate of 60 L/min with the lowest and the highest temperature was at 284 ºC, and 612 ºC and the position of the thermocouple were at 150 mm and 375 mm, in the gasifier in almost all moisture content, respectively. While in **Figure 54** shows that the observation was done on the air flow rate 80 L/min. Similarly, the lowest and the highest temperature were reached up to 315 ºC and 678.27 ºC, and the position of thermocouple was at 350 mm and 425 mm in gasifier with almost same condition in the all moisture content 2 wt%, 4 wt% and 6 wt%, respectively. Ultimately, the temperature affects the production of producer gas, which is the highest temperature caused the complete gasification process and produced much of producer gas. On the other hand, the lignin, as the wood pellet forming material did not gasify well at a lower temperature and this material called as tar.

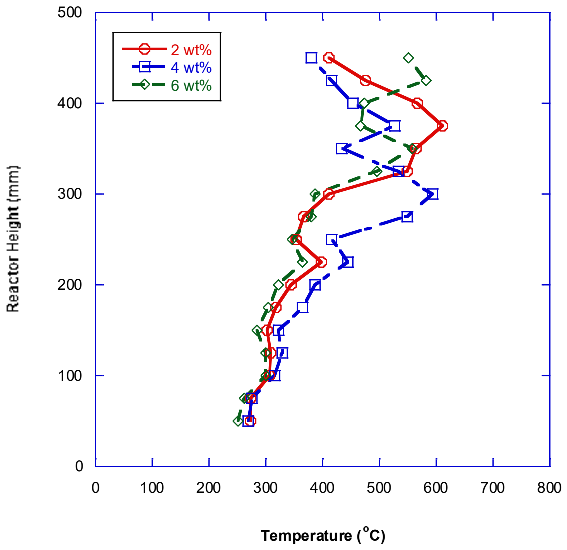

Figure 52. Temperature Inside Gasifier in Airflow Rate 40 L/min with Variation of Moisture Content 2 wt. %, 4 wt. %, and 6 wt. %

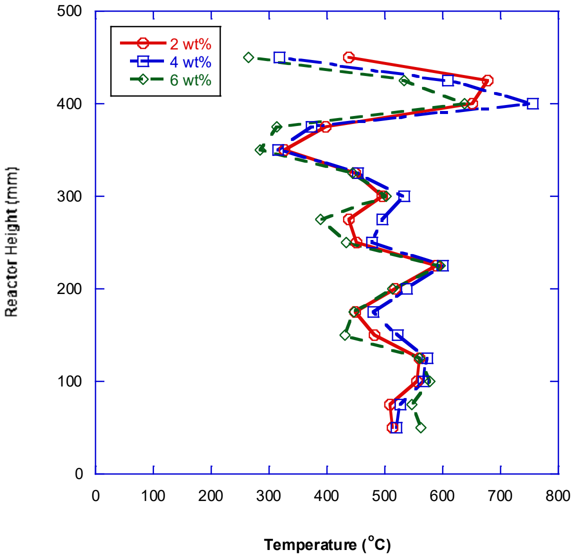

Figure 53. Temperature Inside Gasifier in Airflow Rate 60 L/min with Variation of Moisture Content 2 wt. %, 4 wt. %, and 6 wt. %

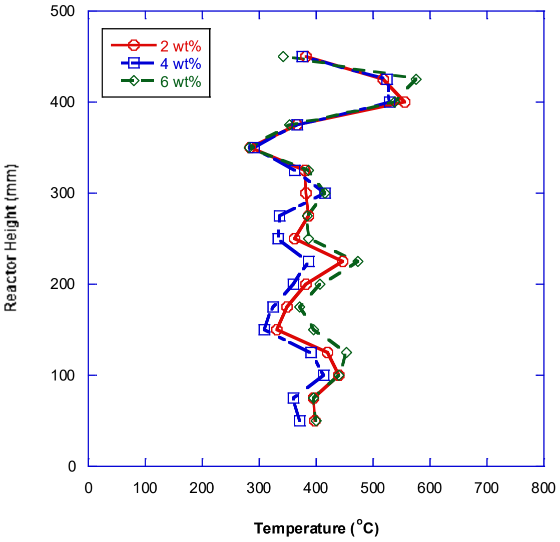

Figure 54. Temperature Inside Gasifier in Airflow Rate 80 L/min with Variation of Moisture Content 2 wt. %, 4 wt. %, and 6 wt. %

Regarding the gas fraction, the gas composition at different gasification temperatures is shown in **Table 14**. The main components are H_2, CO and CO_2 and small quantities of low molecular of methane (CH_4). It revealed that higher temperatures significantly resulted in higher H_2 contents. The main reactions were shown in **Table 13,** specifically in Reaction R4, R5, R10 and R13. All the chemical reactions are endothermic strengthened by increasing temperature. Therefore, the reactor temperature had a significant influence on the contents of H_2 and CO. Temperature increasing from 400 °C to 600 °C, H_2 content increased significantly by 21%, CO_2 content slightly increased from 11.87 %vol to 11.90 %vol and CO content decreased by 3.8%. Hu et al. stated that this result is related to the fact that the fractions of the CO, CO_2 and H_2 are linked together by the equilibrium of the water-gas shift reaction under the test conditions. Methane decomposition was found a slightly decreased in CH_4 content as temperature increases. The decreasing concentration of tar was found with the rising of temperature due to variance moisture contents [9]. Besides, **Table 14** exhibited for the constant moisture content and the variances of airflow rate, the increasing temperature yielded the decreasing of hydrogen (H_2) and carbon monoxide (CO) and the decreasing value of tar concentration. On the other hand, the concentration of CO_2 have an increasing value. The rising of airflow rate leads to the tar reduction based on the chemical reaction from **Table 13**, hence, the total tar concentration had a declining value in temperature of 600 °C.

To summarize, the experiment at the lowest moisture content 2 wt. % produced the highest production of producer gas on inflammable gas such as CH_4 and H_2 and in this condition supplied more producer gas than the condition in moisture content 6 wt. %. On the contrary, the production of CO decreased with the rising of moisture content value. Moreover, the amount of unflammable gas such as CO_2 and N_2 were found in the higher airflow rate in more amount of quantity. Therefore, the increasing value of the temperature 400 °C to 600 °C made the total tar concentration decreased and when the temperature was on 600 °C, the tar concentration had the lowest value. On the other hand, this condition existed because the higher air flow rate realized the higher temperature in the gasifier, then more chemical compounds reacted sufficiently.

Table 15 show the composition of product in the different temperature and different moisture content in 2, 4, 6 wt. %, which is the production of H_2 is higher in the higher temperature (600 °C), and the tar concentration on the higher temperature (600 °C) has the lowest tar production although in the high of moisture content (6 wt. %). This is give evidence that higher temperature is produce lowest tar production and this condition better for the maintain the gasification process.

Table 14. Composition of Products in Different Temperature Gasifier and Different Airflow Rate

Parameter	Condition I	Condition II	Condition III
Temperature (°C)	400	500	600
Air Flow Rate (L/min)	40	60	80
Moisture Content (wt. %)	2	2	2
H_2 (%vol)	11.59	9.86	9.28
N_2 (%vol)	52.52	54.37	56.03
CH_4 (%vol)	2.57	2.80	2.50
CO (%vol)	21.19	19.44	18.68
CO_2 (%vol)	11.87	13.09	12.76
Tar Concentration (g/Nm^3)	41.34	35.39	24.36

Table 15. Composition of Products in Different Temperature Gasifier and Different Moisture Content

Parameter	Condition I	Condition II	Condition III
Temperature (°C)	400	500	600
Air Flow Rate (L/min)	80	80	80
Moisture Content (wt. %)	2	4	6
H_2 (%vol)	11.59	12.93	14.00
N_2 (%vol)	52.52	51.93	51.32
CH_4 (%vol)	2.57	2.25	2.12
CO (%vol)	21.19	20.89	20.38
CO_2 (%vol)	11.87	11.63	11.90
Tar Concentration (g/Nm^3)	41.34	40.19	31.85

4.4. Effect of Gasification Operating Condition on Tar Quantification

This research studied the fixed condition of moisture content value and the three different conditions of air flow rate. In other words, the producer gas composition and tar formation were affected by the fuel airflow rate, which is one of the most important fuel properties. Variation of airflow rate with an increase between 40 L/min to 80 L/min was observed and indeed it led to the increase in biomass consumption rate. An increasing in the air flow rate contributed more oxygen to oxidize and a greater amount of biomass will get combusted. The energy release will increase to the gasification rate [10]. In this experiment, to quantify the tar compound, we focused in the nine compounds i.e phenol (C_6H_5OH), toluene (C_7H_8), indene (C_9H_8), naphthalene ($C_{10}H_8$), biphenyl ($C_{12}H_{10}$), fluorene ($C_{13}H_{10}$), phenanthrene ($C_{14}H_{10}$), fluoranthene ($C_{16}H_{10}$) and pyrene ($C_{16}H_{10}$), because all of these compounds appeared in every experiment results.

In this experiment tar weight was measured in order to get the tar concentration. The equation of tar concentration as shown in equation as follow:

$$C_t = \frac{W_t}{V_s}$$

Where is C_t is a concentration of tar in producer gas (g/Nm^3), W_t is weight of tar in producer gas (g), and V_s is normal volume of producer gas (Nm^3). In addition, the result of tar concentration among these experiments were calculated and were shown in the **Figure 55**, **Figure 56**, and **Figure 57**.

The effect of moisture content had studied on the value of 2 wt. %, 4 wt. % and 6 wt. % with variation of air flow rate 40 L/min, 60 L/min and 80 L/min respectively, which the result was shown in **Figure 55**, **Figure 56**, and **Figure 57** as follows. Moreover, the moisture content remained constant when the variable of air flow rate changed. In **Figure 55**, **Figure 55**, and **Figure 56** presents, the tar compounds were found in almost all samples. The majority of tar concentration was phenol (C_6H_5OH) due to wood pellet occurred from lignin, cellulose and hemicellulose, which is cellulose and hemicellulose contain much oxygen. In contrast, the tar concentration of toluene (C_7H_8) and indene (C_9H_8) were very low values in every variation of gasification operating condition. In this experiment display from 14 data in different variation of condition, and use standard deviation of every condition in the three rapid ability.

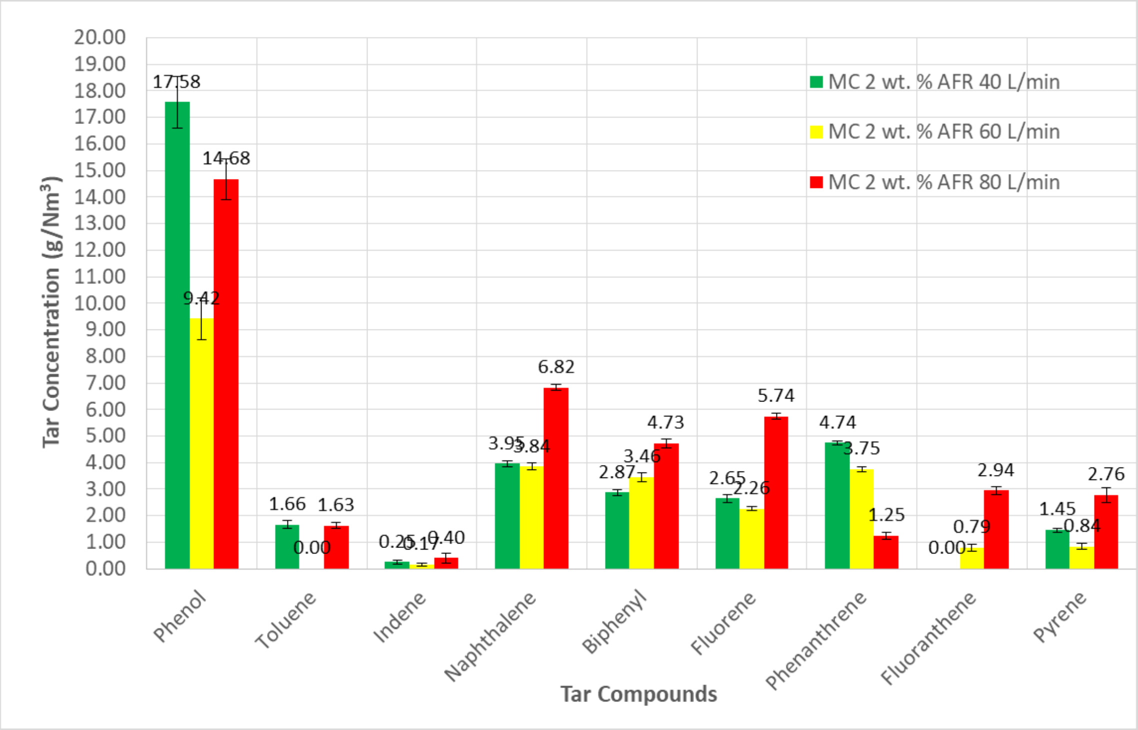

Figure 55. Tar Formation on Moisture Content 2 wt. % with Variation Airflow Rate 40 L/min, 60 L/min and 80 L/min

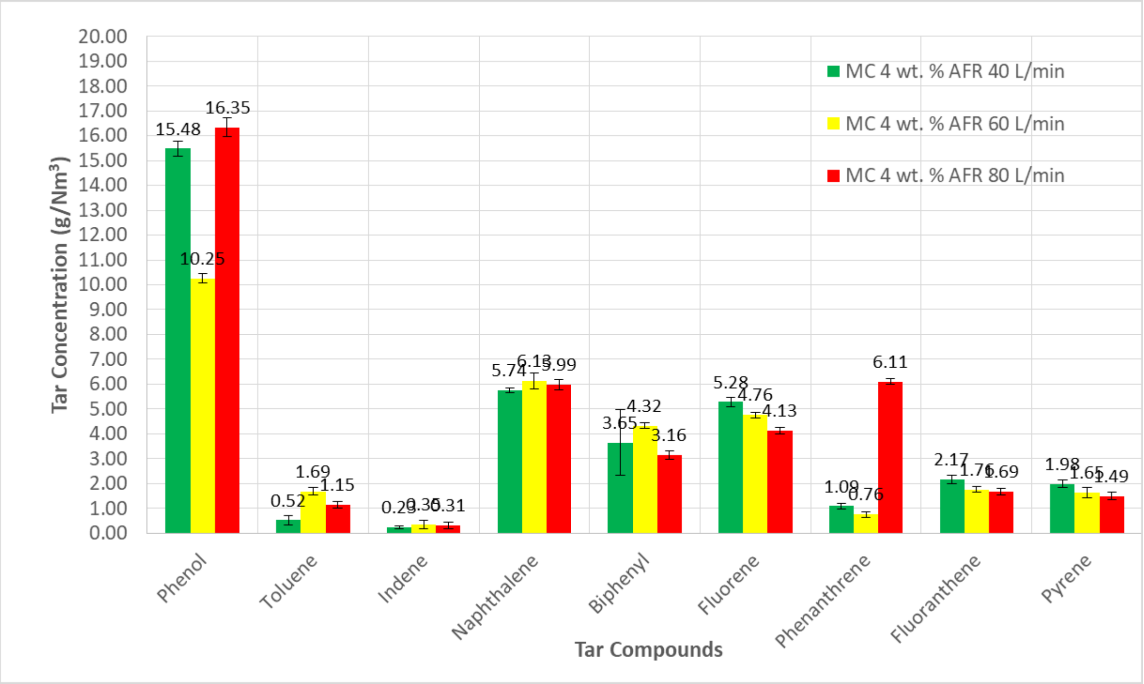

Figure 56. Tar Formation on Moisture Content 4 wt. % with Variation Airflow Rate 40 L/min, 60 L/min and 80 L/min

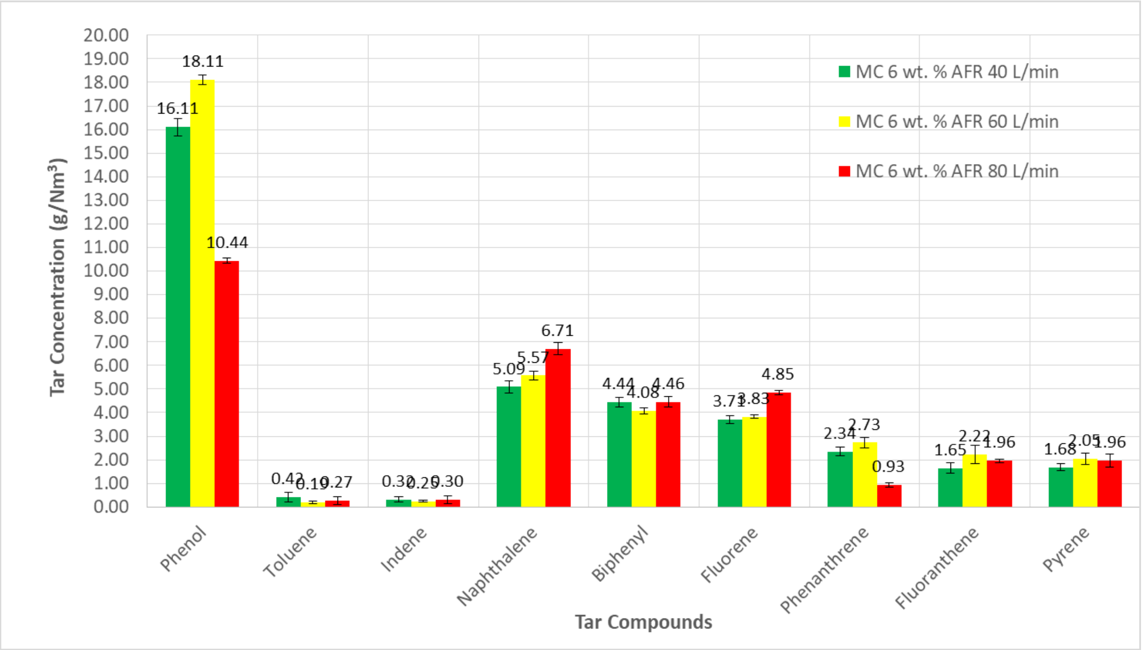

Figure 57. Tar Formation on Moisture Content 6 wt. % with Variation Airflow Rate 40 L/min, 60 L/min And 80 L/min

The highest to smaller of the tar compound in the tar quantification as follows: the highest concentration is phenol, and then naphthalene, fluorene, biphenyl, phenanthrene, fluoranthene, pyrene, toluene and indene.

Most of the four compounds, phenol (C_6H_5OH), naphthalene ($C_{10}H_8$), biphenyl ($C_{12}H_{10}$), fluorene ($C_{13}H_{10}$), were found in the majority concentration in all cases. In this experiment use the range 95% of Confidence Interval (CI) was applied in the Standard Deviation. Phenol (C_6H_5OH) had increased according to increase of moisture content from Moisture content 2 wt. % with tar concentration 9.42 ± 0.78 g/Nm^3 to moisture content 6 wt. % with tar concentration 18.11 ± 0.21 g/Nm^3 in the airflow rate 60 L/min. Naphthalene ($C_{10}H_8$) had a trend increase with increasing of air flow rate from 40 L/min to 80 L/min with tar concentration 3.95 ± 0.12 g/Nm^3 to 6.82 ± 0.11 g/Nm^3 respectively in the airflow rate 2 wt. %. Biphenyl ($C_{12}H_{10}$) in the condition of moisture content 2 wt. % straightly increased with increasing of air flow rate from 40 L/min to 80 L/min with tar concentration 2.87 ± 0.12 g/Nm^3 to 4.73 ± 0.17 g/Nm^3, the condition of moisture content 4 wt. % with tar concentration 3.65 ± 1.33 g/Nm^3 decrease to 3.16 ± 0.17 g/Nm^3 and the same condition in moisture content 6 wt. % with tar concentration 4.44 ± 0.21 g/Nm^3 increase to 4.46 ± 0.23 g/Nm^3. Fluorene ($C_{13}H_{10}$) increased with increasing moisture content from 2 wt. % with tar concentration 2.65 ± 0.15 g/Nm^3 to 5.74 ± 0.11 g/Nm^3 and same condition in moisture content 6 wt. % with value of tar concentration 3.71 ± 0.16 g/Nm^3 to 4.85 ± 0.10 g/Nm^3. This condition, due to the tar composition shifted from phenolic compounds to no substituted Polyaromatic Hydrocarbon (PAH) with the increase of gasifier temperature. Moreover, when the moisture content is up to 6 wt. %, the tar concentration increased because high moisture content makes the combustion in the reactor unsteady [11]. The naphthalene ($C_{14}H_{10}$), biphenyl ($C_{12}H_{10}$), and fluorene ($C_{13}H_{10}$) concentration increased in the tar produced when the higher oxygen content in the moisture content supplied. The overall light polyaromatic compounds in the tar content are comparable when the gasification operating condition, moisture content varying at 2 wt. %, 4 wt. % and 6 wt. %. Since the majority of tar compounds were classified under light polyaromatic compounds, this chemical compound exhibited the high water solubility and led to an increase in temperature.

This experiment with the variation of moisture content on the feedstock and variation of air flow rate in the gasifier is different from the previous experiment which is using $NiFe_2O_4$ oxygen carrier, although the result was almost the same [12]. In this case, small aromatic hydrocarbon i.e. toluene (C_7H_8) existed in a small concentration and light polyaromatic hydrocarbon i.e. indene (C_9H_8) was also in the small amount of concentration. The toluene (C_7H_8) and indene (C_9H_8) were oxidized into small molecular gases, based on the chemical structure of toluene C-C bond and this chemical structure will break the benzene ring with high temperature and generated of amount H_2 and carbon deposition. However, the hydrogen (H_2) yield can be added the composition of H_2 in producer gas production. The same result using $NiFe_2O_4$ oxygen carrier and this experiment is the less minority of tar compound was toluene (C_7H_8), and this compound was avoided due to the tar generated as shown in the chemical reaction below:

$$C_7H_8 \rightarrow C_nH_m + H_2 \ \Delta H > 0$$

Although most of the toluene was in a small concentration and cracked, the free radical generated by the partial breakage of the light hydrocarbon aromatic compound was repolymerized to form a large number of macromolecular compounds (C_nH_m) as called tar compounds deposition.

4.5. Effect of Gasification Operating Condition on Tar Classification

The existence of tar indicated is by the undesirable gasification products and the existence of heavy hydrocarbons with molecular weights higher than benzene [13]. The project of "Primary measures for the reduction of tar production in fluidized-bed gasifier", funded by the Dutch Agency for Research in Sustainable Energy (SDE) had developed the classification of tar based on molecular weight. The project was developed by Energy Research Center of The Netherlands (ECN), Toegepast Natuurwetenschappelijk Onderzoek (TNO) and University of Twente (UT) [14]. **Table 16** shows the molecular weight classification of tar in five classes. The condensing and non-condensing tar division was previously investigated. The condensable tars have been found to cause serious harm, such as filter pores, coke formation and plugging and condensation at cold spots. Therefore, several processes, including cleaning and power generation, have been seriously interrupted. This form of list is listed as pollutants from producer gas [15].

Table 16. Classification of Tar Based on Molecular Weight [13,16]

Tar Class	Property
Class 1	GC undetectable heaviest tars which condense at high temperature and very low concentration
Class 2	Heterocyclic aromatic compounds which are high water solubility such as pyridine, phenol, cresols, quinoline, isoquinoline, and dibenzophenol
Class 3	Light hydrocarbon aromatic compounds (1 ring) which do not cause a problem regarding condensability and solubility such as toluene, ethylbenzene, xylenes, stylene
Class 4	Light polyaromatic hydrocarbon compounds (2–3 rings) which condense at low temperature even at very low concentration such as indene, naphthalene, methylnaphthalene, biphenyl, acenaphtalene, fluorene, phenanthrene, anthracene
Class 5	Heavy polyaromatic hydrocarbon compounds (4–7 rings) which condense at high temperature at low concentration such as fluoranthene, pyrene, chrysene, perylene, coronene

The gasification process was dependent on the quality of tar and its properties and composition. The tar classification was based on class 2, 4, and 5 as the major components of causing the condensation. Those can make the foul the engine and turbine. Hence, the challenge in the producer gas utilization is to remove or to convert class 2, 4, and 5 with the chemical reactions [17]. In this research, we used gasification operating conditions to reduce the production of tar compounds and we determined the nine compounds into several classes. According in **Table 16**, Class 1 on tar classification is a very small compound of concentration and undetectable of Gas Chromatography-Mass Spectrometry (GC-MS). Class 2 is a heterocyclic aromatic compound and included in this class is phenol (C_6H_5OH). Besides, class 3 found toluene (C_7H_8) in light hydrocarbon aromatic compounds, while the involved compound in class 4 is indene (C_9H_8), naphthalene ($C_{10}H_8$), biphenyl ($C_{12}H_{10}$), fluorene ($C_{13}H_{10}$), phenanthrene ($C_{14}H_{10}$) as light polyaromatic hydrocarbon. Lastly, the compound in class 5 is fluoranthene ($C_{16}H_{10}$) and pyrene ($C_{16}H_{10}$) as heavy polyaromatic hydrocarbon.

Figure 58, **Figure 59**, and **Figure 60** displays the tar classification based on molecular weight with fixed moisture content and variations of airflow rate in three different conditions. **Figure 58** shows in the moisture content 2 wt. % indicated class 2 and class 4 are higher amount of tar concentration with the highest tar concentration in 19.07 g/Nm^3 in the air flow rate value of 80 L/min. While in **Figure 59** with moisture content 4 wt. %, we can conclude class 4 has the highest tar concentration with value 19.56 g/Nm^3 on the air flow rate value of 80 L/min and class 4 data had the inclining trend data. Moreover, class 5 had trend the decreased data with the lowest value of 3.20 g/Nm^3 in air flow rate condition 80 L/min. **Figure 60** shows the correlation of moisture content 6 wt. % and the variation of air flow rate. The result showed that the highest concentration was found in class 2 and class 4 with tar concentration 18.11 g/Nm^3 in the air flow rate 60 L/min and 17.21 g/Nm^3 in the air flow rate 80 L/min, respectively. It was found that class 4 on tar classification had the tendency of increasing value, but it was the opposite with the value from class 2, class 3 and class 5.

Due to the chemical reaction in the gasification system, it was shown that in class 4 on tar classification has the highest value caused by the increment of water vapour being set up in wood pellet. Basically, the water content or moisture content in the wood pellet were contained by 7 wt. % and then, it would be constructed into 2 wt. %, 4 wt. % and 6 wt. % for the experiments. The effect of airflow rate on tar concentration had investigated. In fact, a relationship between total concentrations of Polyaromatic hydrocarbon indicated that the rising value of airflow rate was significant on the rising concentration of PAH in class 4 and class 5. From this result, this experiment gave the evidence to show that the lowest moisture content produced the lowest tar concentration and it is a good condition to drive the engine and another machine.

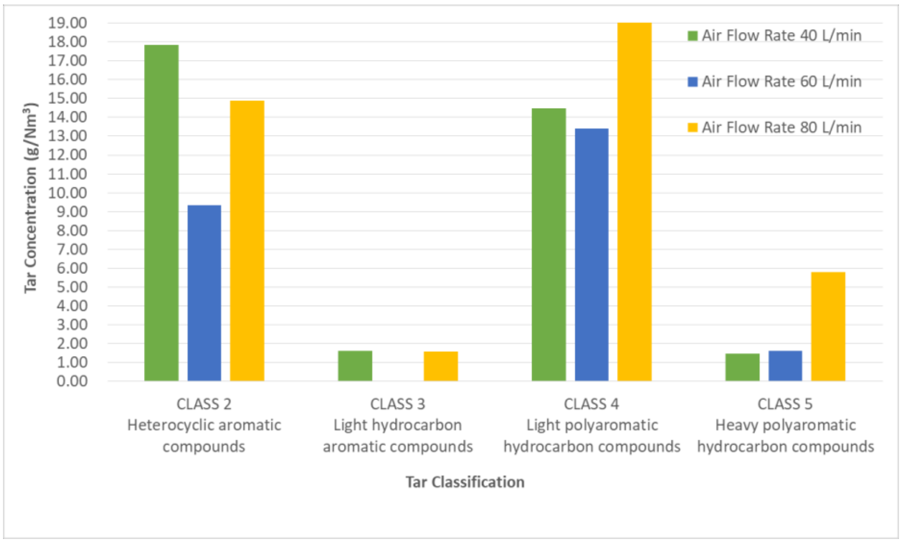

Figure 58. Tar Classification Based on Molecular Weight with Moisture Content 2 wt. % in Variation of Airflow Rate 40 L/min, 60 L/min, 80 L/min

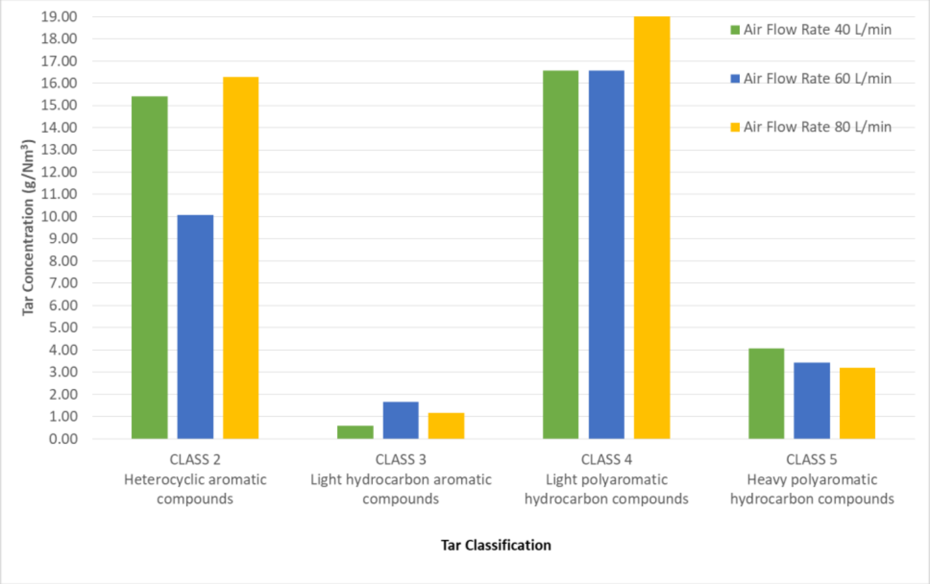

Figure 59. Tar Classification Based on Molecular Weight with Moisture Content 4 wt. % in Variation of Airflow Rate 40 L/min, 60 L/min, 80 L/min

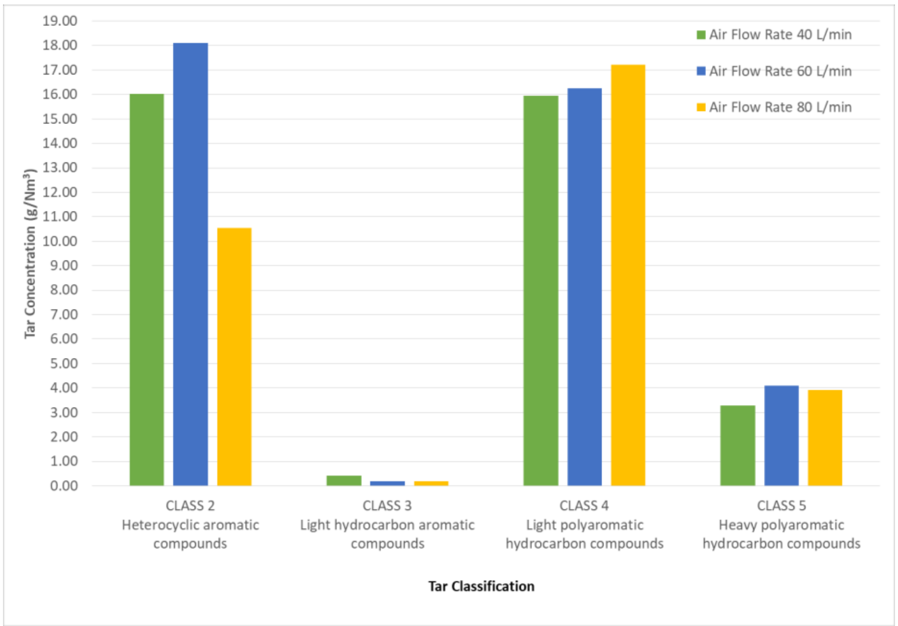

Figure 60. Tar Classification Based on Molecular Weight with Moisture Content 6 wt. % in Variation of Airflow Rate 40 L/min, 60 L/min, 80 L/min

4.6. Effect of Gasification Operating Condition on Light Tar and Heavy Tar

Based on **Table 13** in the chemical reaction mechanism from gasification. In general tar reaction mechanism in tar mainly happen occurs due to tar formation, in the steam reforming, dry reforming and thermal cracking. In steam reforming reaction mechanism (reaction R13) the high temperature and H_2O needed to crack the tar (C_nH_m) and will produce the syngas in H_2 and CO. In the Dry reforming mechanism reaction which is reaction with CO_2 (reaction R14) make the increasing of production CO and H_2 in the process of gasification. Additionally, in the Hydrogen and Thermal Cracking reaction mechanism (reaction R15 and R16) the tar (C_nH_m) will produce methane (CH_4) in the high temperature.

Many researcher used tar compounds as the tar model, in this experiment the parameter is phenol because it's almost the highest concentration in every experiment.

During dry reforming reaction with CO_2, and thermal cracking produce phenol compounds and other 8 compounds around 60% from total tar compounds. Tar compounds was classify with 90 percent identical in total ionic carbon (TIC) and analysis with nine tar compounds standard. The temperature in this experiment around 400 ºC to 600 ºC.

While tar is a major issue lately, tar terminology is not clearly defined. Similar compounds with a molecular weight of more than 78 (benzene) may be classified as tar compounds according to Maniatis et al. [18]. A gas chromatography technique was used to measure the tar sample and the tar formation was achieved. The work has been focused on the nine tar compounds such as phenol, toluene, indene, naphthalene, biphenyl, fluorene, phenanthrene, fluoranthene, and pyrene. This research focused on the 9 tar compounds, all of which were found in the results of each experiment. **Table 17** shows these nine tar compounds.

Table 17. The Nine Tar Compounds in Biomass

Compound	Chemical Formula	Molecular Weight (g/mol)	Boiling Point (°C)
Phenol	C_6H_5OH	94.11	181.7
Toluene	C_7H_8	92.14	110.6
Indene	C_9H_8	116.16	181.6
Naphthalene	$C_{10}H_8$	128.17	218
Biphenyl	$C_{12}H_{10}$	154.21	255
Fluorene	$C_{13}H_{10}$	166.22	295
Phenanthrene	$C_{14}H_{10}$	178.23	336
Fluoranthene	$C_{16}H_{10}$	202,26	375
Pyrene	$C_{16}H_{10}$	202.25	404

There is an active study of a method for analyzing the tar classification of biomass gas. This analysis sought to divide the price category into two categories, including heavy and light tar. Light tar consists primarily of aromatic and phenol composites that are volatile and semi-volatile, while heavy tar comprises non-volatile polar compounds. A capillary gas chromatography (GC) column could pass through light tar while heavy tar might damage equipment operation. Zhang et al. indicate that gas chromatography can be used to determine the differentiated price classification based on molecular weight [19].

Syngas / producer gas and tar were created by biomass gasification, although the high moisture content of feedstock was difficult to flame. Its gasification led to low gas yield and increased tar production. The higher moisture content of the downdraft gasifier reduced the temperature of the reaction zone and resulted in the gasifier depositing tar. Tar was divided into light tar and heavy tar with phenol as the standard parameter in the experiment. Included as light tar are the compounds with a lower molecular weight than the phenol. Otherwise they are used as heavy tar if the chemical compounds are more molecular than phenol.

The light tar and heavy tar formation in the biomass gasification cycle with variations in moisture content is demonstrate in **Figures 61**, **Figure 62**, and **Figure 63**. The formation of tar in moisture 2 wt. % was shown in **Figure 61**. Similar tests indicate a percentage with an air flow rate of 80 L / min. The tar level of light tar is 13.18 g/Nm^3, equivalent to 15.70% of the total tar. The concentration of heavy tar is 70.77 g/Nm^3, equivalent to 84.30 % of 83.95 g/Nm^3. The tar grade with a moisture content of 4 wt. % is shown in **Figure 62**. Which is 2.81 g/Nm^3, equivalent to 3.42 % of light tar percent. Heavy tar is 79.41 g / Nm^3, which corresponds to 96.58 % of the total 82.22 g / Nm^3 concentration. The parameter with a moisture content of 6 wt. % is shown in **Figure 63**. In the **Figure 63** show 1.55 g/Nm^3 or 2.16 % for the light tar concentration and the heavy tar is 70.32 g/Nm^3 or 97.84 % from the total of 71.87 g/Nm^3. This finding indicates that light tar production has dropped, along with an increase in moisture content, while heavy tar production increase in the higher moisture content. This indicates that the feedstock with humidity or moisture content of 2 wt. % is produce the lowest of heavy tar. The lowest heavy tar production in the percentages production of total tar is better for the bio gasification process**.** Greater heavy tar output leads to substantial failure and valve connection and decreases the operating system's efficiency with biomass. Compared with heavy tar, light tar was much easier burnt. This was due to light tar's more volatile chemicals including hydrocarbon compounds. The much light tar production compare then heavy tar production is more economical in the gasification process and power plant production.

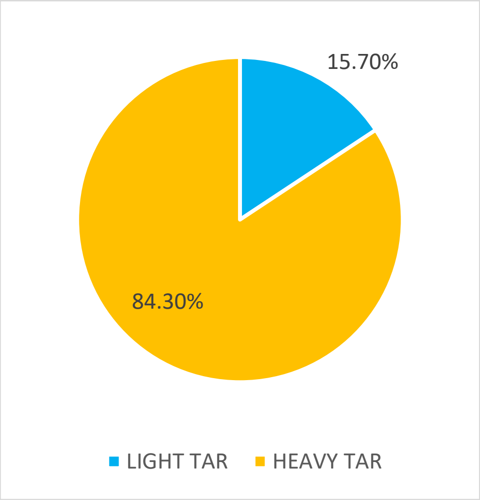

Figure 61. Tar Formation in Light Tar and Heavy Tar in Moisture Content 2 wt. %

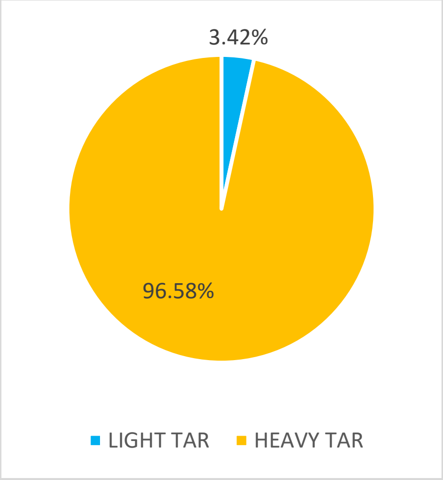

Figure 62. Tar Formation in Light Tar and Heavy Tar in Moisture Content 4 wt. %

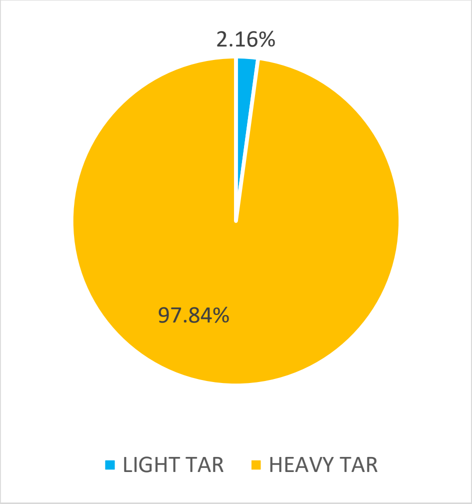

Figure 63. Tar Formation in Light Tar and Heavy Tar in Moisture Content 6 wt. %

4.7. Effect of Gasification Operating Condition on Tar Density

A recent problem solution in tar subject had been introduced on the study of tar protocol. The tar protocol includes standardized methods for sampling and analyzing tar from gasification plants. The tar protocol guideline contributes to the alternatives of the gravimetric method and gas chromatography to identify the compound. The analysis from gas chromatography with the former is widely implemented in the study of tar gasification.

Gravimetric determination of tars is done by distillation of solvent i.e., acetone and evaporation of tar compounds by temperature evaporate [20,21].

In this experiment, we used a gravimetric analysis method to measure the tar density. The principle of gravimetric is the distillation process to evaporate the solvent with the boiling condition. In this case, 3 grams mixture of tar sample and acetone is heated for 5 hours with temperature 65 °C because the boiling point of acetone is 56 °C to separate tar sample from other compounds and the entire all acetone will evaporate, just only a mass of pure tar in residue and this condition can be defined tar density.

To define tar density, the first step that must be done is to calculate the total amount of tar in producer gas use the equation as follows:

$$vol_{tar} = FR_{\ producer\ gas} . t_{producer\ gas}$$

The variable of vol_{tar} is volume of tar in total amount producer gas in sampling (L), and $FR_{\ producer\ gas}$ is flow rate of producer gas in tar sampling (L/min) and $t_{producer\ gas}$ is sampling time of producer gas (min),

For tar density in producer gas can determine using equation as follow:

$$\rho_{tar} = \frac{m_{tar}}{vol_{tar}} 1000$$

Where is ρ_{tar} is tar density in producer gas (mg/m^3), m_{tar} is a mass of tar in producer gas in the sampling (mg), and vol_{tar} is volume of tar in total amount producer gas in the sampling (L).

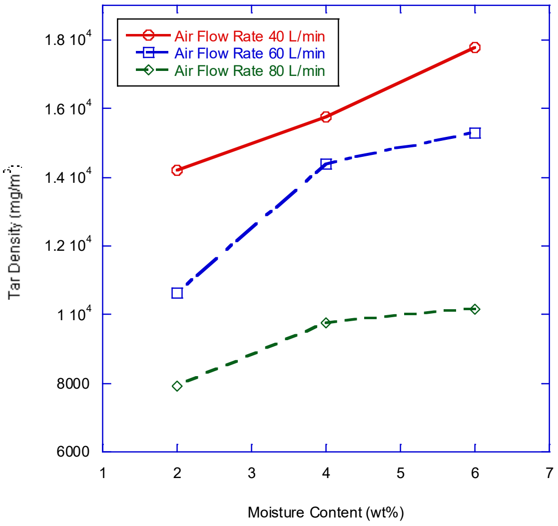

Figure 64. Moisture Content vs Tar Density

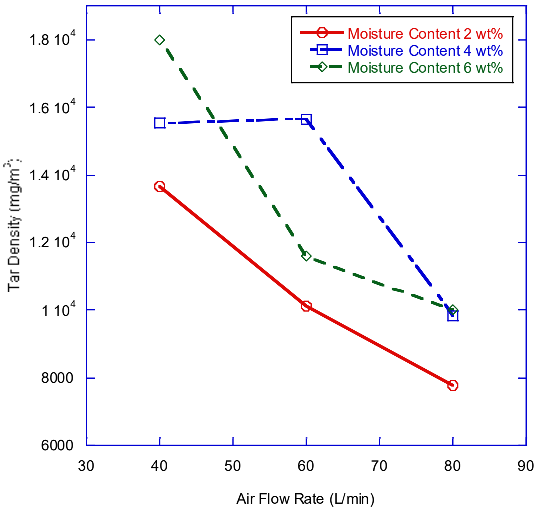

Figure 65. Airflow Rate vs Tar Density

Those **Figure 64** and **Figure 65** exhibit the result of gravimetric analysis for wood pellet in biomass system. **Figure 64** indicated when the air flow rate 40 L/min and the moisture content 2 wt. %, tar density value reached in the lowest value of 14202.3 mg/m^3. This value gradually increased when the moisture content reached until 6 wt. % and the tar density in producer gas attained 17786.2 mg/m^3 on the same condition of air flow rate.

Besides, when the condition of air flow rate remained stable on 60 L/min, the tar density achieved 10621.6 mg/m^3 with moisture content of 2 wt. % and this value increased up to 14386.4 mg/m^3 in moisture content 4 wt. % and then, it raised into 15288.1 mg/m^3 in moisture content of 6 wt. %. It can be told that the air flow rate on the stable value of 80 L/min, the tar density value raised with the increasing of moisture content value. For the moisture content 2 wt. %, the tar density value is 7928.4 mg/m^3 and the increasing of moisture content 6 wt. %, the tar density value is 10170.8 mg/m^3. Ultimately, the changing of tar density was affected by rising moisture content. The lowest value of moisture content will reach the minimum amount of tar density.

Figure 65 exposes the gravimetric analysis correlation between air flow rate and tar density. It found that the moisture content 2 wt. %, in air flow rate 40 L/min, the amount of tar density was 13645.6 mg/m^3 and it decreased into 10123 mg/m^3 and 7772.5 mg/m^3 in the condition of air flow rate 60 L/min and 80 L/min, respectively. The value on the condition of moisture content 4 wt. %, the tar density 15549 mg/m^3 in air flow rate 40 L/min, and it remained constant in 15650 mg/m^3 in air flow rate 60 L/min. This value dropped into 9829.5 mg/m^3 of tar density in air flow rate 80 L/min. In addition, the condition for moisture content 6 wt. % and air flow rate 40 L/min, the tar density gained into 17984 mg/m^3. It decreased quickly up to 11615 mg/m^3 in air flow rate 60 L/min, and finally, it decreased into 10005 mg/m^3 in air flow rate 80 L/min. This condition occurred because the temperature in the inside of the gasifier was uniform. Moreover, it made the tar density had a decreasing value in a higher air flow rate value. This experiment revealed that to make a tar reduction using lower moisture content of feedstock and the gasification process was executed in a higher air flow rate.

4.8. Effect of COV- Indication of Mean Effective Pressure (IMEP) & Combustible Rate on Internal Combustion Engine

The process of biomass gasification will occur in the gasifier and will drive on R-ICE had been conducted using various types of gas, such as city gas, mixing between city gas and syngas/producer gas, syngas/producer gas, and mixing between syngas/producer gas and hydrogen. The current experiment found that Indication of Mean Effective Pressure (IMEP) parameter has a relation with the combustible rate. The IMEP is an average quantity relating to the operation of the R-ICE and measuring on an engine's capacity and necessary to estimate the indication of torque in R-ICE and contribute an important report of mechanical efficiency [22]. Also, since the torque is divided by the engine capacity, the IMEP parameter can be used to compare the internal combustion engine of different displacement. IMEP calculated from in-cylinder pressure over compression and expansion portion of an engine cycle in 360° in a four-stroke or 180° in a two-stroke.

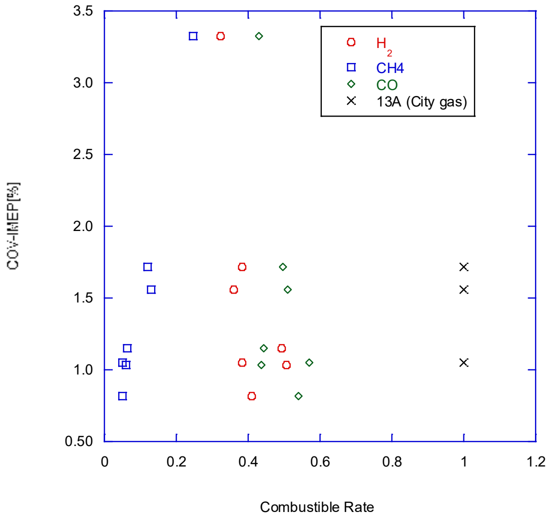

Figure 66. Combustible Rate vs COV-IMEP

The effect of producer gas composition in flammable gas such as H_2, CH_4 and CO can be seen from the **Figure 66** that the trend of combustible rate versus COV-IMEP for the CH_4 gas the combustible increased while combustible rate increased, besides that for inclined H_2 gas and CO gas the effect of combustible rate is declined, and for 13A (city gas) the increased COV-IMEP, the combustible rate of 13A (city gas) remained constant. The result from the figure shown that the highest combustible rate was achieved on 13A (city gas) because of the calculated pressure was the highest.

Different fuels need a different amount of air to create expected air-gas mixtures which can be burned in an engine. Thus, the calorific value of an air-gas mixture, the flammability limits, and the flame speed of combustible rate, are the next important parameters to, consider.

In this study, the first point of interest in evaluating the validity of the producer gas fuel as a suitable fuel for R-ICE engine was to obtain stable combustion at a given intake air to fuel ratio. Once stable combustion was achieved, the fuel flow was changed (and the ignition timing was adjusted) therefore varying the mixture equivalence ratio to determine an affective lean operating limit.

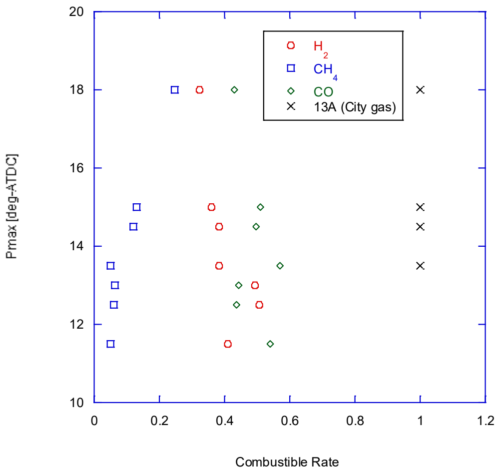

Figure 67. Combustible Rate vs Pmax Position

Figure 67 reveals that there has been a gradually increased on combustible rate, while the Pmax was increased too for CH_4. Besides that, for inclined H_2 gas and CO gas, the effect of Pmax are declined, and for 13A (city gas) the increased Pmax, the combustible rate of 13A (city gas) remained constant. This matter was caused by heaviness of molecular weight for CH_4 heavier than another gas compound.

4.9. Effect of Burn Duration on Internal Combustion Engine

The percentage of Burn Duration for 0-10% achieved the highest rate for city gas with increasing on Maximum In-Cylinder Pressure; this condition occurs because of the increasing of pressure. While the Burn Duration for 10-90% was likely to increase for city gas and reached the highest value, this statement figured out in **Figure 68** and **Figure 69**. It can be caused by the flammability of city gas was higher than the other gas.

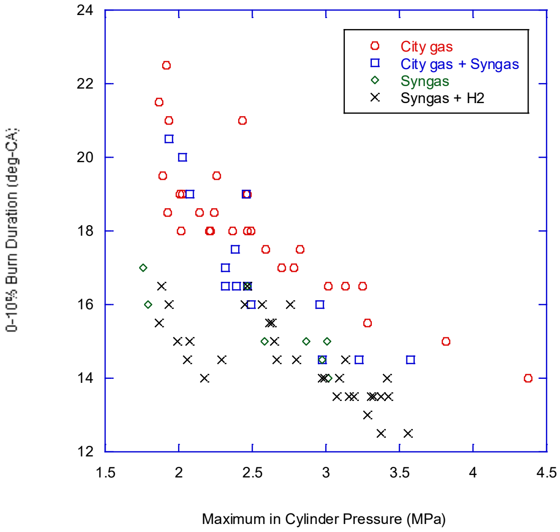

Figure 68. Maximum in Cylinder Pressure vs 0-10% Burn Duration

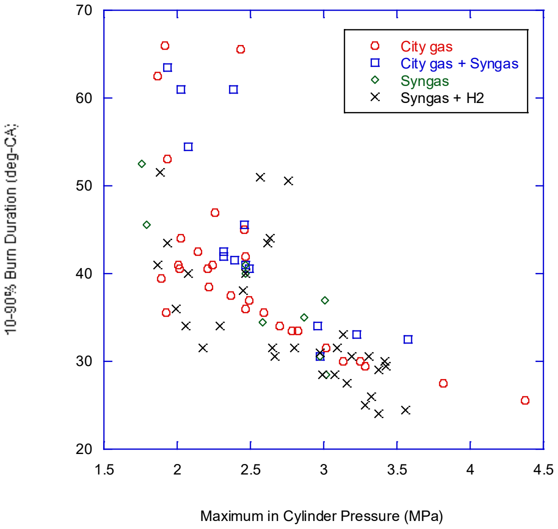

Figure 69. Maximum in Cylinder Pressure vs 10-90% Burn Duration

4.10. Effect of Air Excess Rate (AER) on Internal Combustion Engine

Figure 70 shows that when the condition of Air Excess Rate (AER) is less than 1, the condition is called rich, which means the composition of fuel is larger than air. This condition happens in the city gas. Meanwhile, the value of Air Excess Rate (AER) is more than 1, and the condition called lean, so the composition of fuel is smaller than air, which happens on syngas, mixing between syngas and H_2, mixing between city gas and syngas, and syngas. The value of Air Excess Rate (AER) did not effect on the Indication of Mean Effective Pressure (IMEP) because the value of IMEP measurement varies from small to a large value.

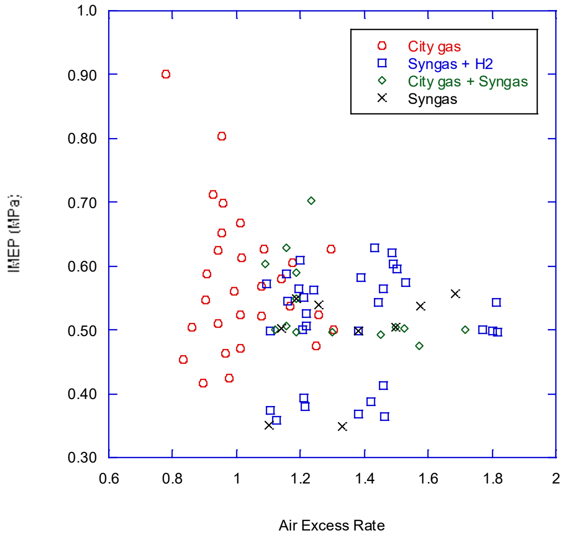

Figure 70. Air Exces Rate vs IMEP in All Fuel

Cylinder pressure information can be used to consider the work transfer from the gas to the piston. This is generally expressed as the indicated mean effective pressure (IMEP) and is a measure of the work output for the swept volume of the engine. The result is an essential parameter for definitive engine efficiency as it is independent of speed, number of cylinders, and displacement of the engine. The IMEP prediction is basically the enclosed area of the high-pressure part of the Pressure (P) – Volume (V) diagram and can be derived via integration:

$$IMEP = \int P\,dv$$

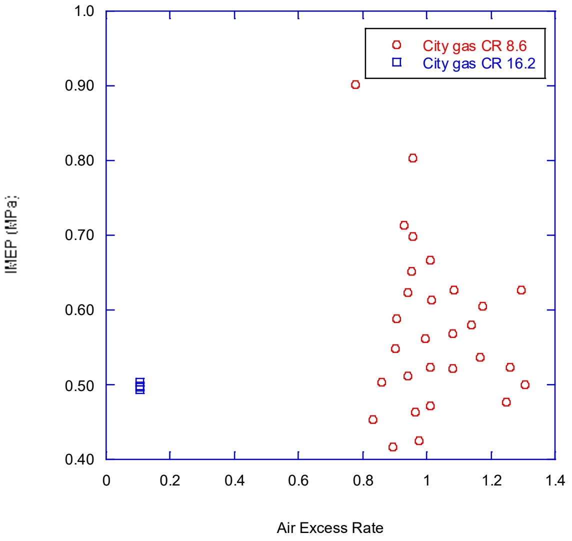

Figure 71. Air Excess Rate vs IMEP in City Gas

The compression ratio is the ratio of the volume of the cylinder and the combustion chamber when the piston is at the bottom dead center, and the volume of the combustion chamber when the piston is at the after top dead center. The Automotive engine can improve fuel efficiency and fuel economy by designing engines with high compression ratio. From **Figure 71** we can see that the inclining value of compression ratio on engine FD750 with compression ratio (CR) 8.6 and the air excess rate (AER) became greater than 0.8, otherwise, the declining value of compression ratio on engine D905D with compression ratio (CR) 16.2 the Air Excess Rate (AER) and IMEP become lower than 0.8 so that the fuel composition is relatively reduce. It can be seen from the obtained result that the Air Excess Rate (AER) are greatly influence on the IMEP. Moreover, the decreasing of IMEP will effect of increasing the Air Excess Rate (AER), because of the low Air Excess Rate, IMEP decreases almost linearly, than IMEP falls with non-linear behaviour.

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CHAPTER 5. SUMMARY AND FUTURE WOKS

5.1. Brief Introduction

In order to reduce the dependence of non-renewable energy sources, biomass gasification is a promising technology for improving the global green energy system. During biomass gasification, tar formation generates a serious problem, creating high operational costs and reducing the system performance. Tar is a mixture of five-ring hydrocarbons, including aromatic compounds, oxygenated as Polycyclic Aromatic Hydrocarbon content (PAH). There have been significant attempts to classify and interconnect all of the tar components. A number of researchers tried to put tars into various groups and to observe their behavior. In this present work, tar is examined as all organic contaminants with a molecular weight larger than benzene. Instead of reactivities based on molecular weight, this classification is mainly based upon the solubility and condensability of various tar compounds and divided into 5 classes; there are class 1 (GC undetectable), class 2 (heterocyclic aromatic compounds), class 3 (Light hydrocarbon aromatic compounds), class 4 (Light polyaromatic hydrocarbon compounds) and class 5 (Heavy polyaromatic hydrocarbon compounds).

This research has produced a new tar classification for tar-based on phenol molecular weight. Light tar has a molecular weight lower than phenol. Otherwise, heavy tar has a molecular weight more than the molecular weight of phenol. Compared to heavy tar, the light tar was burning much better. More about heavy tar output leads to a large failure and valve link, which lower the biomass operating system efficiency.

Due to the fact that tar characteristics have many parameters including tar density, tar classification and tar quantification, those parameters that have commonly calculated beneficial for the optimal production. Tar quantification can be determined as quantification of tar for each tar compound, which calculated as a result of the GCMS in producer gas. Tar classification is the classified tar with many parameters used in this research use tar classification based on the molecular weight in 5 classes insolubility. The new parameter of tar classification has been introduced in this research, which is use the molecular of phenol as a parameter to classify tar compound, in the light tar and heavy tar. On the other side, the main goal of this experiment is to determine the optimal production of producer gas with low tar density, use the wood pellet as feedstock.

5.2. General Conclusion

The aim of this research is to determine the optimal production of low tar density in producer gas using wood pellets feedstock in a downdraft gasifier system. The experiments had been conducted under the variation of gasification operating conditions. In order to ensure effective gasification performance and to contain the negative effect of the producer gas heating value, the balance of producer gas and energy conversion qualities should be lowered the moisture content at least 20 - 25 wt. %, and the ignition becomes difficult in case the value of the moisture content is more than 8 wt. % in cedar wood pellet. Therefore, the effective value of moisture content for this research was chosen between 2 wt. % until 6 wt. %. The airflow rate is around 40 L/min, 60 L/min and 80 L/min to supply air in the gasifier system. The range of 40 L/min to 80 L/min was chosen to maintain the temperature inside the gasifier between 400 ^{o}C - 600 ^{o}C and optimize the system performance. The gasifier produces "clinker" in the more than 600 ^{o}C temperature. Clinkering occurs in the biomass gasification process inside of the gasifier when ash melt and fuses into a hard and glassy slag. It also happens when ash is a noncombustible powder residue left over after the wood pellet has burnt. This clinker sometimes blocks the feed movement and causes a discontinuity in the operation of the gasifier. Several conclusions can be made as follow:

1. In the gasification process produce gaseous fuel as "producer gas". Gasification operating conditions influenced the yield of producer gas, with the parameter of moisture content and airflow rate. It revealed that the decrease in moisture content affected the increase of combustible gas production (H_2, CO, and CH_4) and the decrease of carbon dioxide (CO_2). The effective value of the airflow rate was achieved on the number of 80 L/min, and this value reached the highest concentration of the total combustible gas of producer gas production. The amount of inflammable gas was found in the producer gas as follows CH_4, CO, and H_2 with the result around 2-3 %vol, 17-22 %vol, 12-20 %vol, respectively. This result is in accordance with the statement of S.C Bhatia.
2. This experiment executes the result of Shimadzu GC-MS QP2010 Plus to identify the tar composition from tar sampling in 2 ml vial bottle as well as the existence of phenol, toluene, indene, naphthalene, biphenyl, fluorene, phenanthrene, fluoranthene, and pyrene. Furthermore, GC Postrun was used for analysing data from GCMS to identify tar compounds in the sample. The highest to smaller of the tar compound in the tar quantification as follows: the highest concentration is phenol, and then naphthalene, fluorene, biphenyl, phenanthrene, fluoranthene, pyrene, toluene, and indene. The result showed that the phenol compounds are the highest in tar concentration. On the other side, the indene is the lowest in the tar concentration in the tar quantification.
3. In the tar classification based on molecular weight show that the class 2 (heterocyclic aromatic compounds) and the class 4 (Light polyaromatic hydrocarbon) is the highest in the concentration, and the class 3 (Light hydrocarbon aromatic

compounds) is the lowest. Class 3, such as toluene do not cause a problem regarding condensability, and class 4, have typically at low temperature and very low concentration. This experiment gave the evidence to show that the lowest moisture content produced the lowest tar concentration, and it is a good condition to drive the engine and another machine.

4. This result shows that the production of light tar decreased along with an increase in moisture content, while the heavy tar increased along with an increase in moisture content. This is the evidence to show that the lowest moisture content of 2 wt. % is better for the biomass gasification process due to a lower yield of heavy tar. The light tar was much more easily burnt compared to the heavy tar. This was due to the more volatile chemical composition of light tar, such as the hydrocarbon compounds. The increase in moisture content resulted in heavy tar, which reduced the temperature of the reaction zone and led to the deposition of tar in the gasifier. In consequence, the existence of heavy tar caused the extensive failure and plugging of the valve, reducing the performance of the biomass operating system.
5. Gravimetric analysis is a technique using a tar sample to analyze and determine the density of a tar compound. The Tar density can be described by the total volume of tar in producer gas derived from the Gravimetric analysis. In these experiments, the acetone in the tar sample was evaporated to get the pure mass of the tar compounds by IRIS OHYAMA (dryer-evaporation machine) and set to a temperature of 65 °C. Finally, with a tar-weight measuring machine (Chyo JL-200), the pure weight of the tar compounds was measured, and the sensitivity was 0.1 mg. The lowest amount of tar density was formed for the condition with the highest air flow rate (80 L/min) and lowest moisture content (2 wt. %). This is because the lowest moisture content and the highest air flow rate made the temperature in the gasifier in the uniform

condition and make the combustion perfectly, and all of the feedstock burned. The lowest tar density is better to drive the engine and avoid the gasifier system from the failed operation.

5.3. Recommendations for the future works

The gasification process significantly influenced tar characteristics. This study examined the effect of moisture content and flow rate on tar characteristics and define in the tar quantification and tar classification. When the moisture content increased, the tar concentration of the phenol compound decreased. The phenol is included in the heterocyclic aromatic compound due to the existence of lignin, cellulose, and hemicellulose in the wood pellet, which contains much oxygen. Moreover, the tar concentration of toluene and indene decreased. The increase in moisture content resulted in heavy tar, which reduced the temperature of the reaction zone and led to the deposition of tar in the gasifier. In consequence, the existence of heavy tar caused the extensive failure and plugging of the valve, reducing the performance of the biomass operating system. Furthermore, the increase in moisture content initially increased the tar density, which led to the failure of the gasification process. In contrast, the lowest moisture content produced lower tar density, which is good for the gasification operating process, with the condition of future works below. We can continue the research to identify the effect of tar in any condition and having results in the tar compound and can be classified with the many parameters. Such as classification of tar-based on appearance, classification of tar-based on reactive and non-reactive in burning time, measuring tar deposition in the gasifier equipment tool, etc.

The condition of future work as follows:

1. The gasification process uses a variation of size and variation of shape from wood pellet feedstock, or with palm oil pellet feedstock.

2. The gasification process uses a variation of temperature to justify exactly clinker formation in the gasification process.
3. The gasification process uses a variation of catalyst to reduce tar production in producer gas.

APPENDIX 1. LIST OF PUBLISHED PAPERS

Journal Papers:

[1] Rizqi Fitri Naryanto, Hiroshi Enomoto, Noburu Hieda, Yoshikazu Teraoka, Chuntima Chunti, Reiji Noda, *The Influence of Wood Pellet Feedstock Water Content on Tar Component in Biomass System Using Downdraft Gasifier*, Journal of The Japan Institute of Energy, pp. 115-118, 4 pages, published, Vol 98, Issue 5, May 2019. https://doi.org/10.3775/jie.98.115

[2] Rizqi Fitri Naryanto, Hiroshi Enomoto, Anh Vo Cong, Kazuki Fukadu, Zheng Zong, Mera Kartika Delimayanti, Chuntima Chunti, Reiji Noda, *The Effect of Moisture Content on The Tar Characteristic of Wood Pellet Feedstock in a Downdraft Gasifier*, Applied Sciences, 12 pages, published, vol. 10, issue 8, April. 2020, 2760; doi:10.3390/app10082760.

Conference paper:

[1] Rizqi Fitri Naryanto, Hiroshi Enomoto, Noburu Hieda, Yoshikazu Teraoka, *Numerical Simulation with Discrete Phase Model of Fixed Bed Reactor for a Small Combustion Engine*, Proceeding of 23rd Small Engine Technology Conference "Small Engine Technology Generating A Promising Future", November 15th-17th, 2017, Jakarta, Indonesia, 1 pages, published

[2] Rizqi Fitri Naryanto, Hiroshi Enomoto, Noburu Hieda, Yoshikazu Teraoka, Chuntima Chunti, Reiji Noda, *The Influence of Wood Pellet Feedstock Water Content on Tar Component in Biomass System Using Downdraft Gasifier*, Proceeding of 6th Asian Conference on Biomass Science, July 31th, 2018, Bogor, Indonesia, pp. 23-26, 4 pages, published.

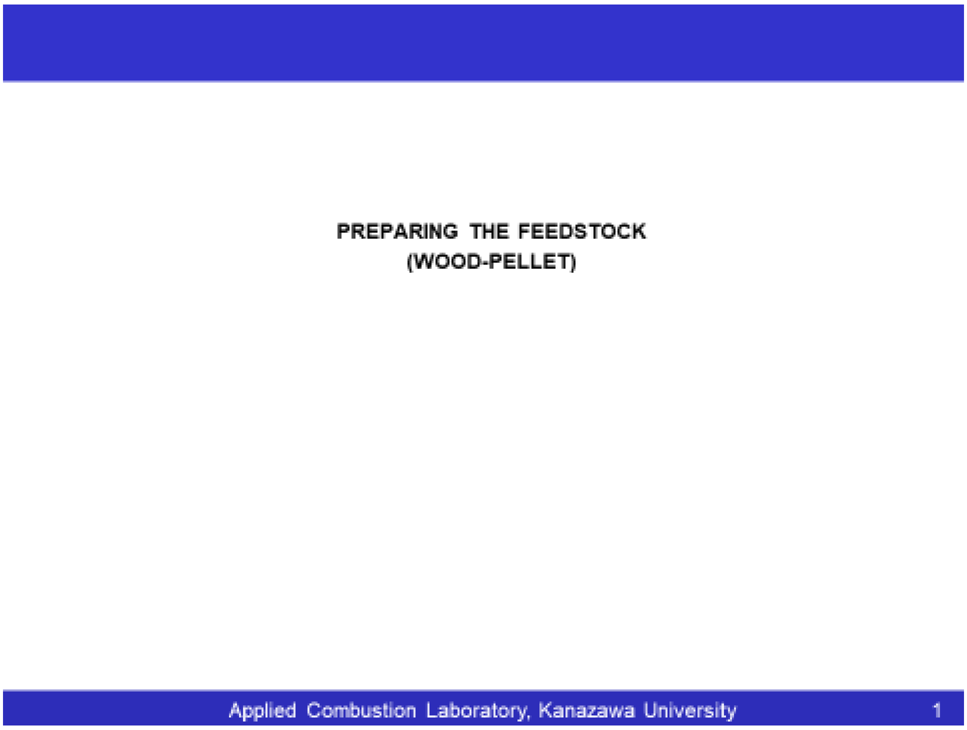
[3] Rizqi Fitri Naryanto, Hiroshi Enomoto, Vo Cong Anh, Chuntima Chunti, Reiji Noda, *Effect of Tar Formation on Biomass Downdraft Gasification Reactor of Wood Pellet with Variation of Moisture Content*, Proceeding of 14th Biomass Science Conference, January16th-18th, 2019, Hiroshima, Japan,
pp. 39-40, 2 pages, published.

[4] R F Naryanto, H Enomoto, VC Anh, K Fukadu, S Iwai, and R Noda, *Investigation of producer gas biomass gasification on reciprocated internal combustion engine*, Proceeding of International Conference of Biomass and Bioenergy 2019, August 19th-20th, 2019, Bogor, Indonesia, 8 pages, Under review in IOP Conference Series Scopus Index. IOP Conference Series: Earth and Environmental Science doi:10.1088/1755-1315/460/1/012016, https://iopscience.iop.org/issue/1755-1315/460/1

[5] Anh Vo Cong, Hiroshi Enomoto, Rizqi Fitri Naryanto, Kazushi Fukadu, Zheng Zong, Chuntima Chunti, and Reiji Noda, *Major Tar Compounds in Raw Producer Gas and Deposits from a Small Downdraft Gasifier: Analysis and Comparison*, BioResources, pp.1773-1790, 18 pages, published, Vol 15, Issue 1, February 2020.

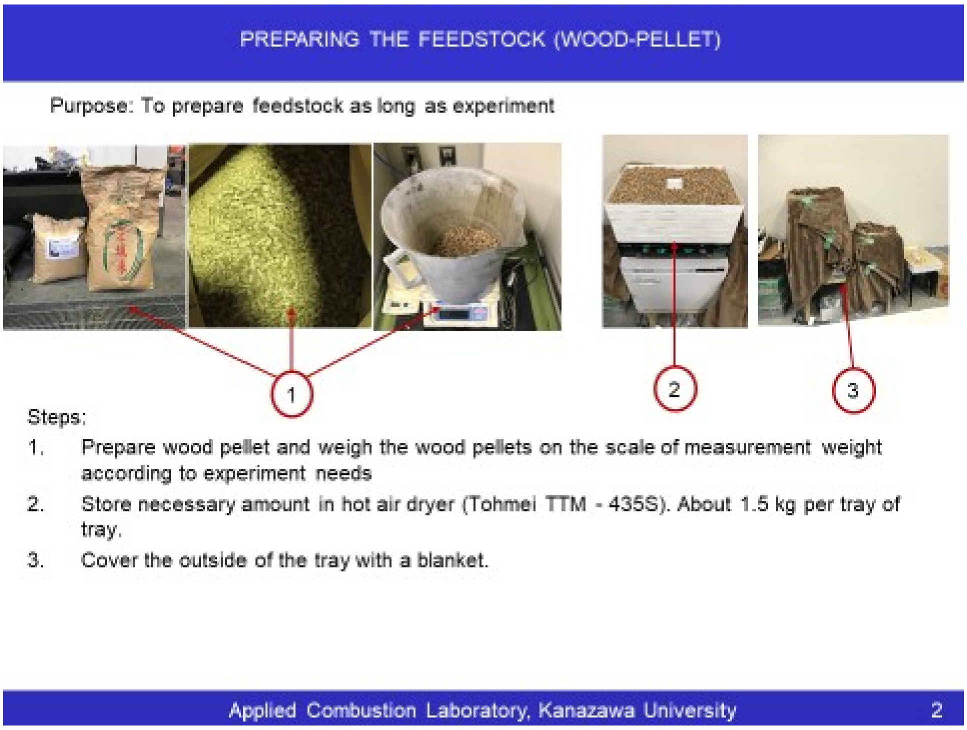
APPENDIX 2. EXPERIMENT PROCEDURE

PREPARING FEEDSTOCK



PREPARING THE FEEDSTOCK
(WOOD-PELLET)

Applied Combustion Laboratory, Kanazawa University 1



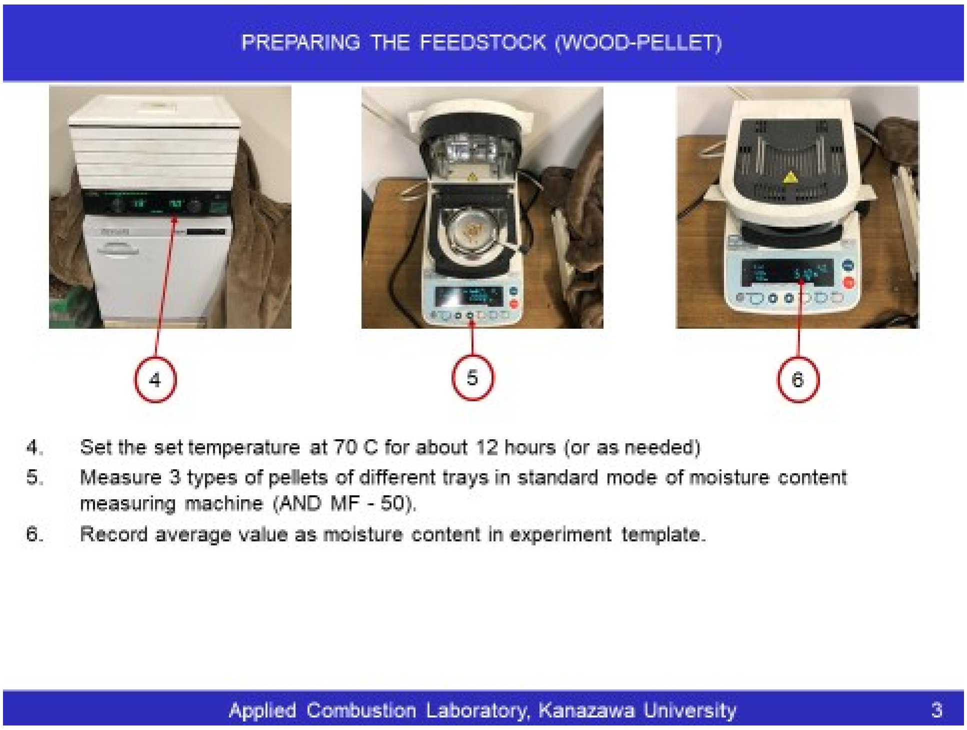
PREPARING THE FEEDSTOCK (WOOD-PELLET)

Purpose: To prepare feedstock as long as experiment

Steps:

1. Prepare wood pellet and weigh the wood pellets on the scale of measurement weight according to experiment needs
2. Store necessary amount in hot air dryer (Tohmei TTM - 435S). About 1.5 kg per tray of tray.
3. Cover the outside of the tray with a blanket.

Applied Combustion Laboratory, Kanazawa University 2



PREPARING THE FEEDSTOCK (WOOD-PELLET)

4. Set the set temperature at 70 C for about 12 hours (or as needed)
5. Measure 3 types of pellets of different trays in standard mode of moisture content measuring machine (AND MF - 50).
6. Record average value as moisture content in experiment template.

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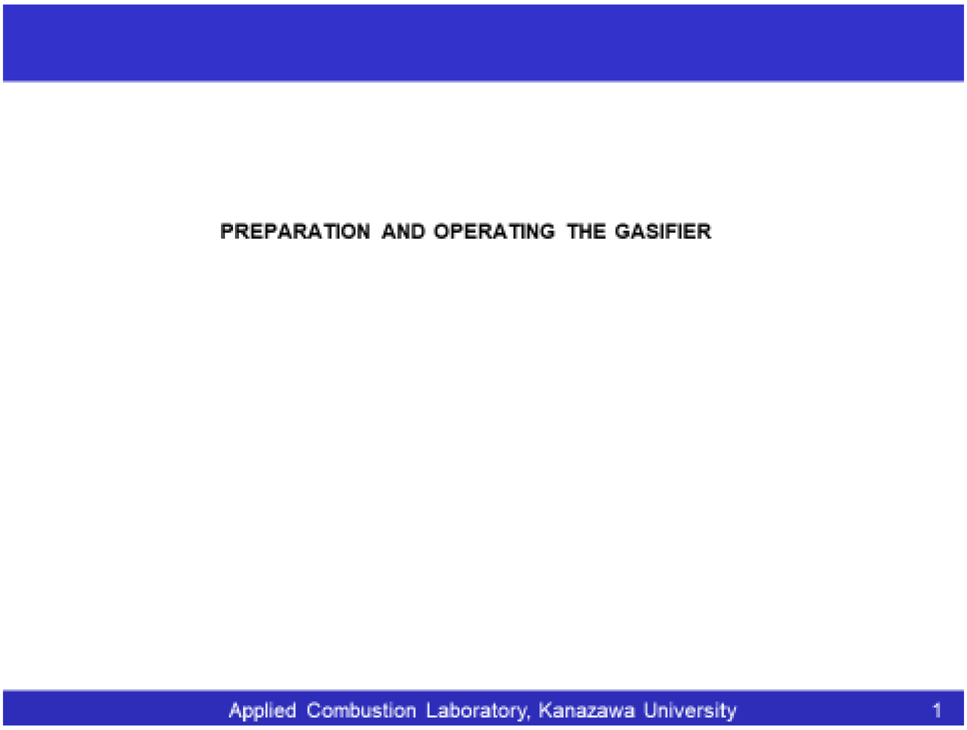
APPENDIX 3. EXPERIMENT PROCEDURE

GASIFIER EXPERIMENT PROCEDURE

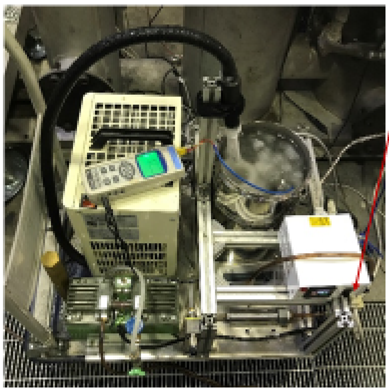


PREPARATION AND OPERATING THE GASIFIER

OPERATING THE GASIFIER

OPERATING THE GASIFIER

Purpose: To get syngas and tar as long as experiment



Steps:

1. Turn on the cooling of tar device to get enough temperature at -20C (because to get temperature -20C need more time at least 1 hour before gasifier system begins).

INDICATOR of Heater :

temperature will show value 250 C

INDICATOR of Cooling In Antifreeze :

temperature will show value at least -20 C

PREPARATION: Removing Tar

2. Removing Tar from gasifier system before take the experiment by remove tar in the clear tube to avoid the overflow of tar.

INDICATOR:

Tar tube clear without tar

PREPARATION: Removing Tar

2. Removing ash from gasifier system before take the experiment by open the ash port below the reactor

INDICATOR:

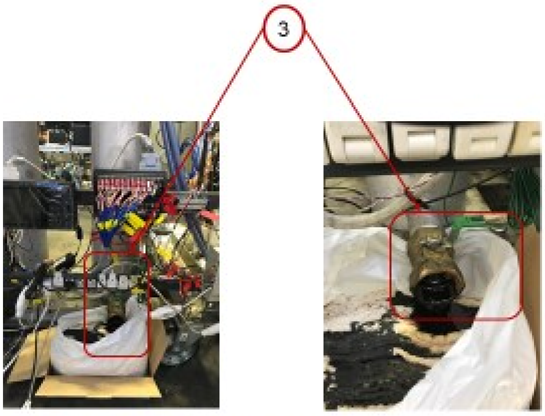
Ash Port clean without ash

PREPARATION: Close Drain Valve

3. Close the drain valve before ignition.

INDICATOR:

The air does not enter the gasifier system, and a small amount of O2 is detected in the gasifier system.



PREPARATION: Moisture Removal Device & Gas Chromatograph

5.1.Turn on the moisture removal device and gas chromatograph
2. Wait until the display on moisture removal device reaches 5^{0}C (about 5 minutes)
3. When the temperature reaches 5^{0}C, turn on the pump switch

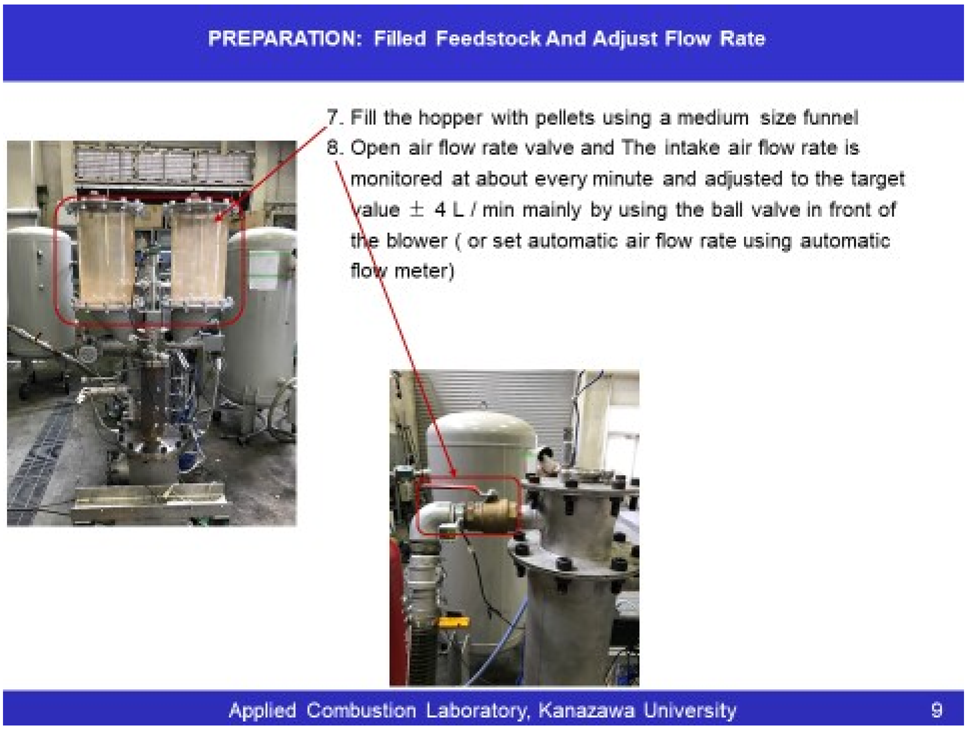
INDICATOR:
Wait until display in the layer moisture reach 5C, we can use

PREPARATION: Supply of gas carrier (argon)

6.1. Confirm that the secondary side valve is closed
2. Open the main valve
3. Adjust the pressure to 0.55 MPa

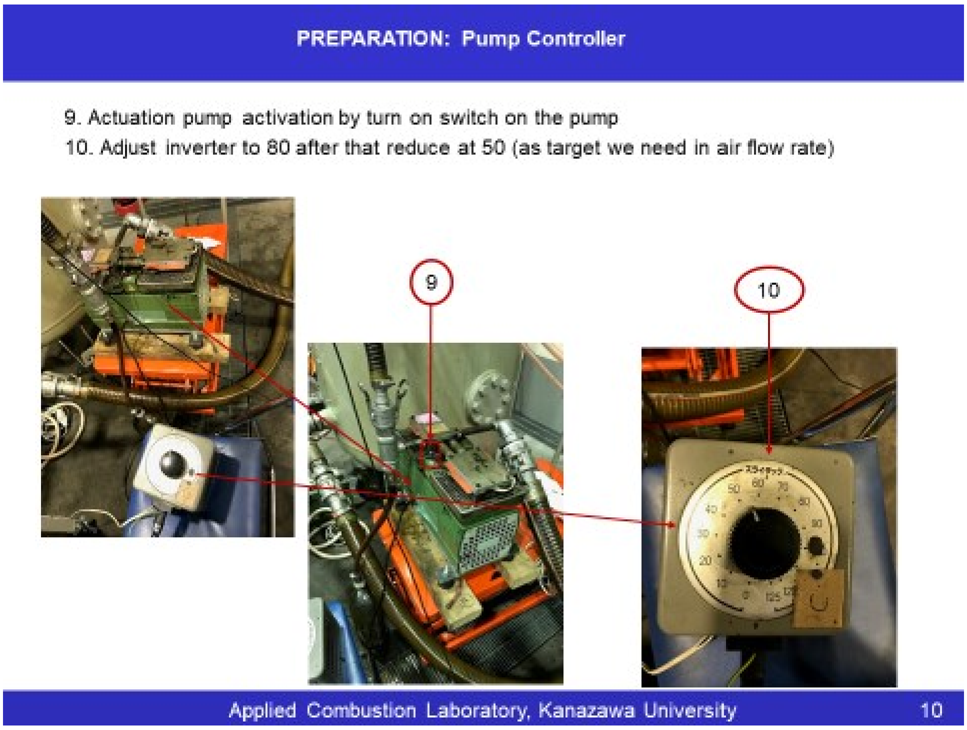
6. 4 Adjust the argon gas firs and Start gas chromatography (GLS micro GC) and data logger for gasification furnace (Graphtec DL 820).
It connects to PC with USB

INDICATOR:
Waiting the gas chromatography monitor until green check, we can use



PREPARATION: Filled Feedstock And Adjust Flow Rate

7. Fill the hopper with pellets using a medium size funnel
8. Open air flow rate valve and The intake air flow rate is monitored at about every minute and adjusted to the target value ± 4 L / min mainly by using the ball valve in front of the blower (or set automatic air flow rate using automatic flow meter)



PREPARATION: Pump Controller

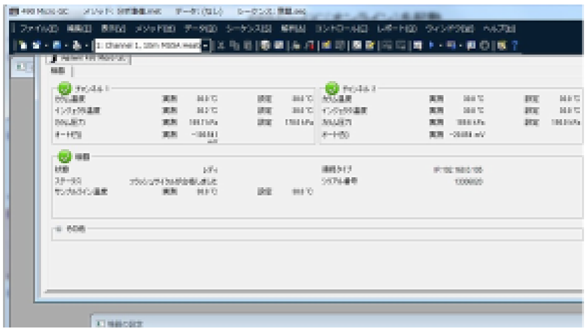
9. Actuation pump activation by turn on switch on the pump
10. Adjust inverter to 80 after that reduce at 50 (as target we need in air flow rate)

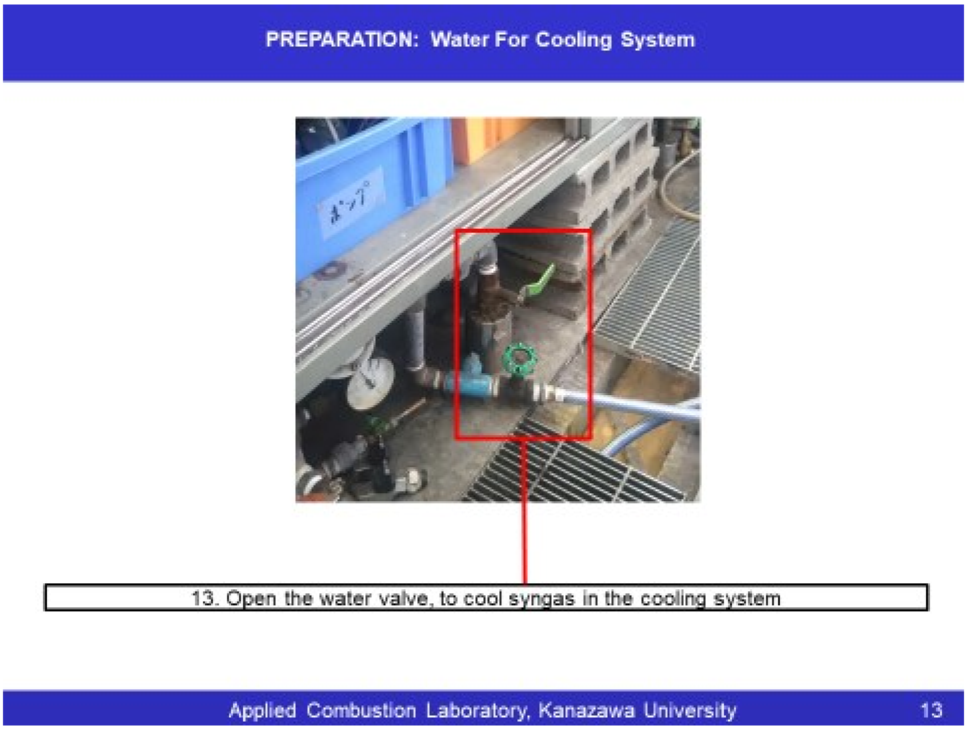
PREPARATION: Start The Gas Chromatograph Analyze

11.1. Open the 490 Micro GC (online)
2. Open the 490 Micro GC (offline) to display the results
3. To prepare for analysis
→File (F) →Open (O)→Method (M)→ Preparation for analysis
→Control (C) → Download Method
→Wait until the light noticed the device status becomes green

PREPARATION: Start The Gas Chromatograph Analyze

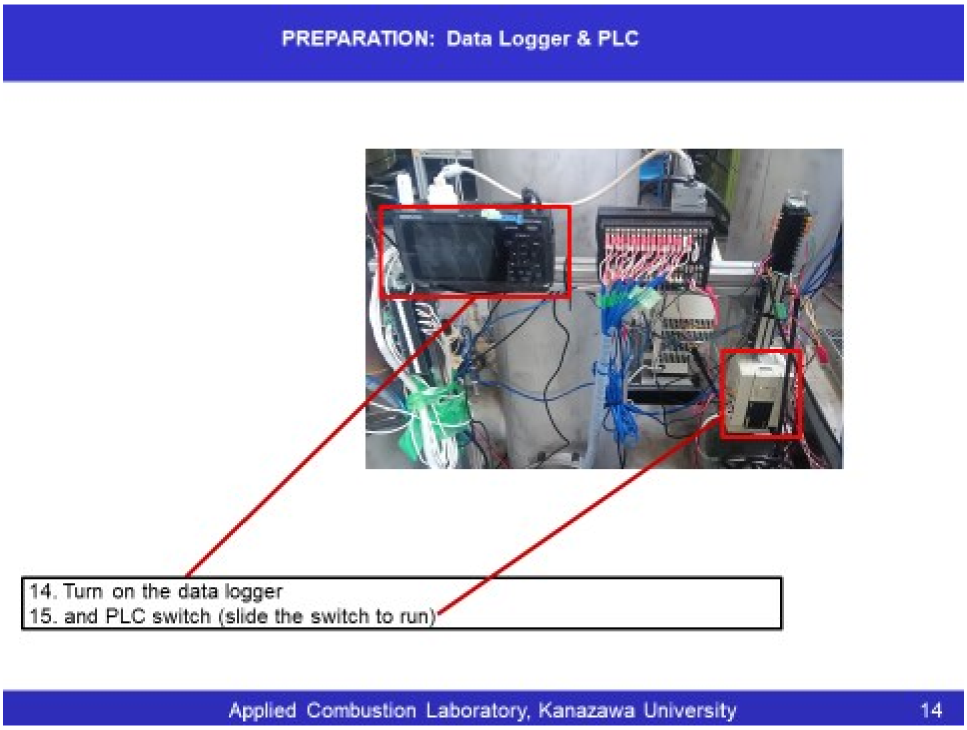
12. Load the analysis state
The same process of preparation for analysis
→File (F) →Open (O)→Method (M)→ Preparation for analysis
→Control (C) → Download Method
→Wait until the light noticed the device status becomes green





PREPARATION: Water For Cooling System

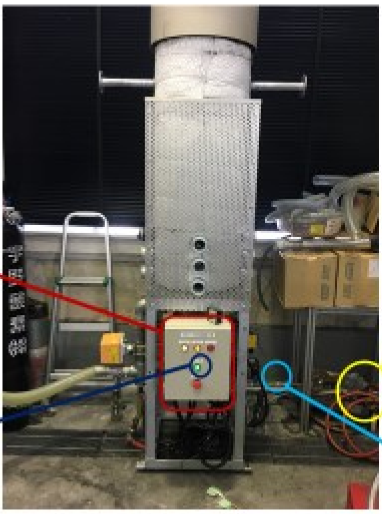
13. Open the water valve, to cool syngas in the cooling system



PREPARATION: Data Logger & PLC

14. Turn on the data logger
15. and PLC switch (slide the switch to run)

PREPARATION: Flare



16.1.Turn on the electric power

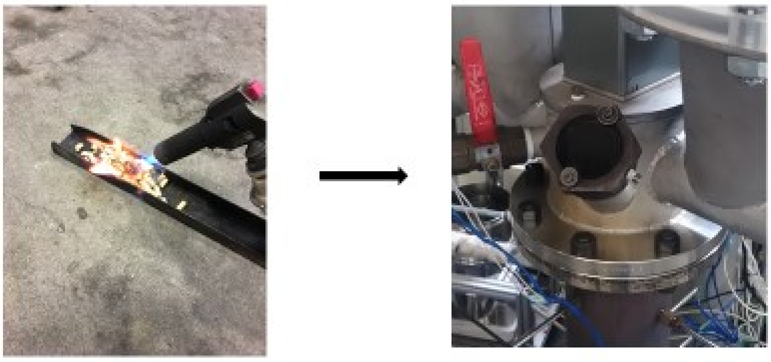
16.2.Open the city gas valve

16.3.Open the valve for flare about 20°

16.4.Turn on the power switch

PREPARATION: Ignition

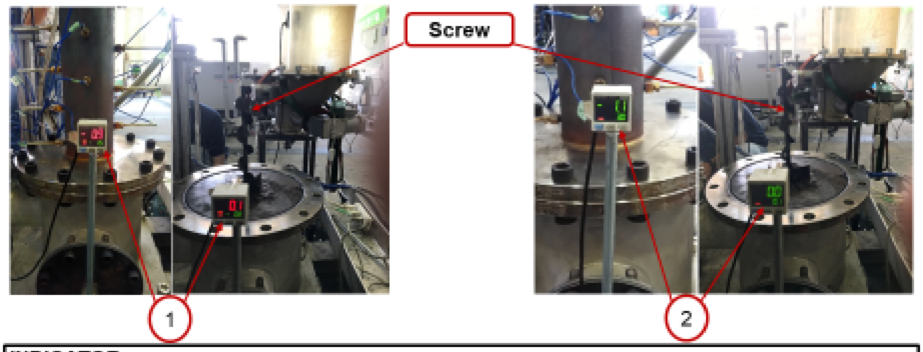
17.1. Burn pellet with gas burner
2. After pellet burn sufficiently, fill it in the observation window
3. Check the air flow rate of the flow meter and adjust the valve



CAUTION: Operate the blower before filling the pellet burn in the reactor because CO gas of the previous experiment may still be left.

PREPARATION: Setting Screw in the inside of Reactor

18.The screw inside reactor can be set according to needs
To set the pressure just press ⬇ button to reduce pressure and press ⬆ button to increase the pressure.
1. The pressure in monitor will be red, it means that the screw will stop rotating and
2. The pressure in monitor will be green, it means that the screw in “the sensor drive” condition. the screw will rotate with interval: one second rotate and ten seconds stop and will continue



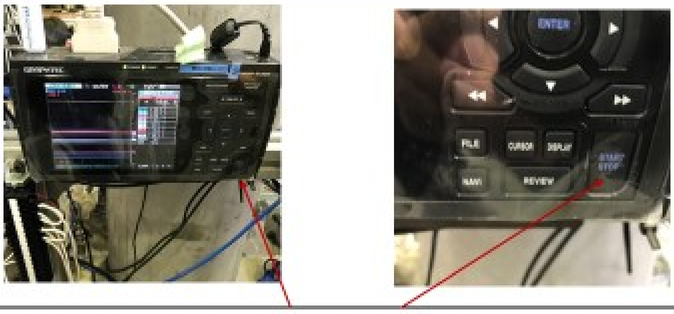
INDICATOR:
- Red color in the monitor of pressure indicated that Screw will stop rotate
- Green Color in the monitor of pressure indicated that “Sensor Drive” Screw (the screw will rotate with interval: one second rotate and ten seconds stop and will continue)

PREPARATION: Feeder

19. 1. Switch “on” button on the feeder to mix the wood pellet in order to burn all pellet.

2. Switch “on” the button to enter wood pellets from feeder to gasifier.

PREPARATION: Record data logger



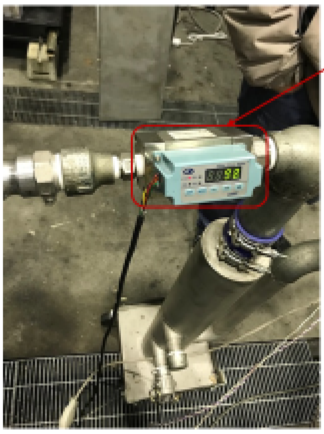
20. Press “start” button on data logger to record the data as long as the experiment process is going on

Data logger → function for recording temperature

INDICATOR:

After temperature in gasifier reach 200 C, we can star record the data logger. If sign “Rec” appear in the data logger monitor, it’s mean that data logger start to record the data.

PREPARATION: Setting Automatic Air Flow Rate



21. Set automatic flow rate

How to set automatic valve:

1. Press in same time (enter and ⬇)
2. Press “enter” button
3. Set as needed using ⬇and ⬆(expl. 75 L/min) in P-01 and in P-02
4. Press “enter” button and
5. Press “display” button

INDICATOR:

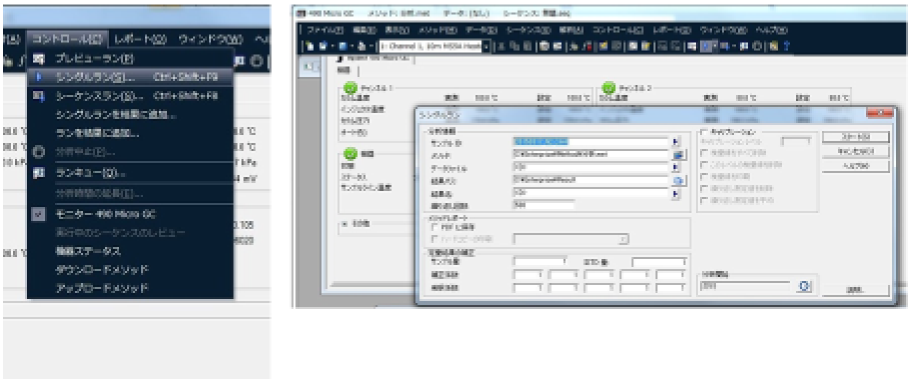
The value of air flow rate usually show in range plus 4 or minus 4 from initial value, example: intial value 70 L/min, the range between (66-74) L/min

PREPARATION: Start Measurement of Gas Chromatograph

22. 490Micro GC（online）: Run → Start

When we want to start gas chromatography, choose 490Micro G（online）

And then choose Run → Start



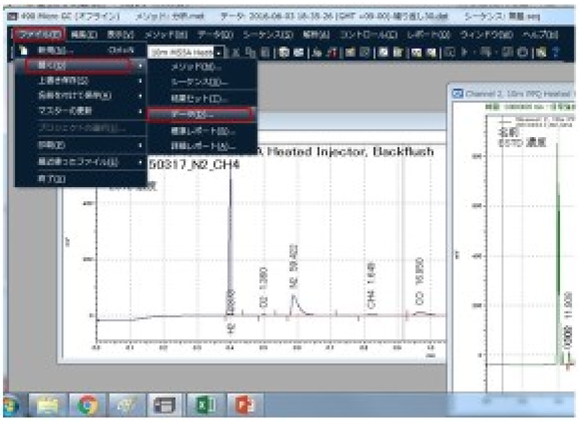
OPERATION DURING THE EXPERIMENT: Display Of Gas Chromatographic Data

23. 490 Micro GC (offline)

File → Open → Data (Open the latest data)

INDICATOR ：

Stable when biosyngas H2, N2, CO, CO2 fluctuation falls below 0.2 point



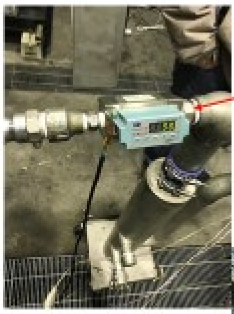
OPERATION DURING THE EXPERIMENT: Feedstock in The Feeder

2.4. A Feeder is feedstock to stable and after one hour usually gasification in the gasifier is stable
2. B Feeder is feedstock to biomass consumption, measure how many minutes the feedstock will burn all.

INDICATOR :

After Feedstock in the feeder all was burned, it's mean that biomass consumption is finish and we can continue with next case/experiment (In the one running system during operation of the experiment we can do more than one case)

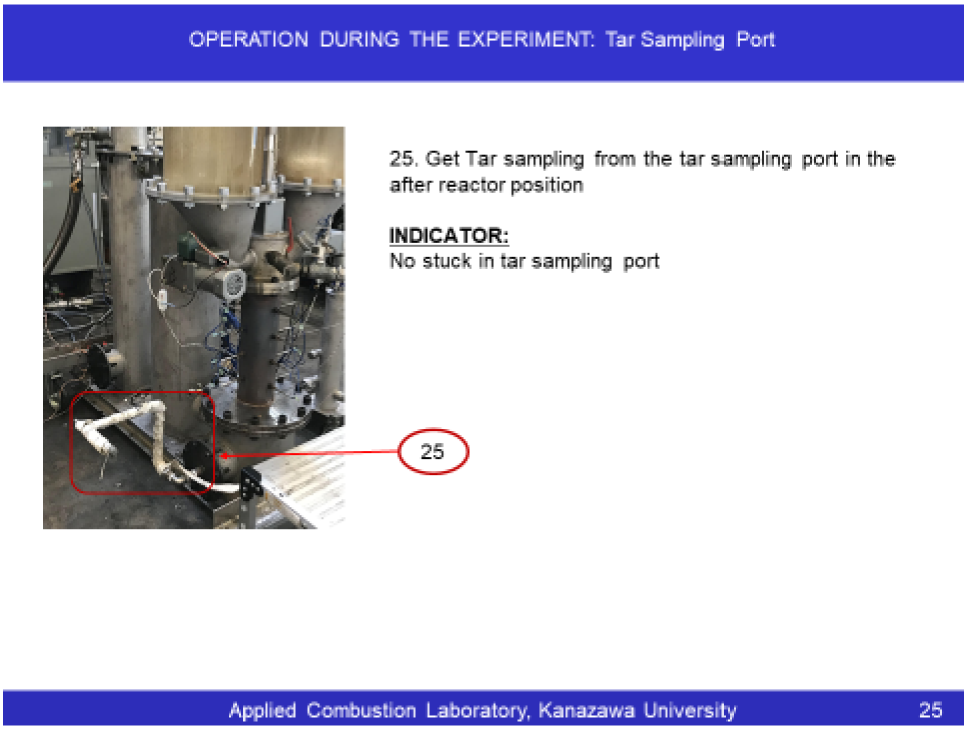
OPERATION DURING THE EXPERIMENT: Check Air Flow Rate



25. Check air flow rate:
    1. Check Air Flow Rate every time.
    2. if the air flow rate less than or more than ± 4 L/min, adjust using ball valve

INDICATOR:

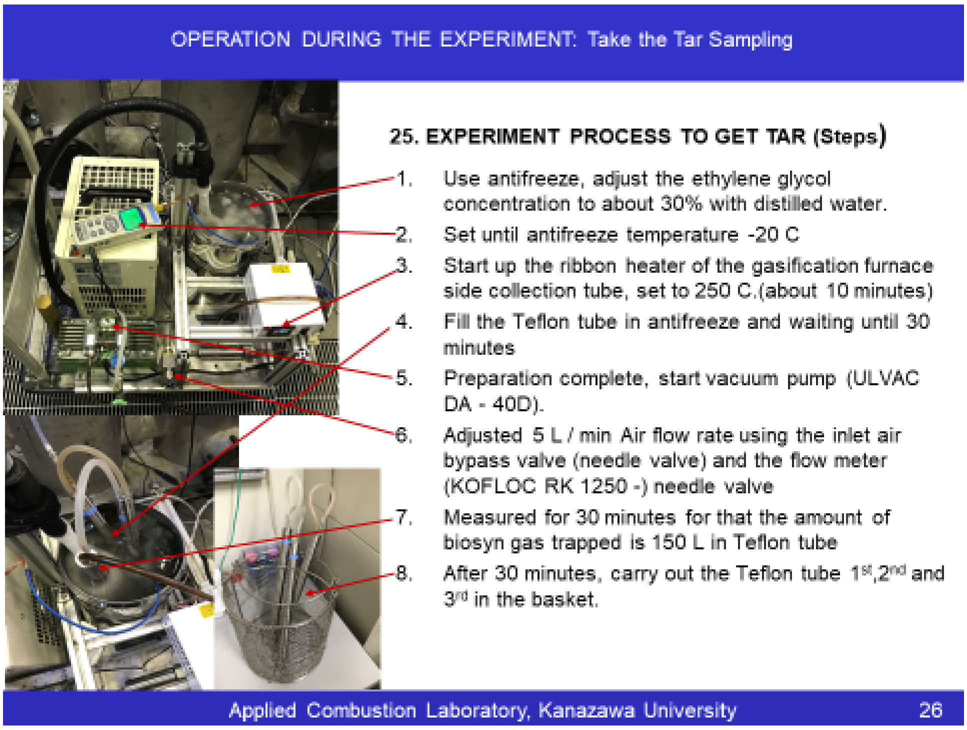
If the Air Flow Rate± 4L/Min from the adjusting, air flow rate is ok



OPERATION DURING THE EXPERIMENT: Tar Sampling Port

25. Get Tar sampling from the tar sampling port in the after reactor position

INDICATOR:
No stuck in tar sampling port



OPERATION DURING THE EXPERIMENT: Take the Tar Sampling

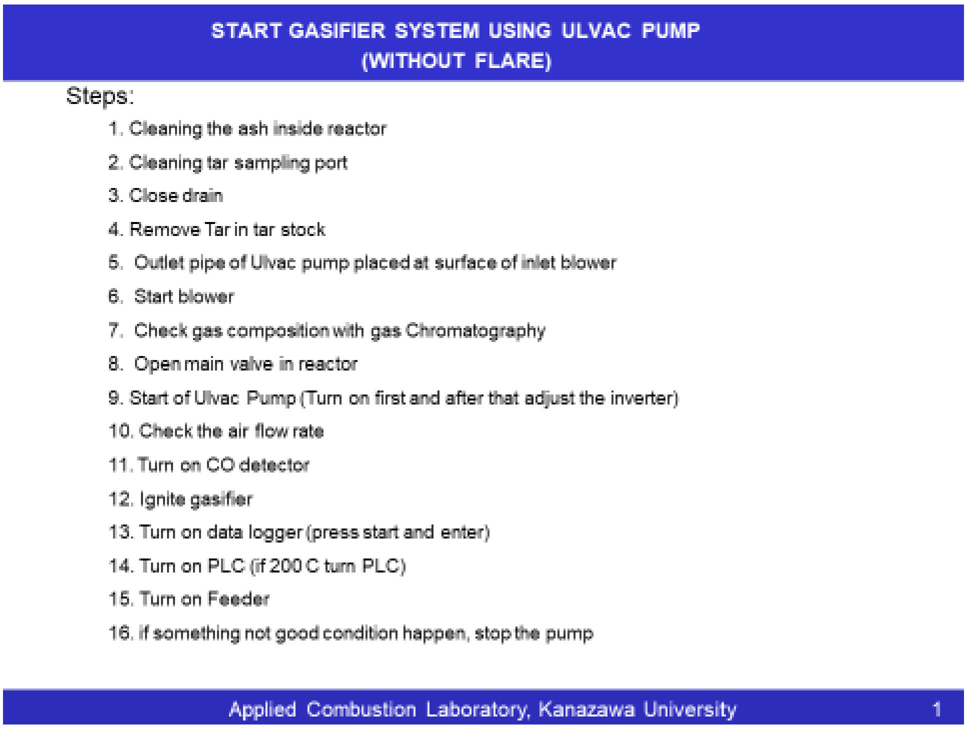
25. EXPERIMENT PROCESS TO GET TAR (Steps)

1. Use antifreeze, adjust the ethylene glycol concentration to about 30% with distilled water.
2. Set until antifreeze temperature -20 C
3. Start up the ribbon heater of the gasification furnace side collection tube, set to 250 C.(about 10 minutes)
4. Fill the Teflon tube in antifreeze and waiting until 30 minutes
5. Preparation complete, start vacuum pump (ULVAC DA - 40D).
6. Adjusted 5 L / min Air flow rate using the inlet air bypass valve (needle valve) and the flow meter (KOFLOC RK 1250 -) needle valve
7. Measured for 30 minutes for that the amount of biosyn gas trapped is 150 L in Teflon tube
8. After 30 minutes, carry out the Teflon tube 1st,2nd and 3rd in the basket.

APPENDIX 4. EXPERIMENT PROCEDURE

GASIFIER EXPERIMENT PROCEDURE

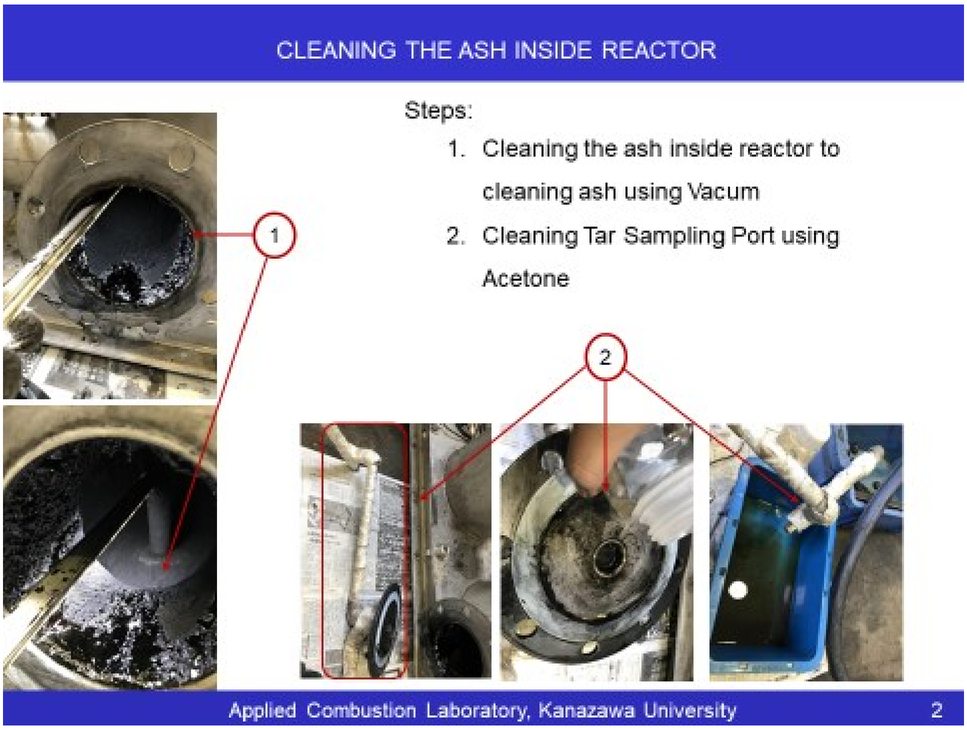
USING CO DETECTOR



START GASIFIER SYSTEM USING ULVAC PUMP (WITHOUT FLARE)

Steps:

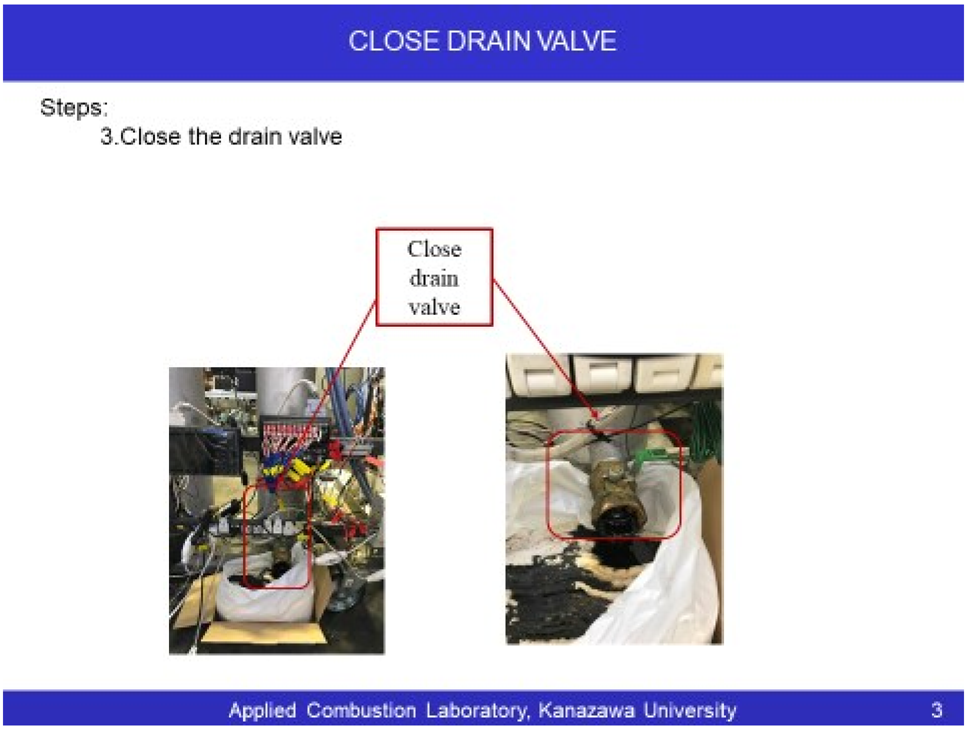
1. Cleaning the ash inside reactor
2. Cleaning tar sampling port
3. Close drain
4. Remove Tar in tar stock
5. Outlet pipe of Ulvac pump placed at surface of inlet blower
6. Start blower
7. Check gas composition with gas Chromatography
8. Open main valve in reactor
9. Start of Ulvac Pump (Turn on first and after that adjust the inverter)
10. Check the air flow rate
11. Turn on CO detector
12. Ignite gasifier
13. Turn on data logger (press start and enter)
14. Turn on PLC (if 200 C turn PLC)
15. Turn on Feeder
16. if something not good condition happen, stop the pump



CLEANING THE ASH INSIDE REACTOR

Steps:

1. Cleaning the ash inside reactor to cleaning ash using Vacum
2. Cleaning Tar Sampling Port using Acetone



CLOSE DRAIN VALVE

Steps:

3.Close the drain valve

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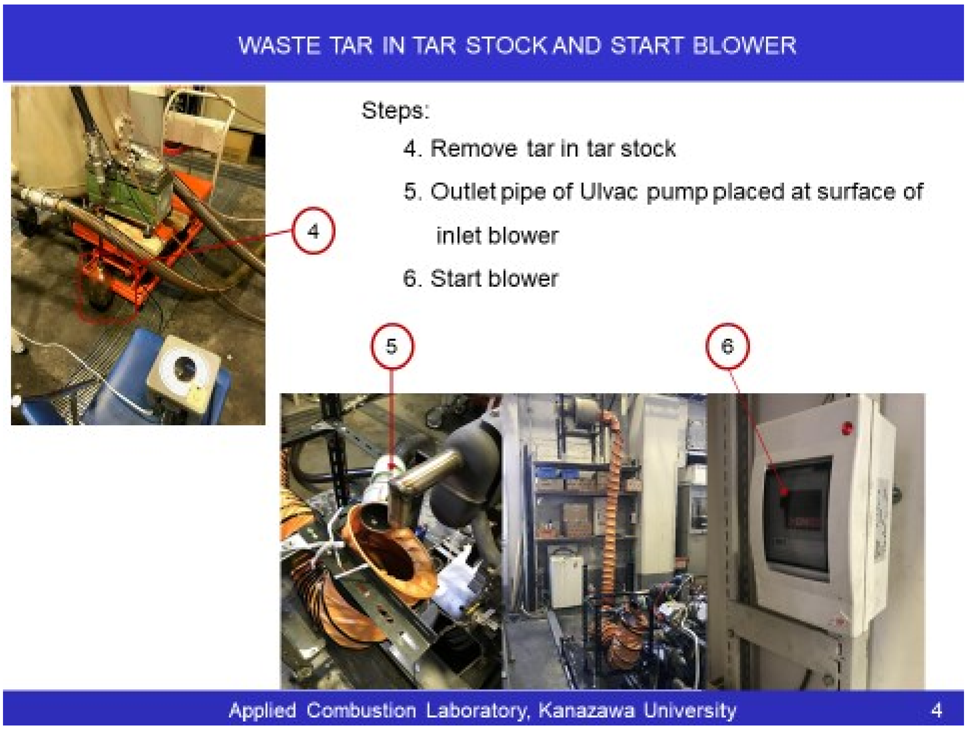

WASTE TAR IN TAR STOCK AND START BLOWER

Steps:

4. Remove tar in tar stock
5. Outlet pipe of Ulvac pump placed at surface of inlet blower
6. Start blower

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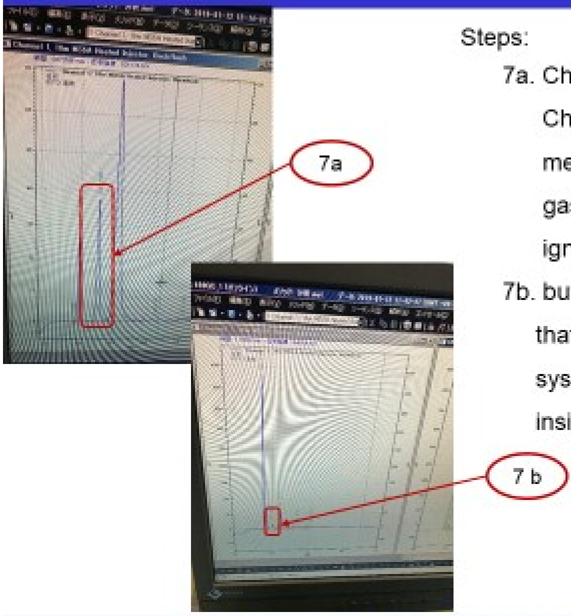
CHECK GAS COMPOSITION

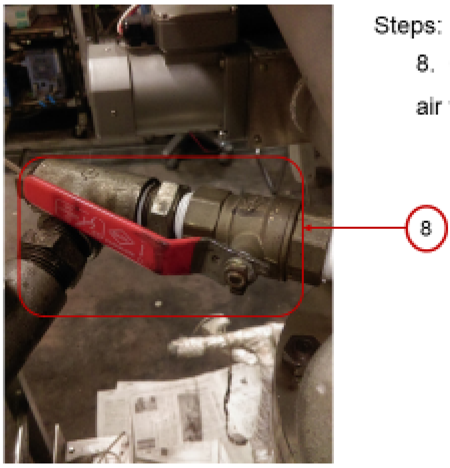


Steps:

7a. Check Gas composition using Gas Chromatography, if Oxygen high, it is mean that no syngas in side the gasifier system, and we can start to ignite,

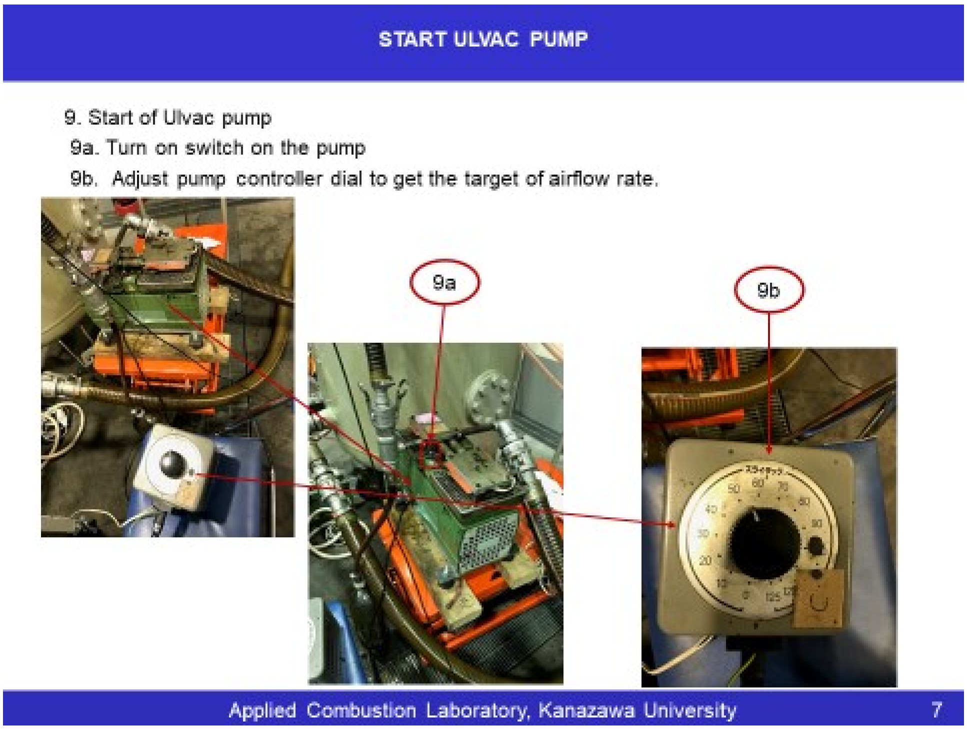
7b. but if oxygen indicated low, it is mean that many syngas inside of gasifier system and we need to remove syngas inside to outside using pump

OPEN MAIN VALVE IN REACTOR



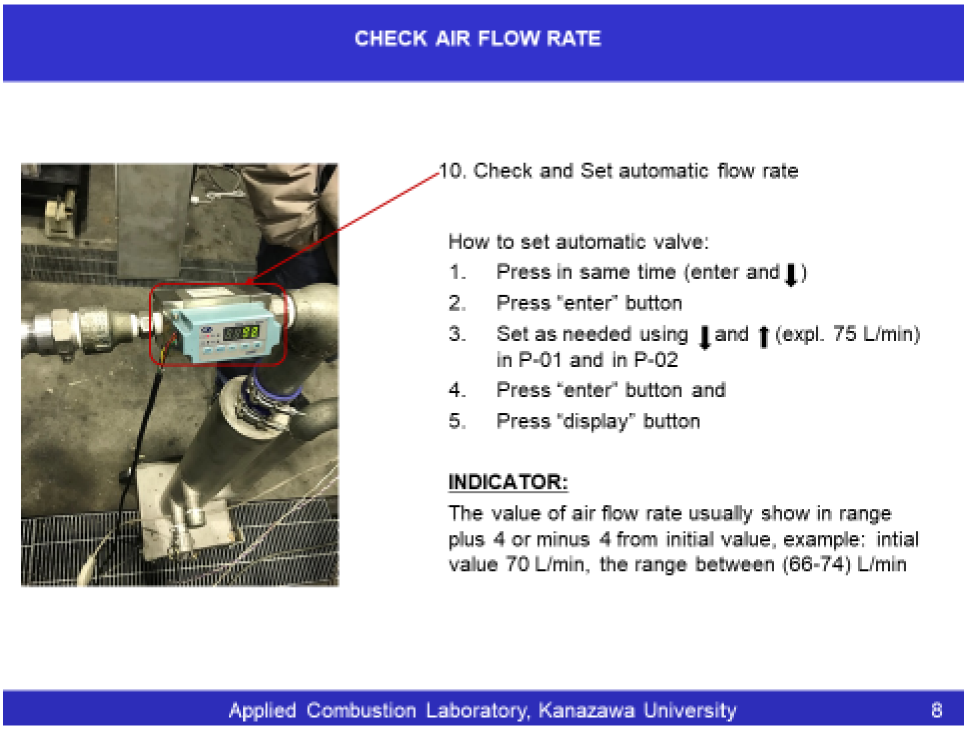
Steps:

8. Open main valve in reactor of gasifier, and air will come to inside of reactor gasifier



START ULVAC PUMP

9. Start of Ulvac pump
9a. Turn on switch on the pump
9b. Adjust pump controller dial to get the target of airflow rate.



CHECK AIR FLOW RATE

10. Check and Set automatic flow rate

How to set automatic valve:

1. Press in same time (enter and ↓)
2. Press “enter” button
3. Set as needed using ↓ and ↑ (expl. 75 L/min) in P-01 and in P-02
4. Press “enter” button and
5. Press “display” button

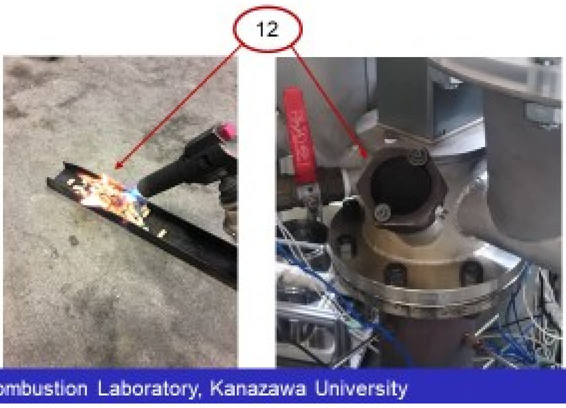
INDICATOR:

The value of air flow rate usually show in range plus 4 or minus 4 from initial value, example: intial value 70 L/min, the range between (66-74) L/min

TURN ON CO DETECTOR AND IGNITE

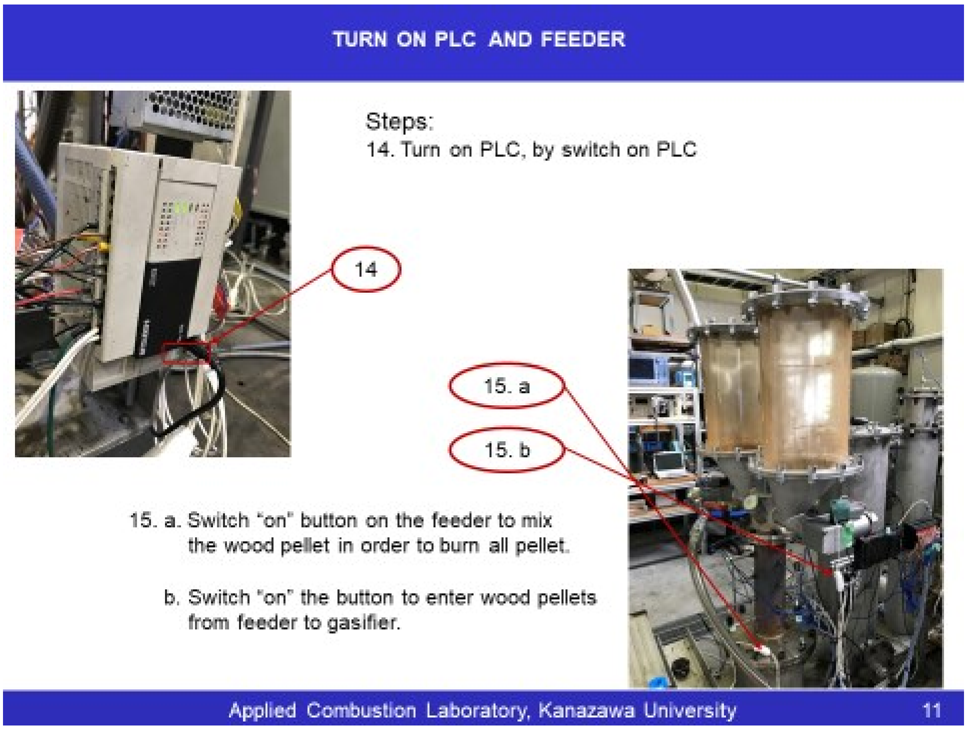
Steps:

11. Turn on CO detector, to indicated CO leak in surrounding area
12. Ignite gasifier, Burn pellet with gas burner, After pellet burn sufficiently, fill it in the observation window



TURN ON DATA LOGGER

Turn on data logger, Press "start" button on data logger and press "enter"to record data.



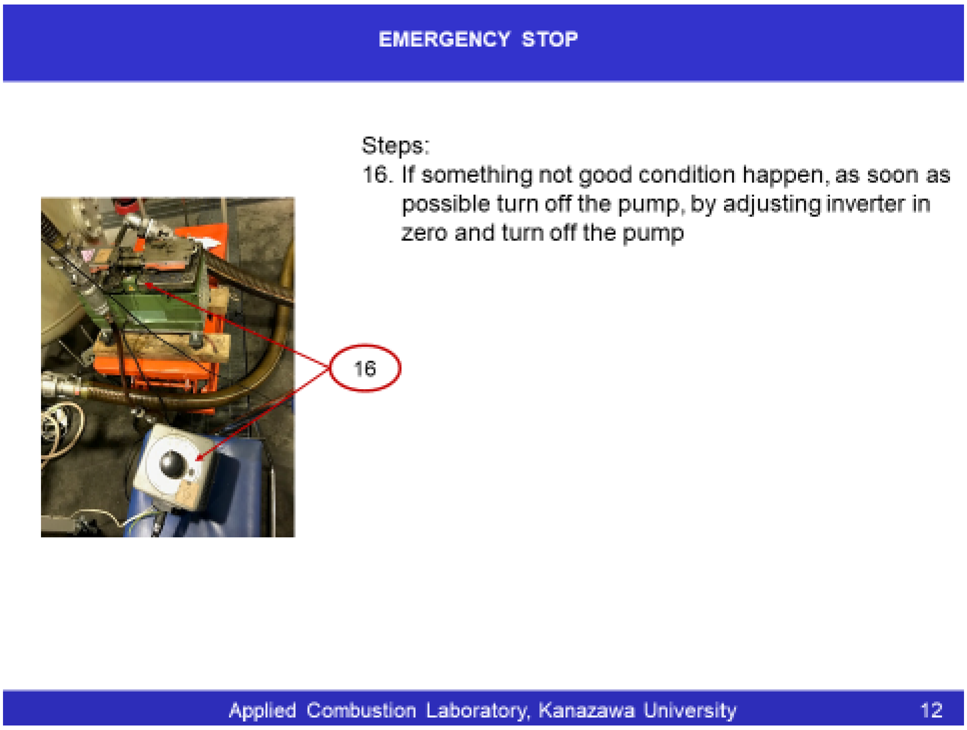
TURN ON PLC AND FEEDER

Steps:

14. Turn on PLC, by switch on PLC

15. a. Switch "on" button on the feeder to mix the wood pellet in order to burn all pellet.

b. Switch "on" the button to enter wood pellets from feeder to gasifier.



EMERGENCY STOP

Steps:

16. If something not good condition happen, as soon as possible turn off the pump, by adjusting inverter in zero and turn off the pump

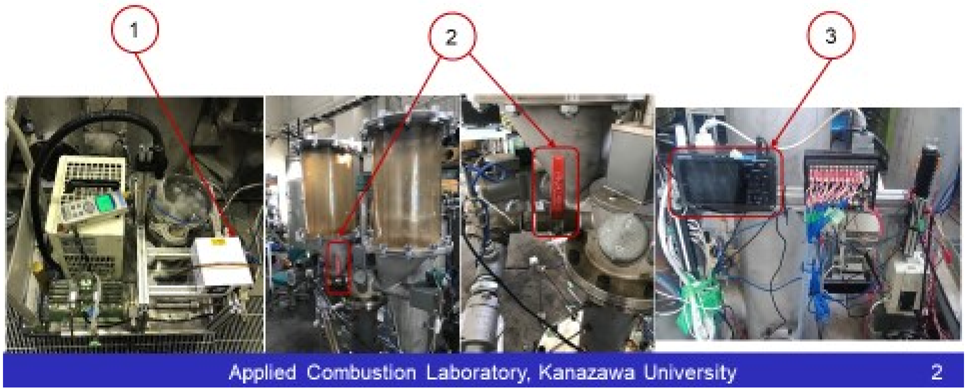
APPENDIX 5. EXPERIMENT PROCEDURE

CLOSING PROCEDURE OF GASIFIER

CLOSING PROCEDURE OF GASIFIER

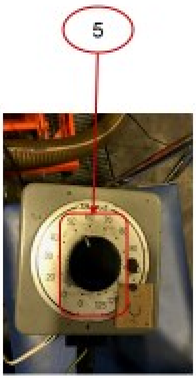
CLOSING PROCEDURE: Stop Device 1

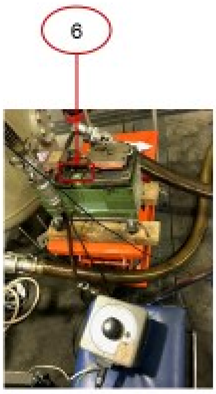
1. When the experiment finished, Stop Cooling System to get tar by press "off" button
2. Close the entrance valve of the reactor by pull "stop" valve in gasifier
3. Stop data logger record, by press unrecorded button



CLOSING PROCEDURE: Stop Device 1

4. Close the water valve by switch "stop" valve
5. Waiting about 5 minutes, adjust inverter to zero by rotate switch in zero and after that
6. We stop the pump by switch "off" button in the pump

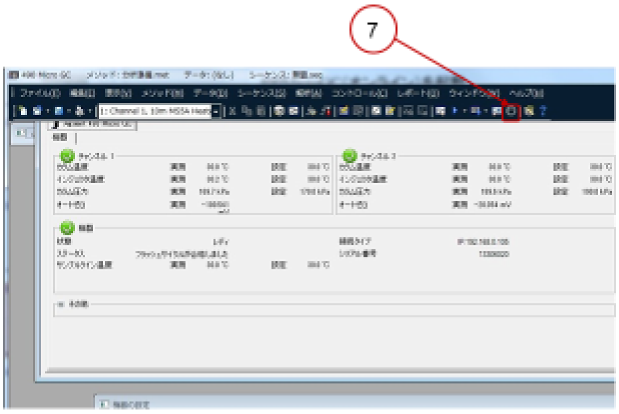




CLOSING PROCEDURE: Stop Device 1

7. Stop recording data of gas chromatography by press "stop analysis" in 490Micro GC（online） → analysis stopped,

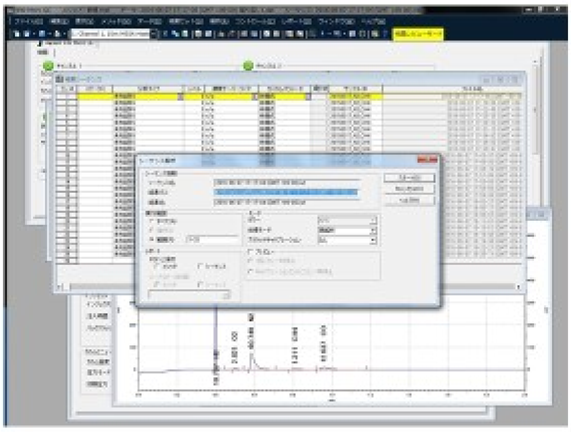
and in the condition of 490Micro GC（offline） by closed software application 490Micro GC（offline）



CLOSING PROCEDURE : Save The Result 1

8. 490 Micro GC (online) File → Open → Result set → Open data
   (For displaying gas composition result)

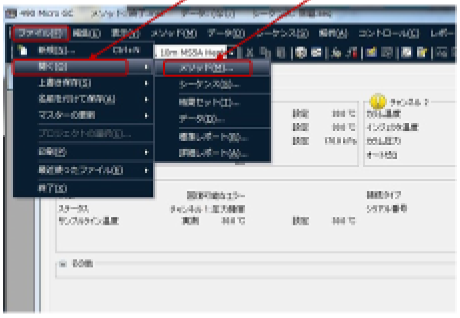
CLOSING PROCEDURE : Save The Result 2

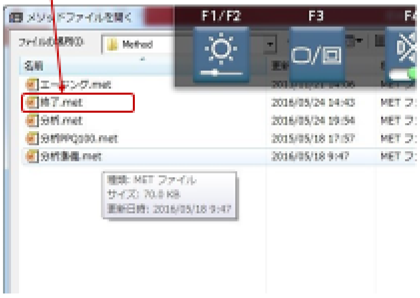


9. Upload data of the data logger together with data from gas chromatograph to laboratory 4 → experiment data.

CLOSING PROCEDURE : Save The Result 2

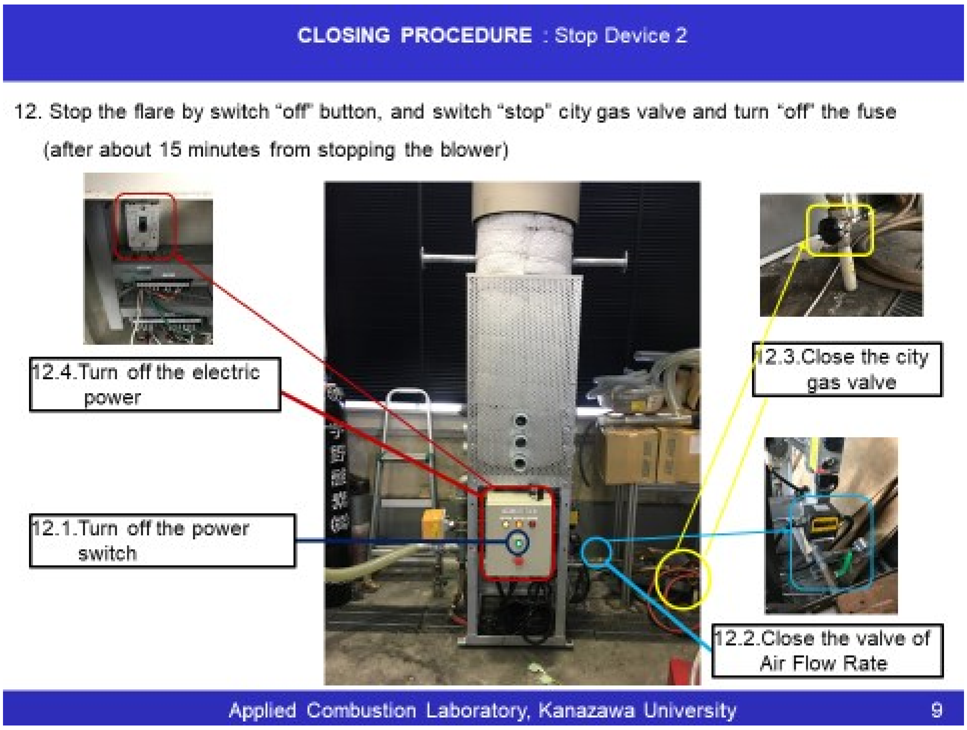
10. Load the exit analyze
    490 Micro GC (Online) → Open file → Method → Exit





CLOSING PROCEDURE : Save The Result 2

11. Control → Download Method → Wait until "instrument status" turns green check. (It takes 15 to 20 minutes)



CLOSING PROCEDURE : Stop Device 2

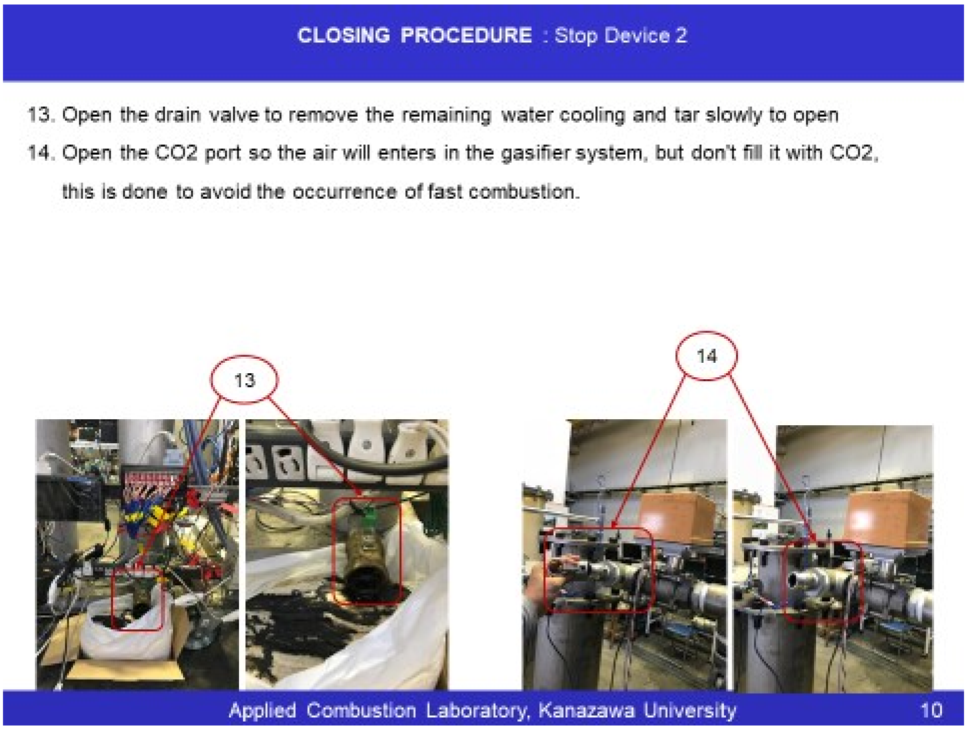
12. Stop the flare by switch "off" button, and switch "stop" city gas valve and turn "off" the fuse (after about 15 minutes from stopping the blower)

12.4.Turn off the electric power

12.3.Close the city gas valve

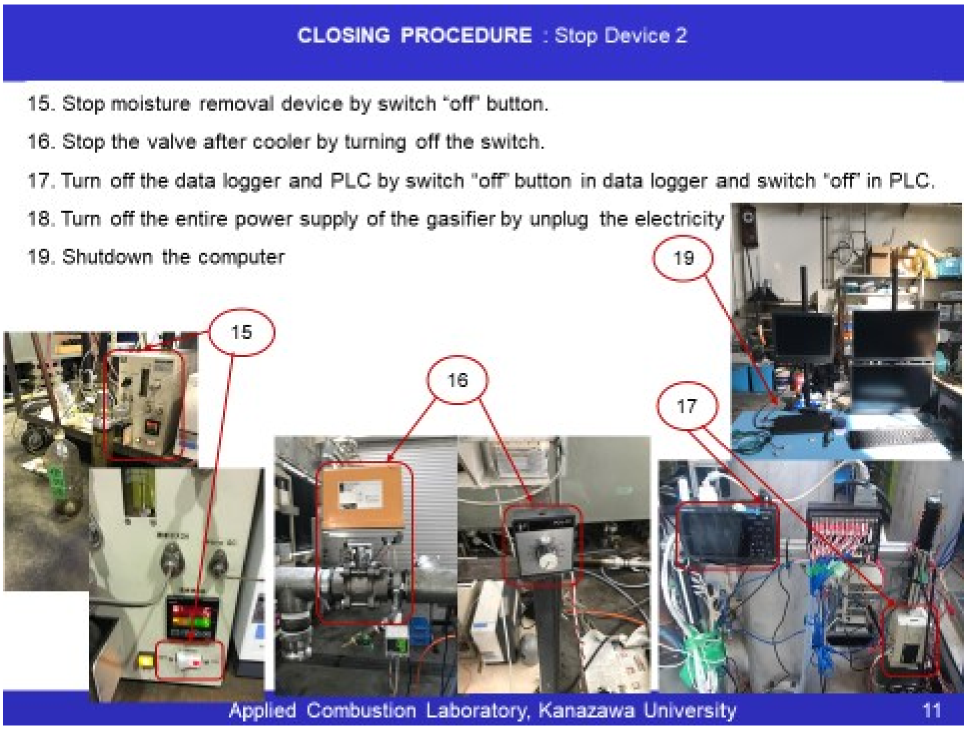
12.1.Turn off the power switch

12.2.Close the valve of Air Flow Rate



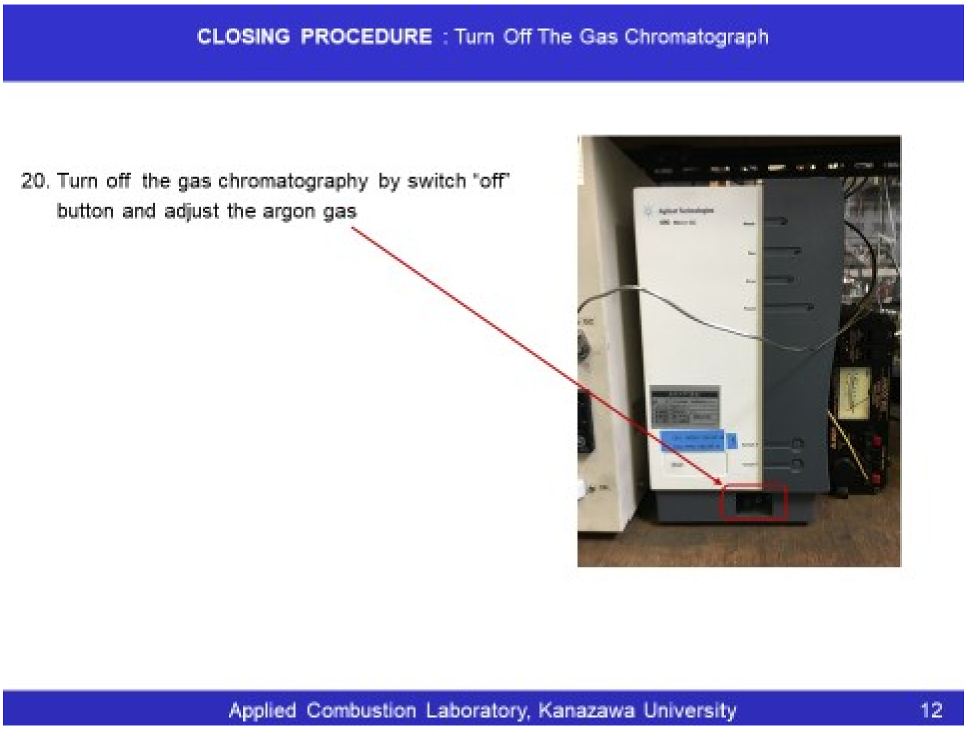
CLOSING PROCEDURE : Stop Device 2

13. Open the drain valve to remove the remaining water cooling and tar slowly to open
14. Open the CO2 port so the air will enters in the gasifier system, but don't fill it with CO2, this is done to avoid the occurrence of fast combustion.



CLOSING PROCEDURE : Stop Device 2

15. Stop moisture removal device by switch "off" button.
16. Stop the valve after cooler by turning off the switch.
17. Turn off the data logger and PLC by switch "off" button in data logger and switch "off" in PLC.
18. Turn off the entire power supply of the gasifier by unplug the electricity
19. Shutdown the computer

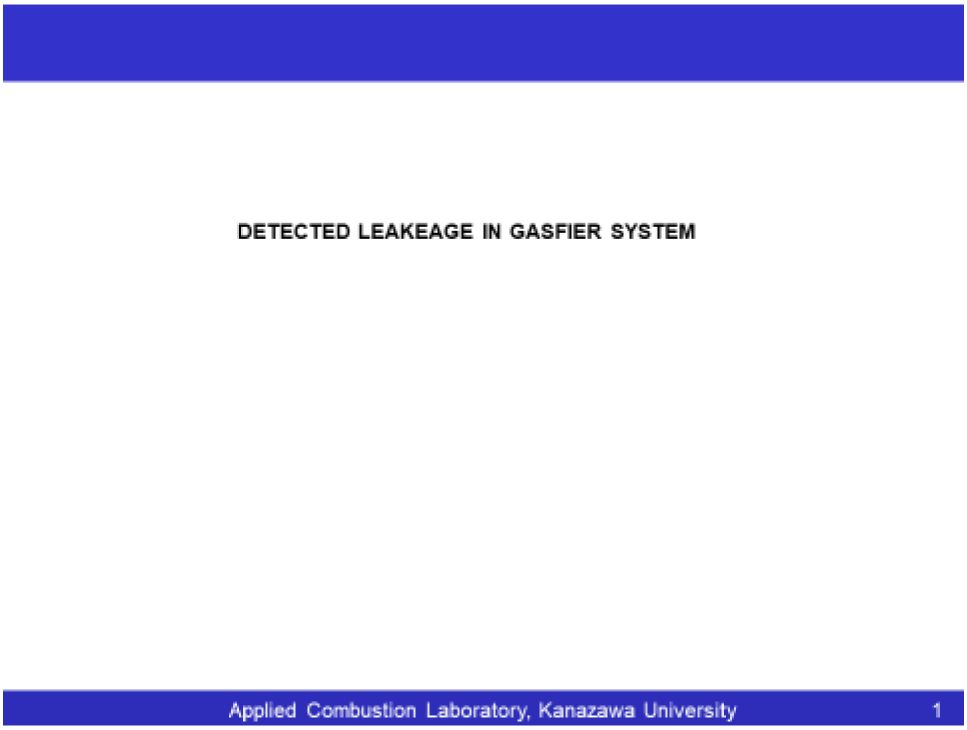


CLOSING PROCEDURE : Turn Off The Gas Chromatograph

20. Turn off the gas chromatography by switch "off" button and adjust the argon gas

APPENDIX 6. EXPERIMENT PROCEDURE

DETECTED LEAKAGE IN GASIFIER



DETECTED LEAKEAGE IN GASFIER SYSTEM

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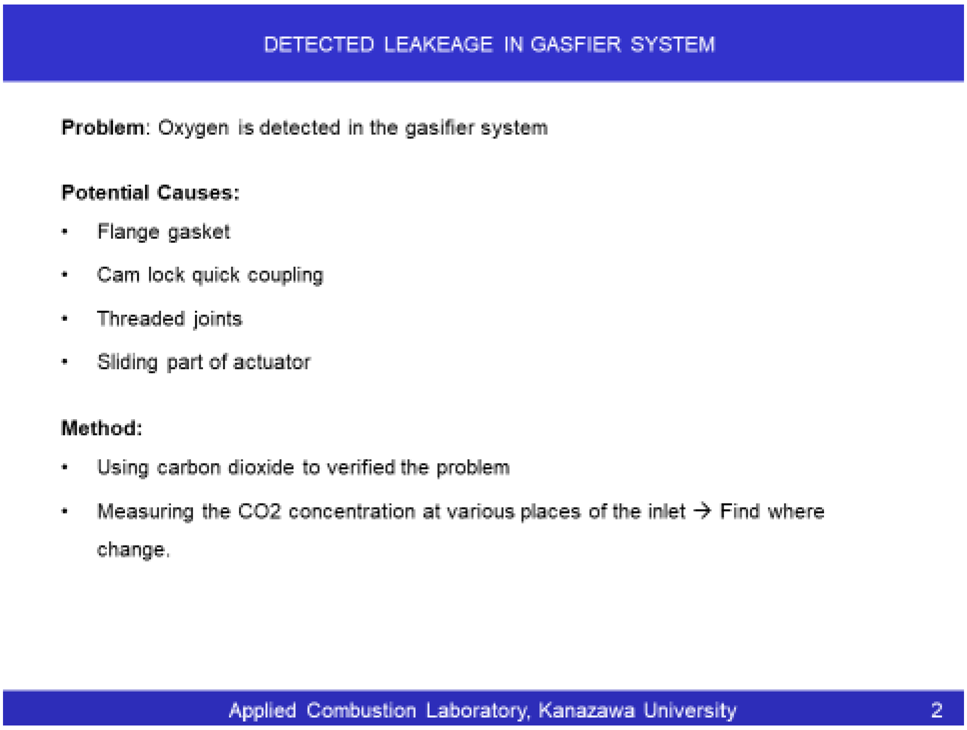

DETECTED LEAKEAGE IN GASFIER SYSTEM

Problem: Oxygen is detected in the gasifier system

Potential Causes:

- Flange gasket
- Cam lock quick coupling
- Threaded joints
- Sliding part of actuator

Method:

- Using carbon dioxide to verified the problem
- Measuring the CO2 concentration at various places of the inlet → Find where change.

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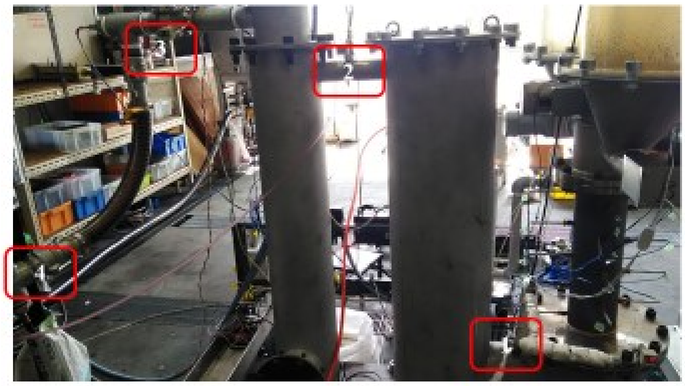
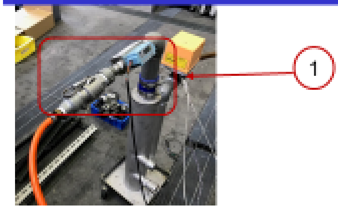
DETECTED LEAKEAGE IN GASFIER SYSTEM

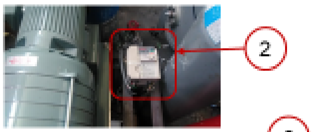
The position measurement



Noted: At one point, measure about 30 minutes

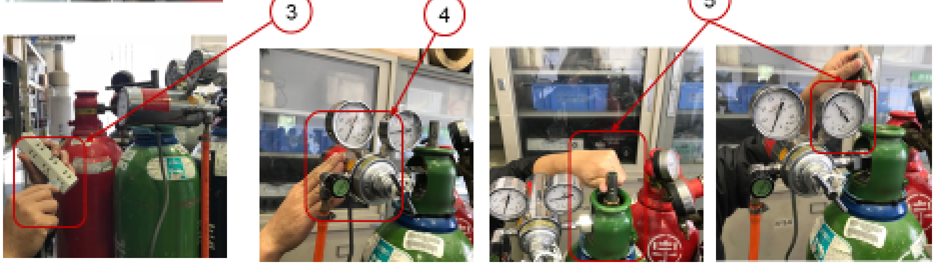
DETECTED LEAKEAGE IN GASFIER SYSTEM

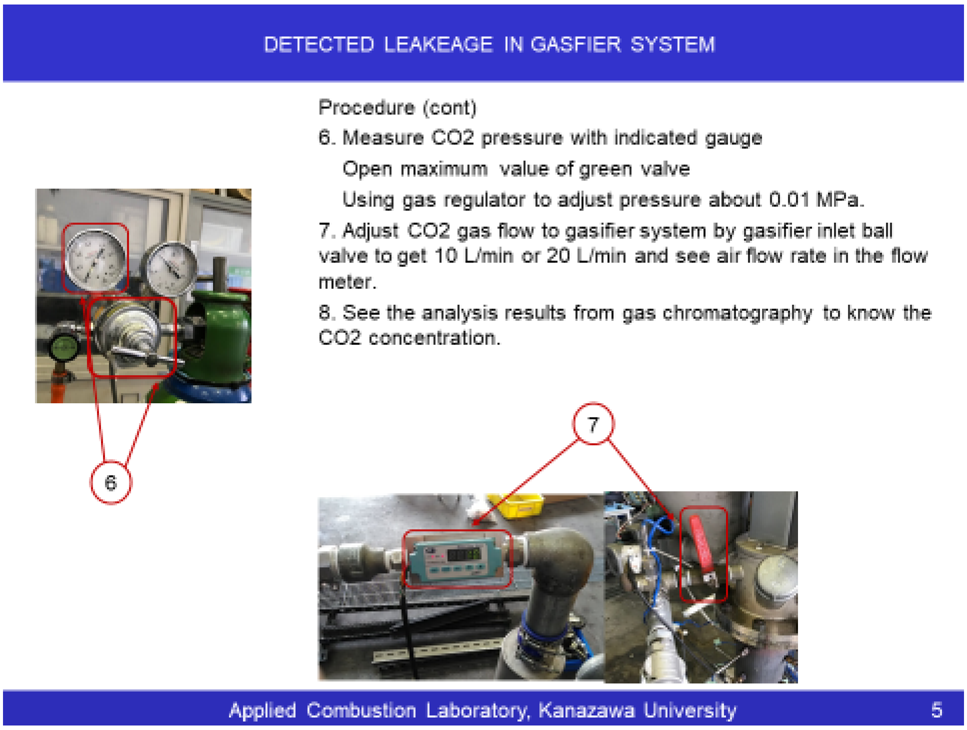




Procedure

1. Set up air flow rate control: 10 L/min
   Connect CO2 pipe with inlet of flowmeter of gasifier system.
2. Open the blower with low speed
3. Plug gas regulator to electric power
4. Touch the gas regulator to make sure that the tool work well because CO2 gas is cool and need heat to use
5. Open main valve. After open main valve, we can see how many CO2 gas in tube





DETECTED LEAKEAGE IN GASFIER SYSTEM

Procedure (cont)

6. Measure CO2 pressure with indicated gauge
   Open maximum value of green valve
   Using gas regulator to adjust pressure about 0.01 MPa.
7. Adjust CO2 gas flow to gasifier system by gasifier inlet ball valve to get 10 L/min or 20 L/min and see air flow rate in the flow meter.
8. See the analysis results from gas chromatography to know the CO2 concentration.

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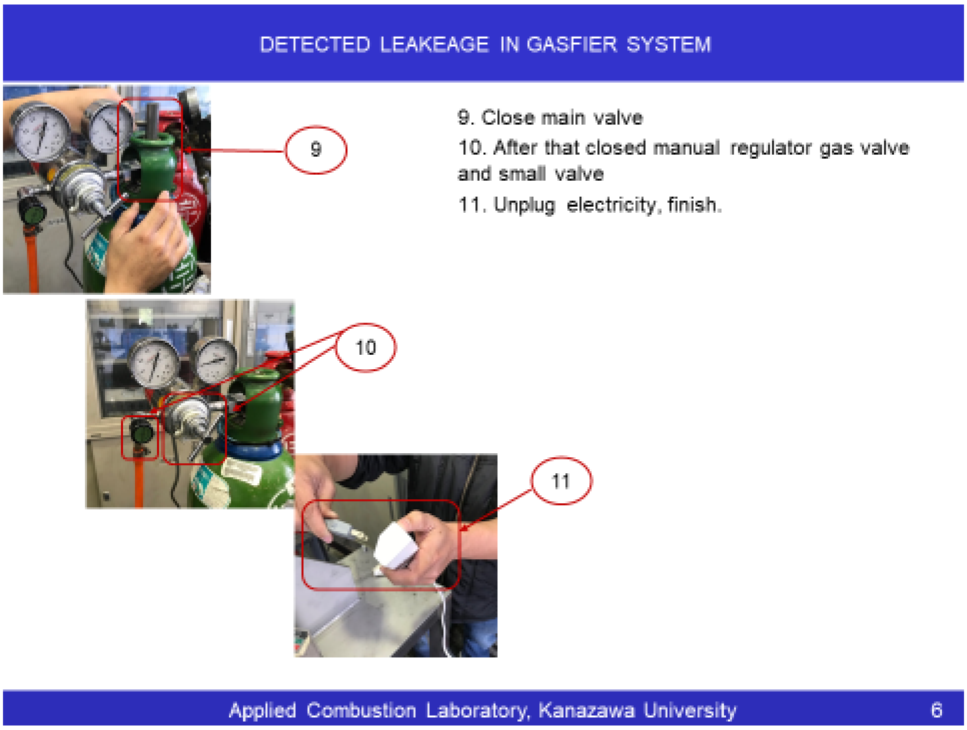

DETECTED LEAKEAGE IN GASFIER SYSTEM

9. Close main valve
10. After that closed manual regulator gas valve and small valve
11. Unplug electricity, finish.

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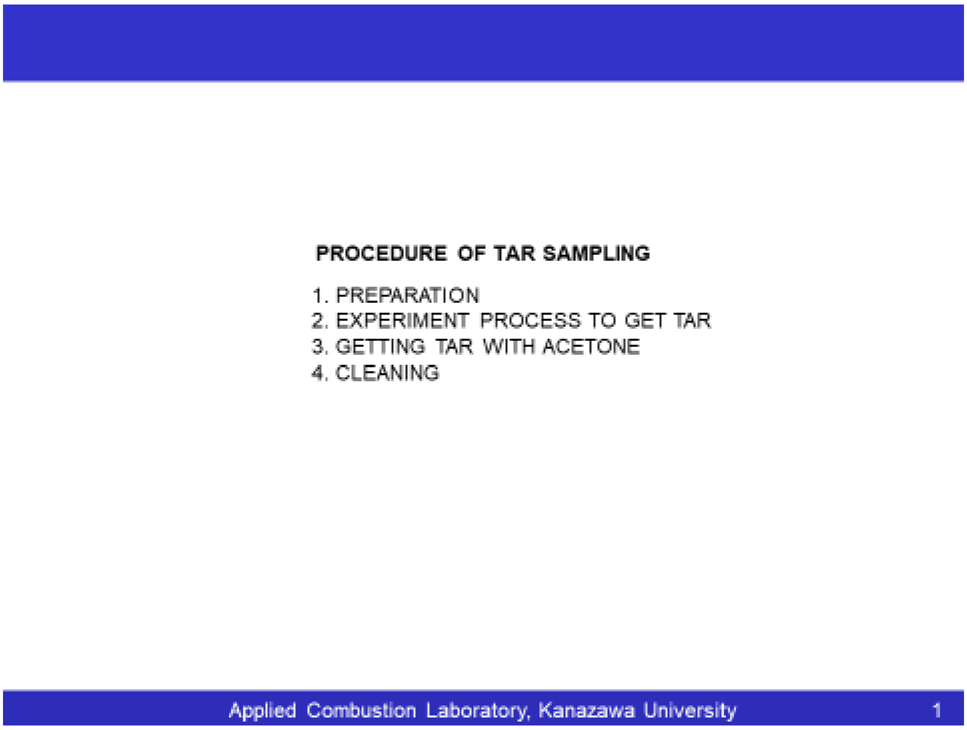
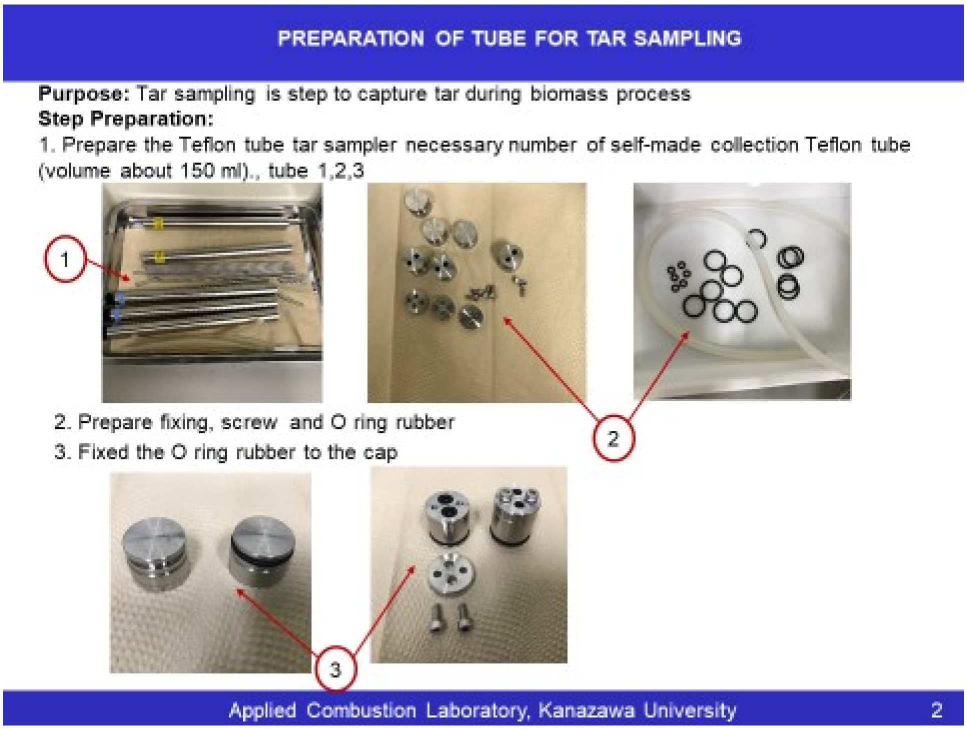
APPENDIX 7. TAR SAMPLING AND EXTRACT TAR PROCEDURE



PROCEDURE OF TAR SAMPLING

1. PREPARATION
2. EXPERIMENT PROCESS TO GET TAR
3. GETTING TAR WITH ACETONE
4. CLEANING



PREPARATION OF TUBE FOR TAR SAMPLING

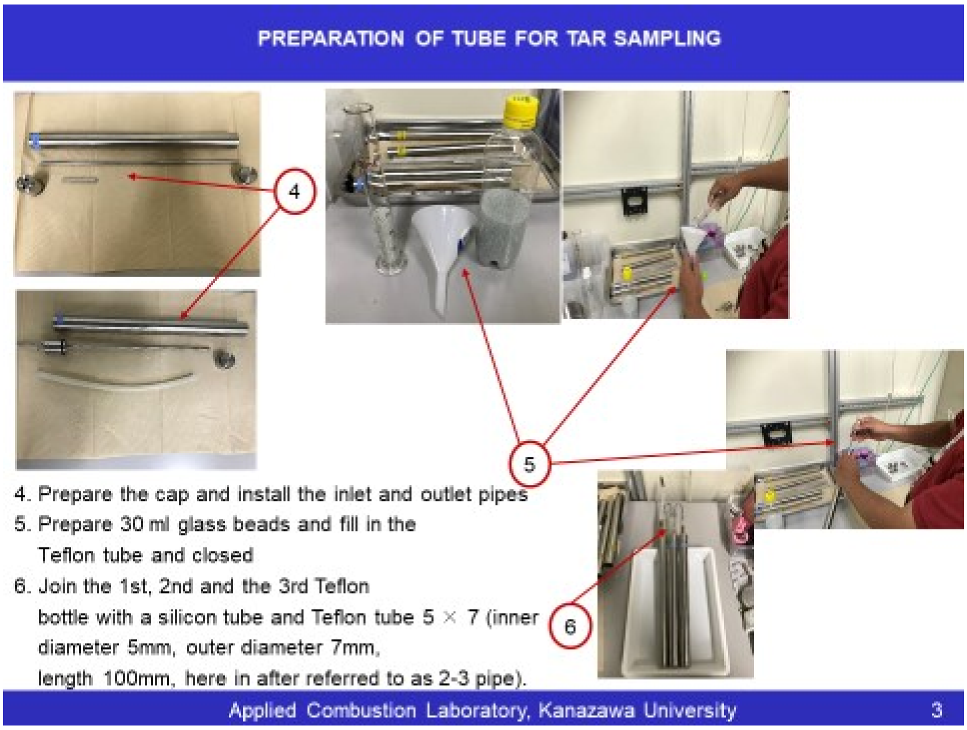
Purpose: Tar sampling is step to capture tar during biomass process

Step Preparation:

1. Prepare the Teflon tube tar sampler necessary number of self-made collection Teflon tube (volume about 150 ml)., tube 1,2,3

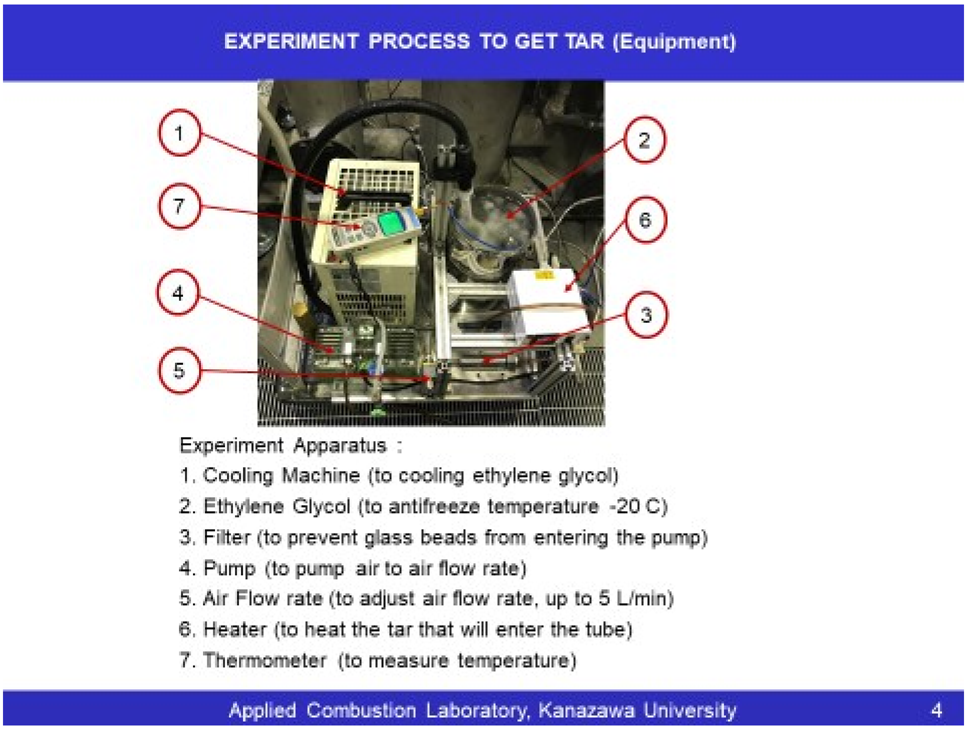
2. Prepare fixing, screw and O ring rubber

3. Fixed the O ring rubber to the cap



PREPARATION OF TUBE FOR TAR SAMPLING

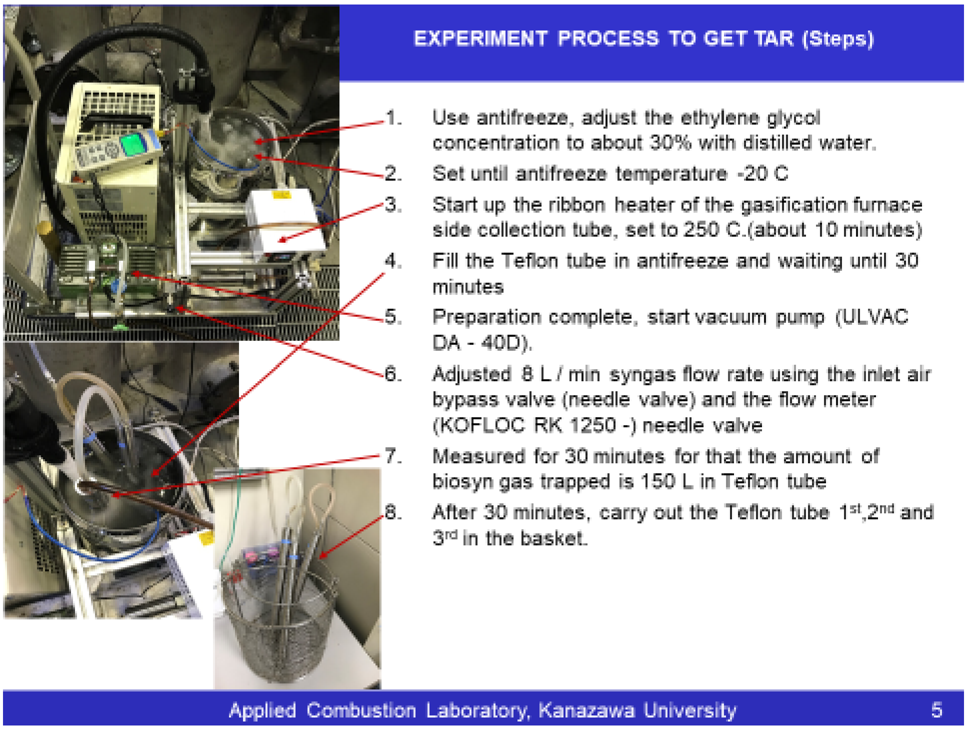
4. Prepare the cap and install the inlet and outlet pipes
5. Prepare 30 ml glass beads and fill in the
   Teflon tube and closed
6. Join the 1st, 2nd and the 3rd Teflon
   bottle with a silicon tube and Teflon tube 5 × 7 (inner
   diameter 5mm, outer diameter 7mm,
   length 100mm, here in after referred to as 2-3 pipe).



EXPERIMENT PROCESS TO GET TAR (Equipment)

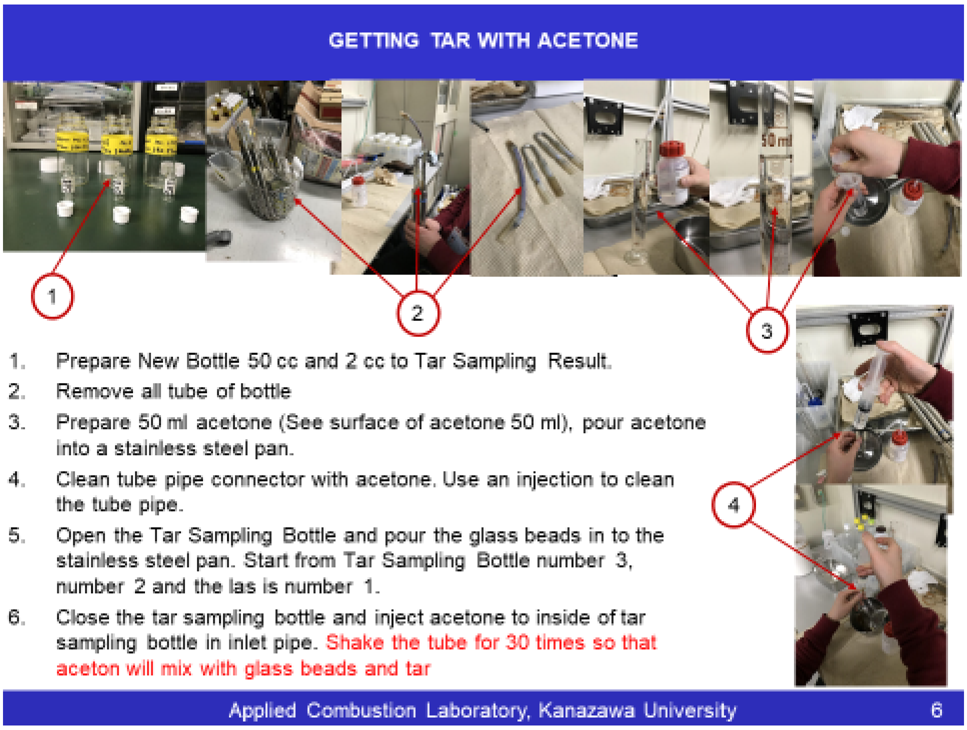
Experiment Apparatus :

1. Cooling Machine (to cooling ethylene glycol)
2. Ethylene Glycol (to antifreeze temperature -20 C)
3. Filter (to prevent glass beads from entering the pump)
4. Pump (to pump air to air flow rate)
5. Air Flow rate (to adjust air flow rate, up to 5 L/min)
6. Heater (to heat the tar that will enter the tube)
7. Thermometer (to measure temperature)



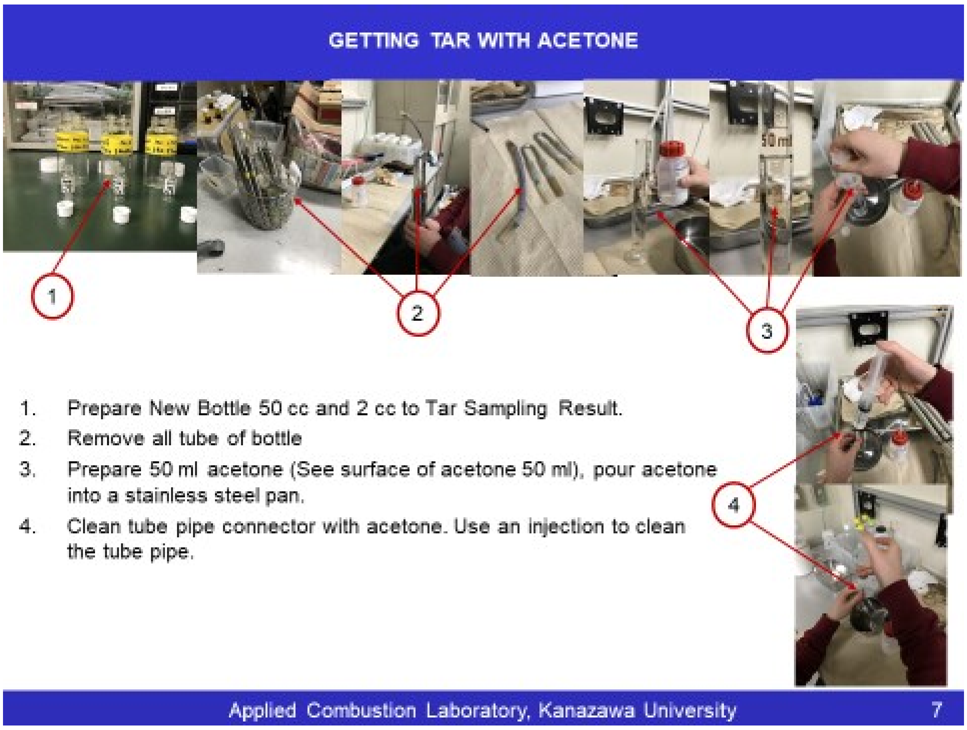
EXPERIMENT PROCESS TO GET TAR (Steps)

1. Use antifreeze, adjust the ethylene glycol concentration to about 30% with distilled water.
2. Set until antifreeze temperature -20 C
3. Start up the ribbon heater of the gasification furnace side collection tube, set to 250 C.(about 10 minutes)
4. Fill the Teflon tube in antifreeze and waiting until 30 minutes
5. Preparation complete, start vacuum pump (ULVAC DA - 40D).
6. Adjusted 8 L / min syngas flow rate using the inlet air bypass valve (needle valve) and the flow meter (KOFLOC RK 1250 -) needle valve
7. Measured for 30 minutes for that the amount of biosyn gas trapped is 150 L in Teflon tube
8. After 30 minutes, carry out the Teflon tube 1st,2nd and 3rd in the basket.



GETTING TAR WITH ACETONE

1. Prepare New Bottle 50 cc and 2 cc to Tar Sampling Result.
2. Remove all tube of bottle
3. Prepare 50 ml acetone (See surface of acetone 50 ml), pour acetone into a stainless steel pan.
4. Clean tube pipe connector with acetone. Use an injection to clean the tube pipe.
5. Open the Tar Sampling Bottle and pour the glass beads in to the stainless steel pan. Start from Tar Sampling Bottle number 3, number 2 and the las is number 1.
6. Close the tar sampling bottle and inject acetone to inside of tar sampling bottle in inlet pipe. Shake the tube for 30 times so that aceton will mix with glass beads and tar



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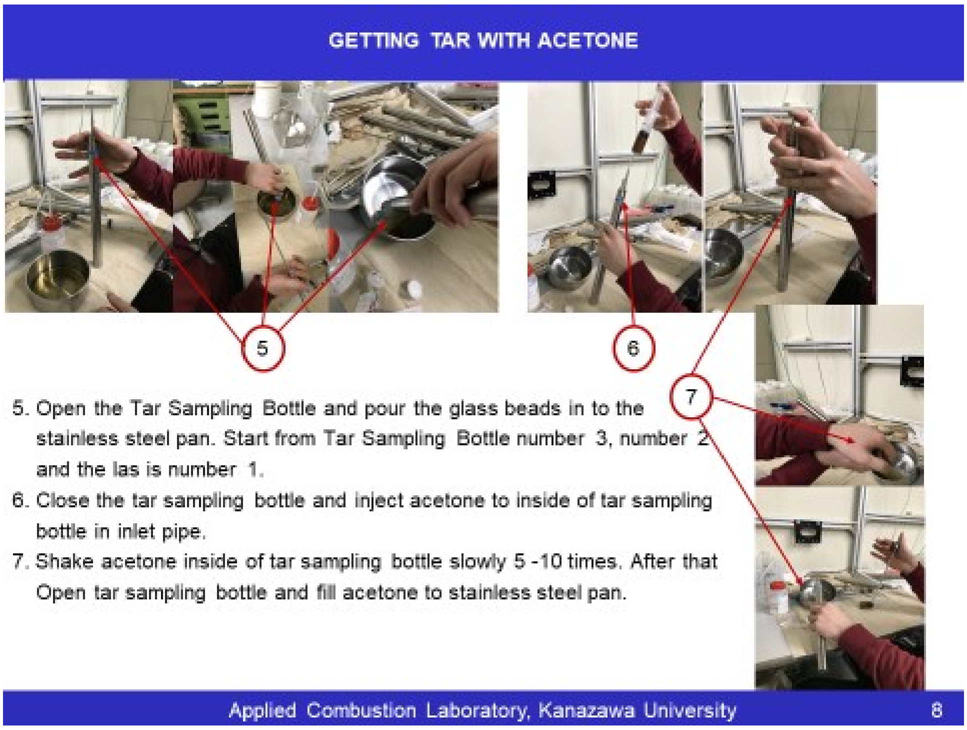
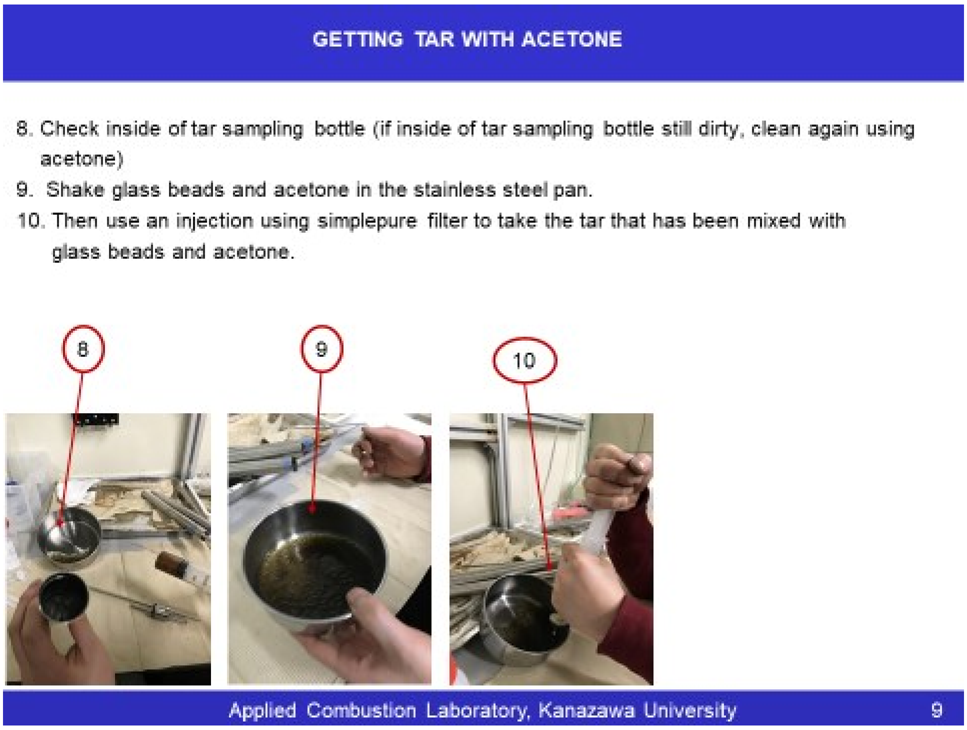


GETTING TAR WITH ACETONE

5. Open the Tar Sampling Bottle and pour the glass beads in to the stainless steel pan. Start from Tar Sampling Bottle number 3, number 2 and the las is number 1.
6. Close the tar sampling bottle and inject acetone to inside of tar sampling bottle in inlet pipe.
7. Shake acetone inside of tar sampling bottle slowly 5 -10 times. After that Open tar sampling bottle and fill acetone to stainless steel pan.



GETTING TAR WITH ACETONE

8. Check inside of tar sampling bottle (if inside of tar sampling bottle still dirty, clean again using acetone)
9. Shake glass beads and acetone in the stainless steel pan.
10. Then use an injection using simplepure filter to take the tar that has been mixed with glass beads and acetone.

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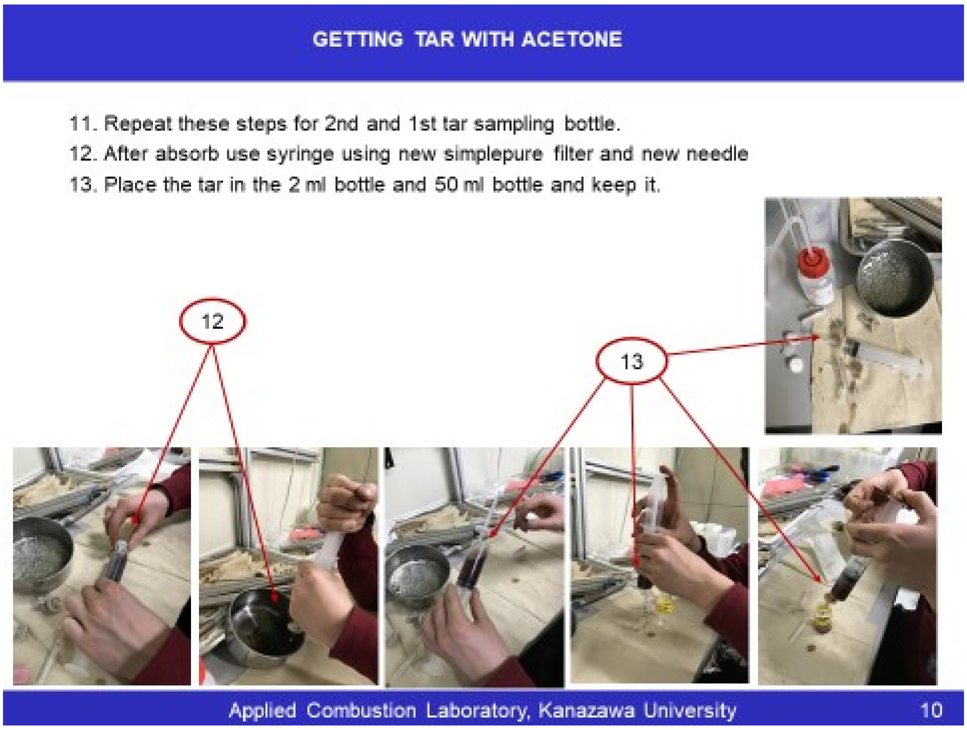

GETTING TAR WITH ACETONE

11. Repeat these steps for 2nd and 1st tar sampling bottle.
12. After absorb use syringe using new simplepure filter and new needle
13. Place the tar in the 2 ml bottle and 50 ml bottle and keep it.

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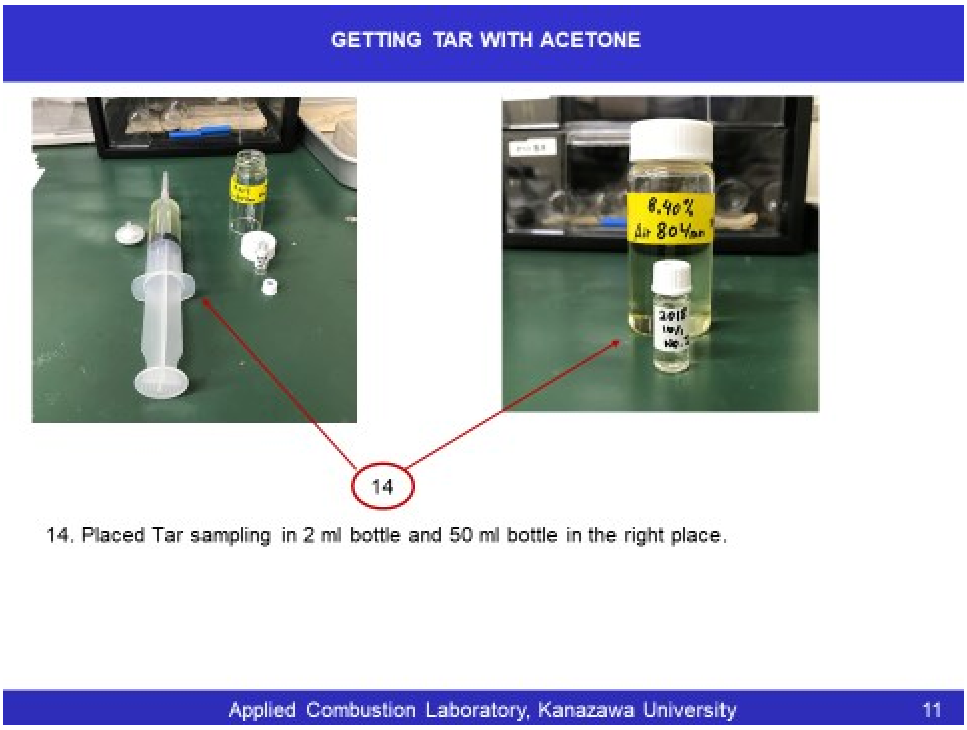
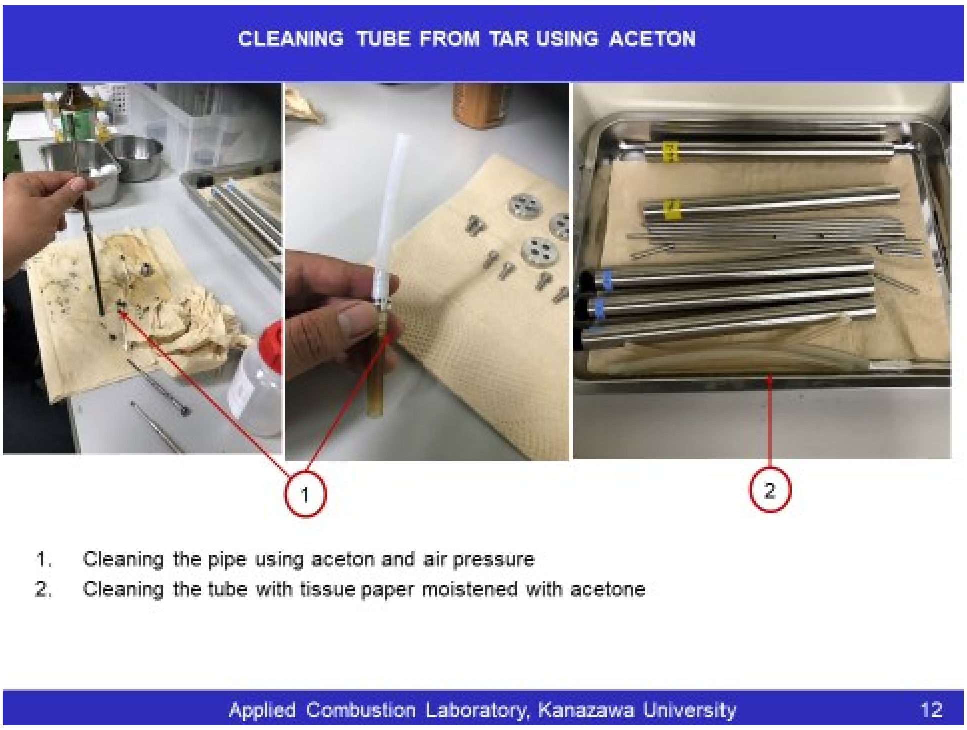


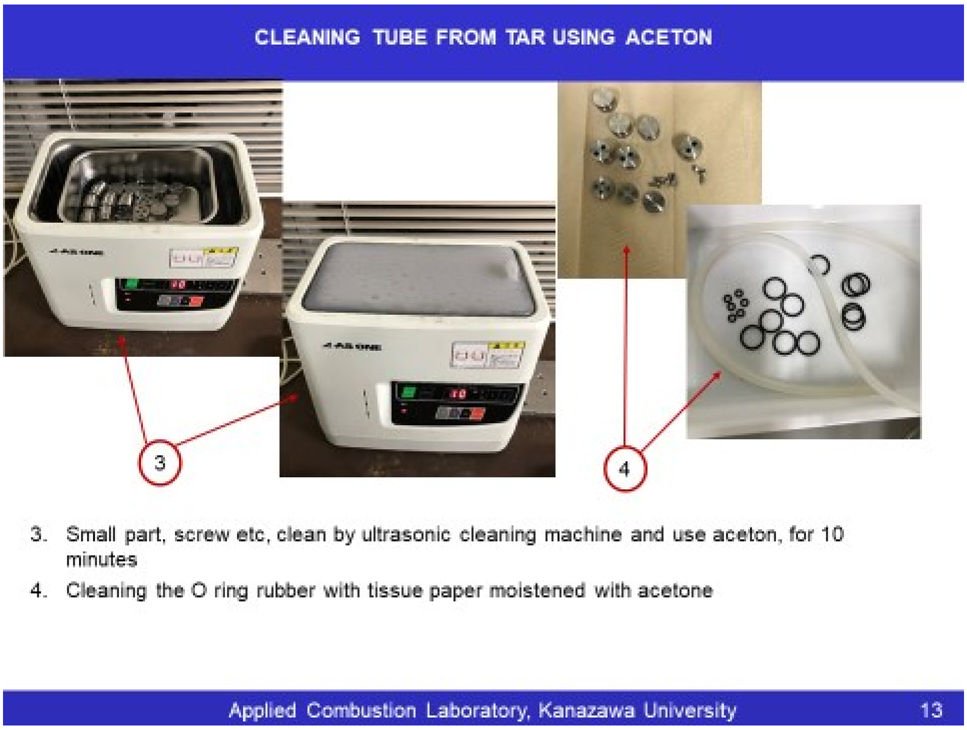
GETTING TAR WITH ACETONE

14. Placed Tar sampling in 2 ml bottle and 50 ml bottle in the right place.



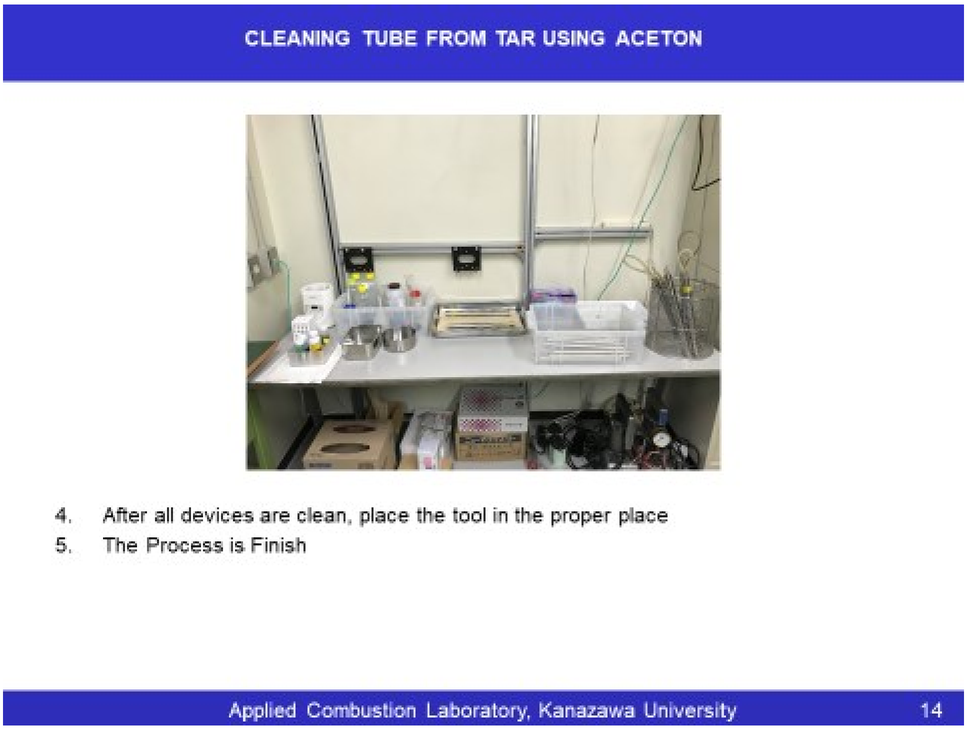
CLEANING TUBE FROM TAR USING ACETON

1. Cleaning the pipe using aceton and air pressure
2. Cleaning the tube with tissue paper moistened with acetone



CLEANING TUBE FROM TAR USING ACETON

3. Small part, screw etc, clean by ultrasonic cleaning machine and use aceton, for 10 minutes
4. Cleaning the O ring rubber with tissue paper moistened with acetone

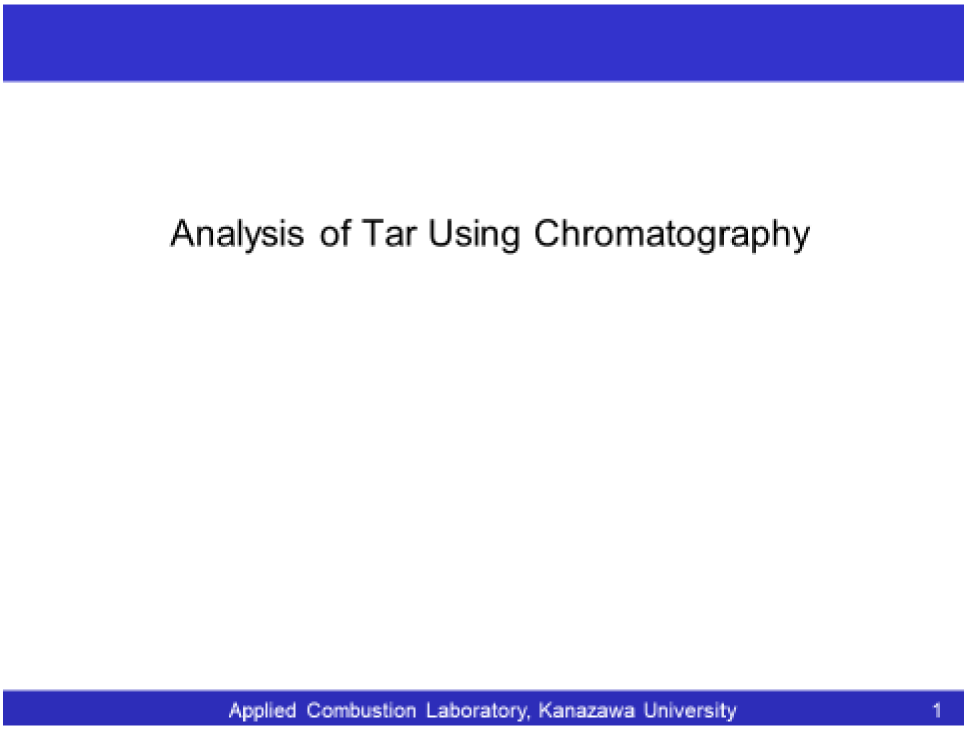


CLEANING TUBE FROM TAR USING ACETON

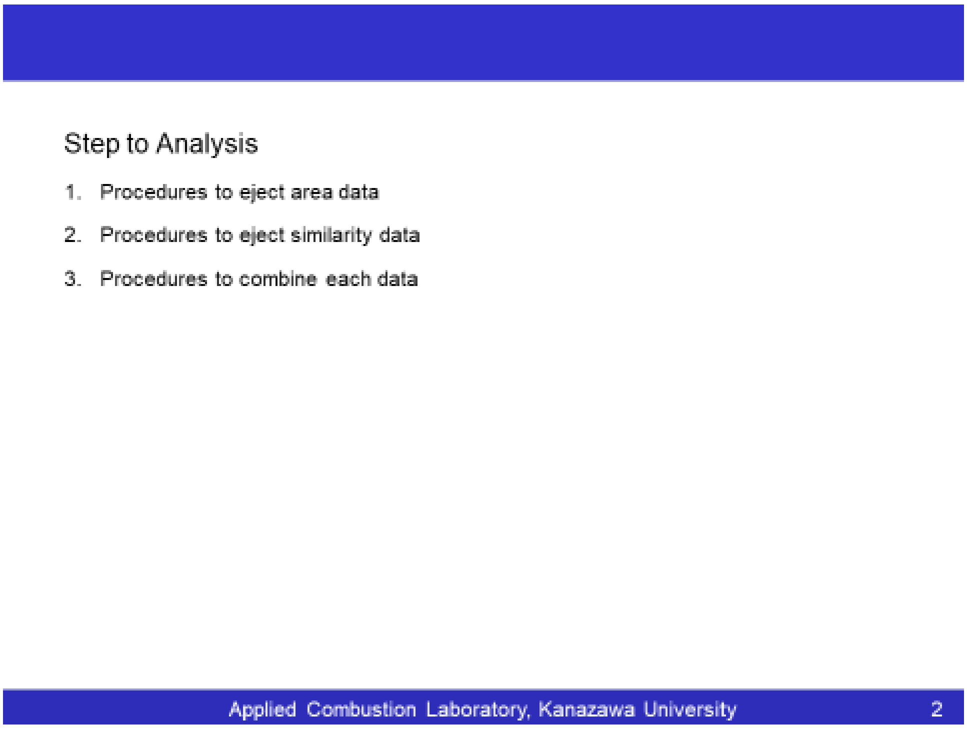
4. After all devices are clean, place the tool in the proper place
5. The Process is Finish

APPENDIX 8. ANALYSIS OF TAR

ANALYSIS OF TAR USING CHROMATOGRAPHY



Analysis of Tar Using Chromatography



Step to Analysis

1. Procedures to eject area data
2. Procedures to eject similarity data
3. Procedures to combine each data

1. Procedures to eject area data

1. Select GCMS Postrun Analysis icon from the desktop

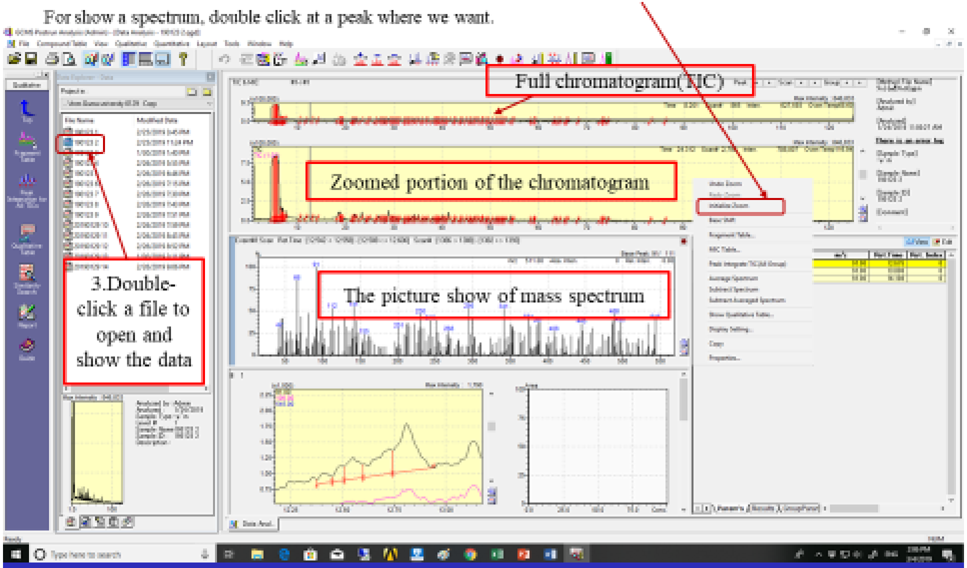
User ID: Admin

Password:

2. Fill User ID: Admin and click OK

1. Procedures to eject area data

3. For look closer of chromatogram peak, drag the peak using mouse.
For zoom out and back to previous condition, right click and select "Initialize Zoom ".
For show a spectrum, double click at a peak where we want.



Full chromatogram(TIC)

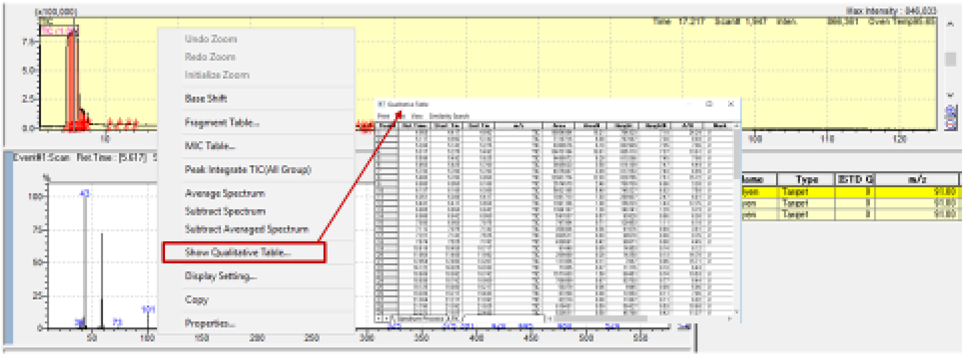
Zoomed portion of the chromatogram

The picture show of mass spectrum

3.Double-click a file to open and show the data

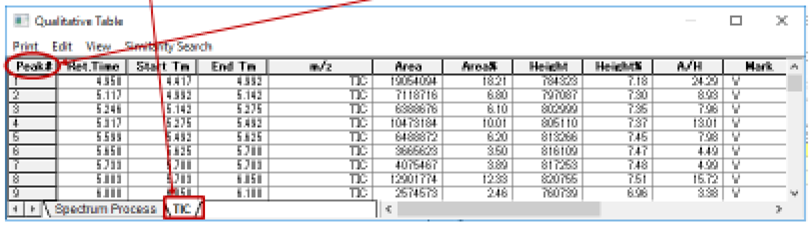
1. Procedures to eject area data

4. Right click in mouse at “Zoom portion” and left click “Show Qualitative Table”, and the Qualitative Table will appear.



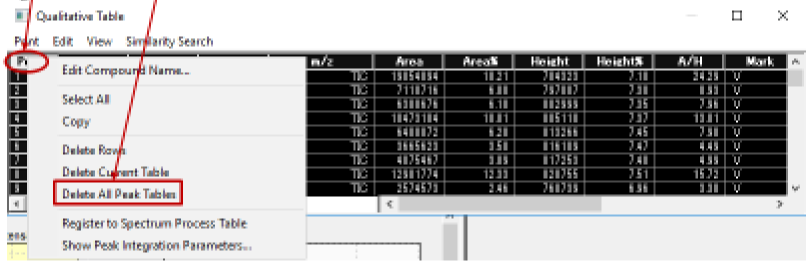
1. Procedures to eject area data

5. Select “TIC” tab and using mouse to left click “upper left corner” to choose all spectrum



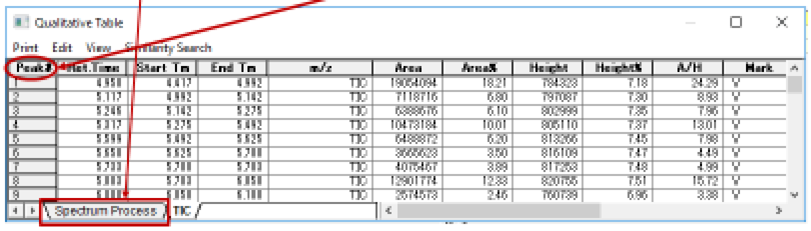
Peak#	Ret.Time	Start Tm	End Tm	m/z	Area	Area%	Height	Height%	A/H	Mark
1	4.850	4.417	4.892	TIC	19054094	18.21	784323	7.18	24.29	V
2	5.117	4.892	5.142	TIC	7118716	6.80	797087	7.30	8.93	V
3	5.246	5.142	5.275	TIC	6388676	6.10	802999	7.35	7.96	V
4	5.317	5.275	5.492	TIC	10473184	10.01	805110	7.37	13.01	V
5	5.599	5.492	5.625	TIC	6488872	6.20	813266	7.45	7.98	V
6	5.650	5.625	5.700	TIC	3665623	3.50	816109	7.47	4.49	V
7	5.733	5.700	5.783	TIC	4075467	3.89	817253	7.48	4.99	V
8	5.883	5.783	6.050	TIC	12901774	12.33	820755	7.51	15.72	V
9	6.083	6.050	6.100	TIC	2574573	2.46	760739	6.96	3.38	V

6. Left Click on left upper corner to choose all spectrum data and we will get “Black Area”, after that Right click “Delete All Peak Tables” in TIC



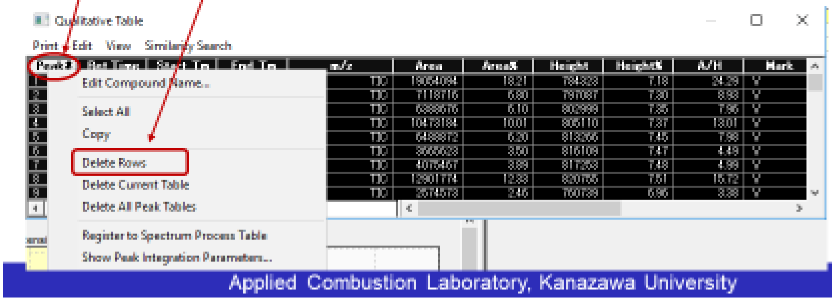
1. Procedures to eject area data

6. Select "Spectrum Process" and left click at "left upper corner" to select all spectrum data



Peak#	Ret.Time	Start Tm	End Tm	m/z	Area	Area%	Height	Height%	A/H	Mark
1	4.958	4.417	4.992	TIC	19054094	18.21	784323	7.18	24.29	V
2	5.117	4.992	5.142	TIC	7118716	6.80	797087	7.30	8.93	V
3	5.246	5.142	5.275	TIC	6388676	6.10	802999	7.35	7.96	V
4	5.317	5.275	5.492	TIC	10473184	10.01	805110	7.37	13.01	V
5	5.599	5.492	5.625	TIC	6488872	6.20	813266	7.45	7.98	V
6	5.658	5.625	5.708	TIC	3665623	3.50	816109	7.47	4.49	V
7	5.733	5.708	5.783	TIC	4075467	3.89	817253	7.48	4.99	V
8	5.883	5.783	6.058	TIC	12901774	12.33	820755	7.51	15.72	V
9	6.083	6.058	6.108	TIC	2574573	2.46	760739	6.96	3.38	V

7. Left click on upper left corner from "Spectrum Process" and after that right click at black area and select "Delete Rows"



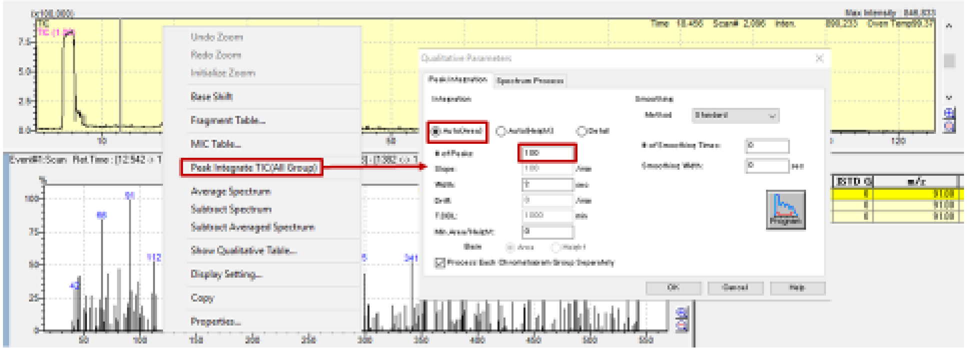
1. Procedures to eject area data

8. Right click at mouse and will appear any choice, choose "Fragment Table"

9. For open MC Fragment Table , select "TIC" and after that click "OK"

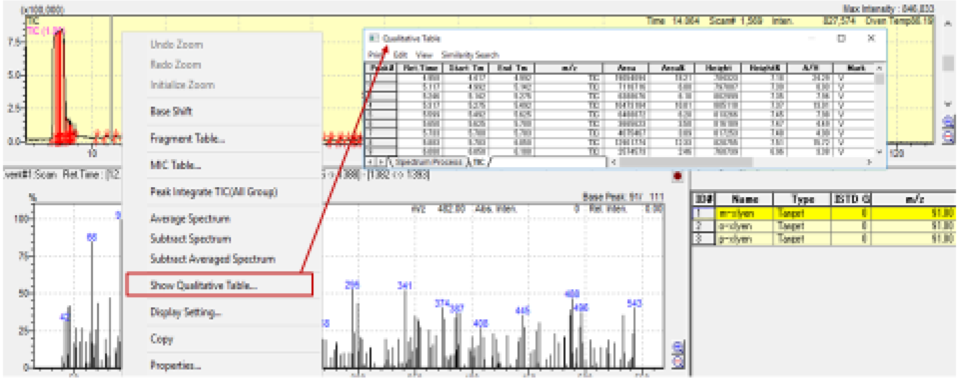
1. Procedures to eject area data

10. Click Right using mouse on “Zoom portion” and choose “Peak Integrate TIC (All Group) to open Qualitative Parameter
11. After that select “Auto(Area)”
12. Fill the number of peaks into “# of Peaks”
13. Click “OK”



1. Procedures to eject area data

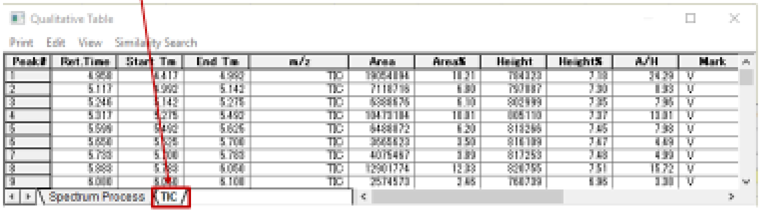
14. Right click on “Zoom portion” to open Qualitative Table
15. This table contain “TIC” and “Spectrum Process”
16. This table show the result of desired



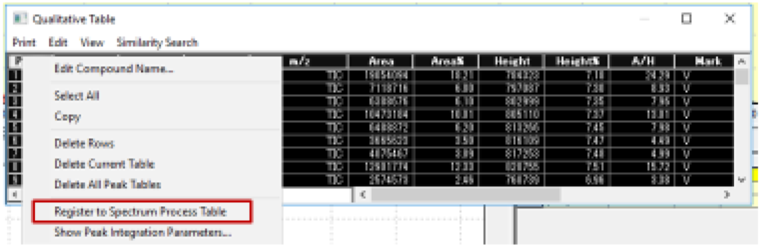
1. Procedures to eject area data

17. Select "TIC" on Qualitative Table

Select one or more or all peak of peak by left click on left upper corner of table.



18. After that Right click on " Black Area" and choose Register to Spectrum Process Table



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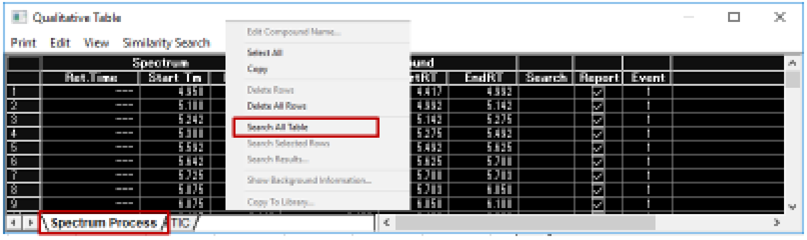
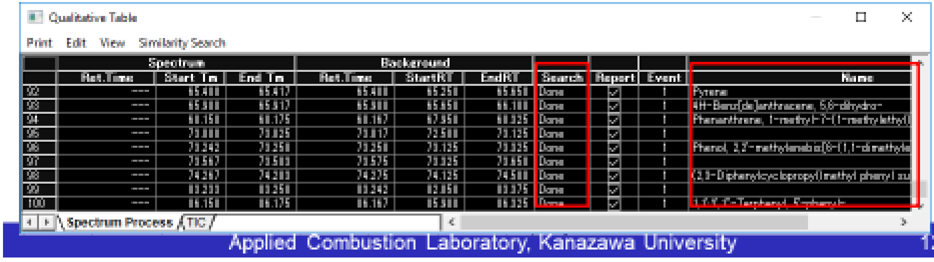
1. Procedures to eject area data

19. Select "Spectrum Process"

Select all peak by Right click on "Black Area" and click " Search All Table" to identify the name of peak from library



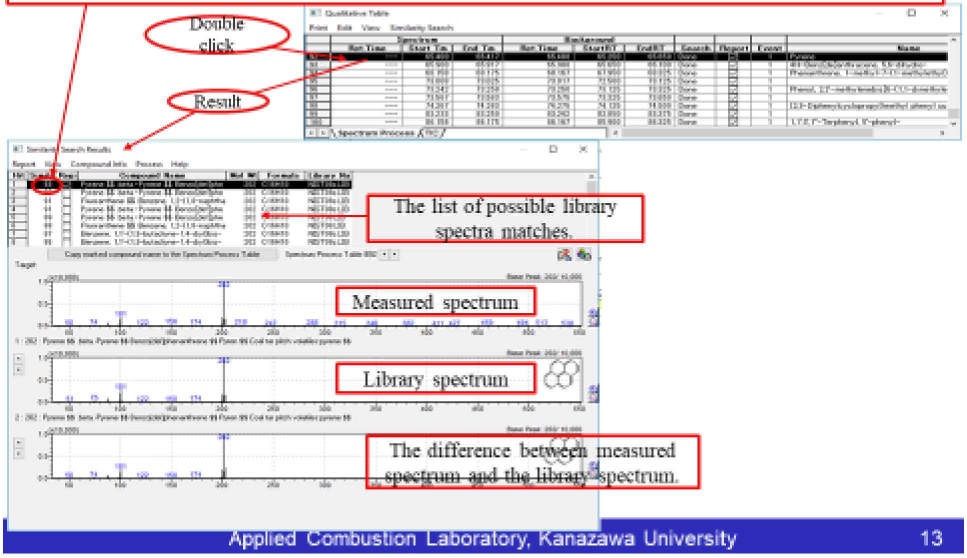
20. Result after reaching name of peak in library will show on search "Search" indicate done and have "Name of compounds" in "Name" coloumn



1. Procedures to eject area data

21. Double click one peak in the “Spectrum Process” to show search result

Make sure to check “similarity” of each substance
If the similarity of compound is less than 80, recommend to delete the rows of compound from TIC table



Double click

Result

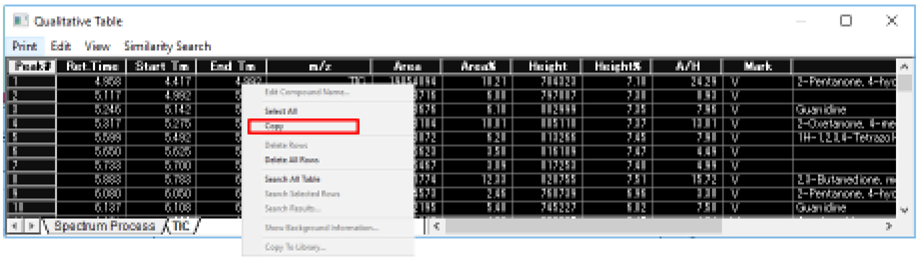
The list of possible library spectra matches.

Measured spectrum

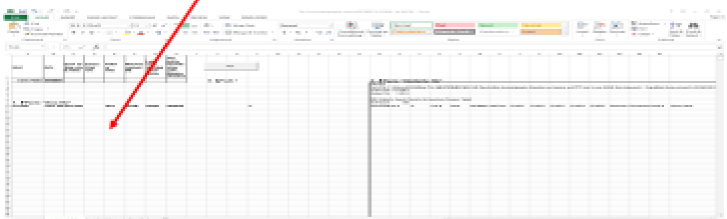
Library spectrum

The difference between measured spectrum and the library spectrum.

1. Procedures to eject area data

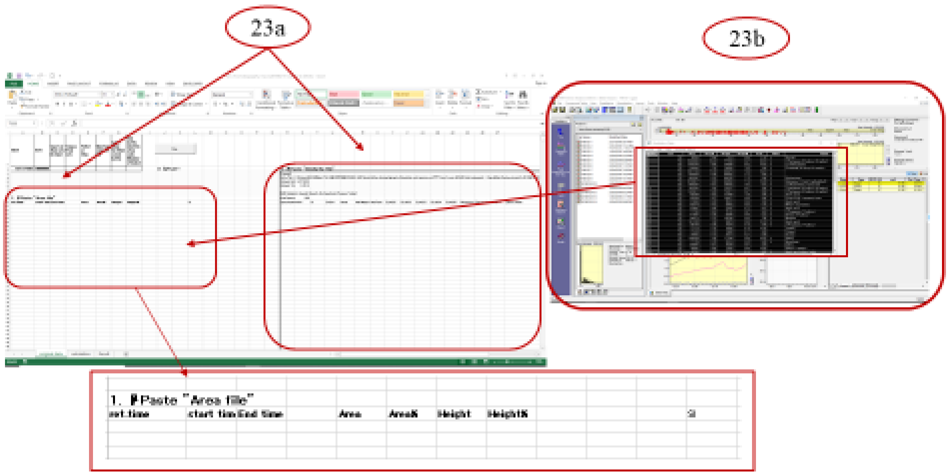


22. Select column of “Ret.time”, “Area” and “Name” in TIC tab, or all column in TIC tab.
Right click on “Balck Area” and select copy.
Open Microsft excel and paste the value to excel



2. Procedures to export similarity data

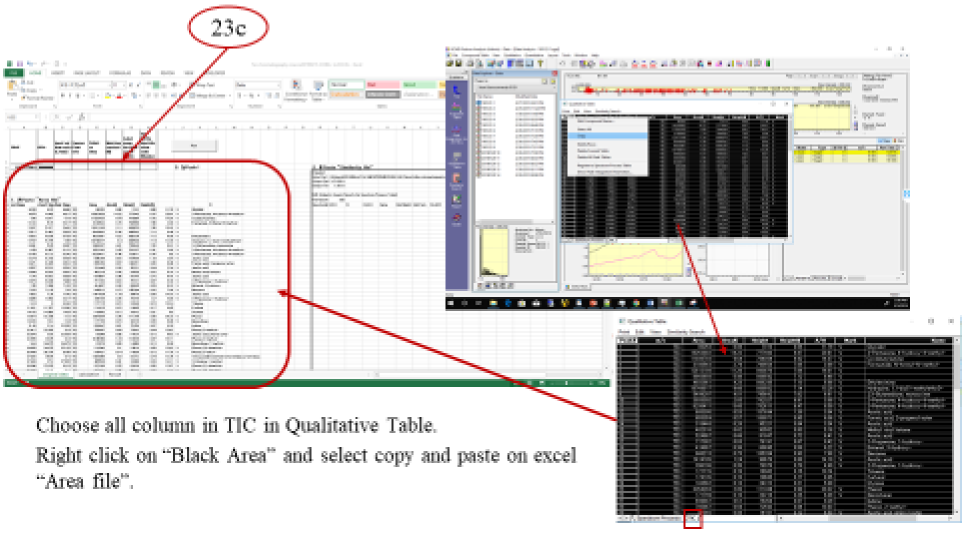
23. After got transfer data from chromato analysis, we analysis data in excel as follow:
    23.a. Delete all data on "Original data" file and including " Area file" and " Similarity file"
    23.b. input data "Area file" using data from "Qualitative table" in chromatography file



1. Paste "Area file"
ret.time start tim End time Area Area% Height Height% SI

2. Procedures to export similarity data

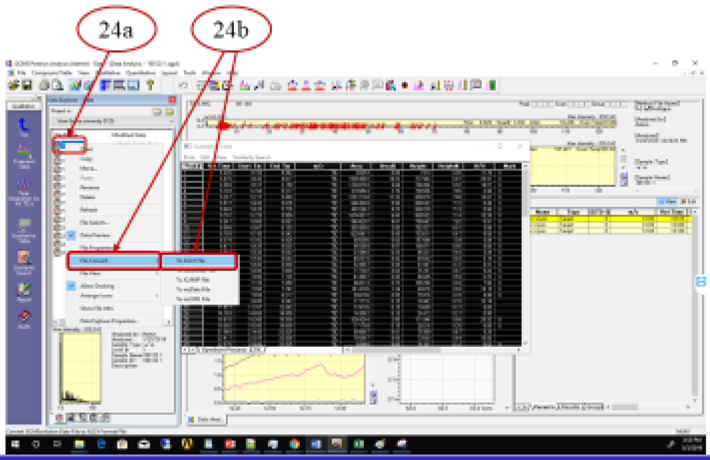
After got transfer data from chromate analysis, we analysis data in excel as follow:
23.c. Result after copy data from "Qualitative table in TIC"



Choose all column in TIC in Qualitative Table.
Right click on "Black Area" and select copy and paste on excel "Area file".

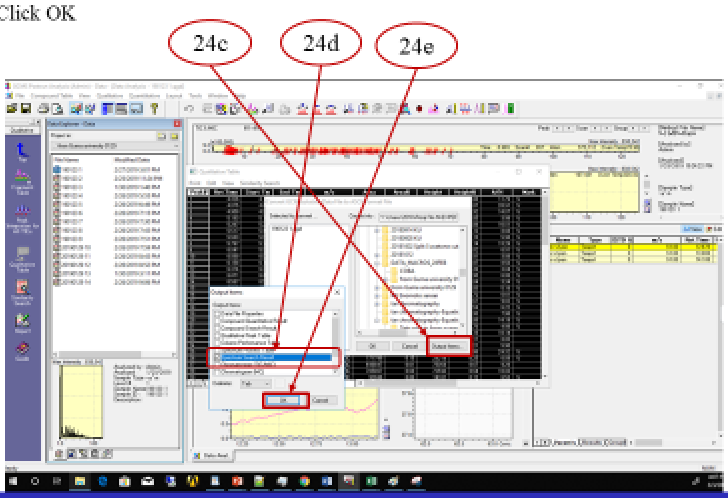
2. Procedures to export similarity data

24.To export similarity data each component is quantified, use this method:
   24.a. Select data which our target from Data explorer and right click.
   24.b. Select file convert in the menu and select output format ASCII



2. Procedures to export similarity data

To export similarity data each component is quantified, use this method:
24.c. Select file, and choose output items,
24.d. Choose Spectrum Search Result
24.e. Click OK

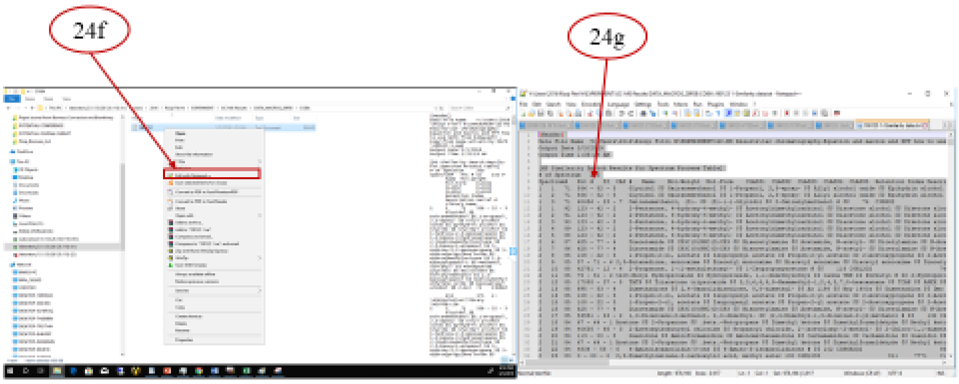


2. Procedures to export similarity data

To export similarity data each component is quantified, use this method:

24.f. After click OK, save the similarity data on the another folder

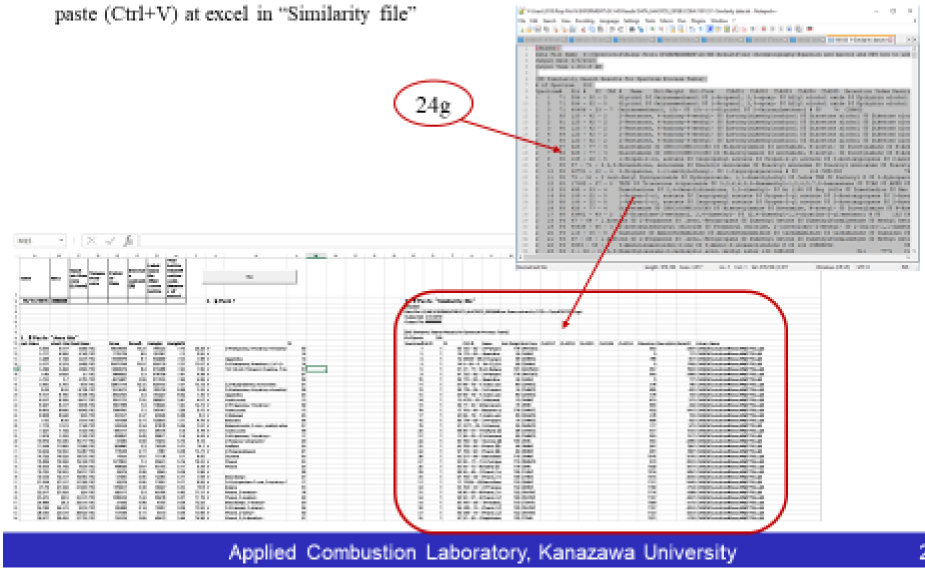
24.g. Exported data in ASCII format using notepad.(select all (Ctrl+A) and copy (Ctrl+C) and paste (Ctrl+V) at excel in “Similarity file”



2. Procedures to export similarity data

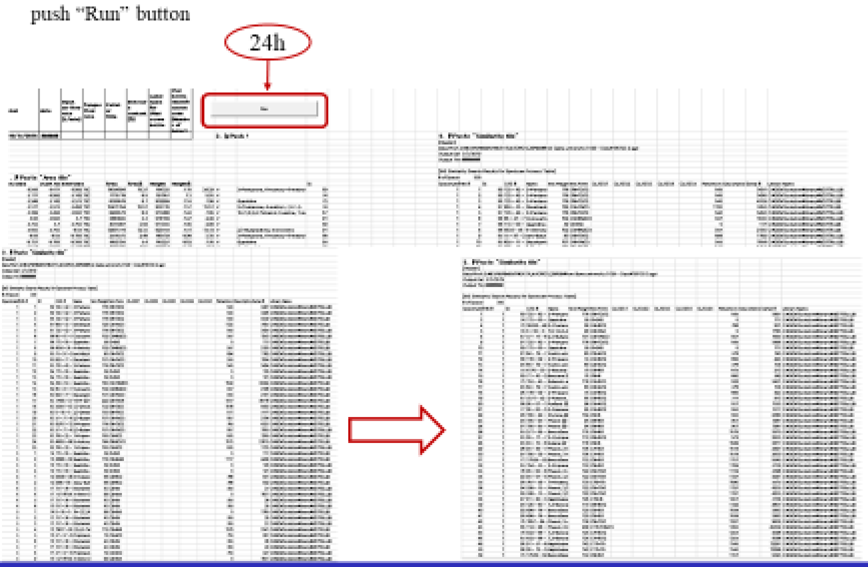
To export similarity data each component is quantified, use this method:

24.g. Exported data in ASCII format using notepad.(select all (Ctrl+A) and copy (Ctrl+C) and paste (Ctrl+V) at excel in “Similarity file”



2. Procedures to export similarity data

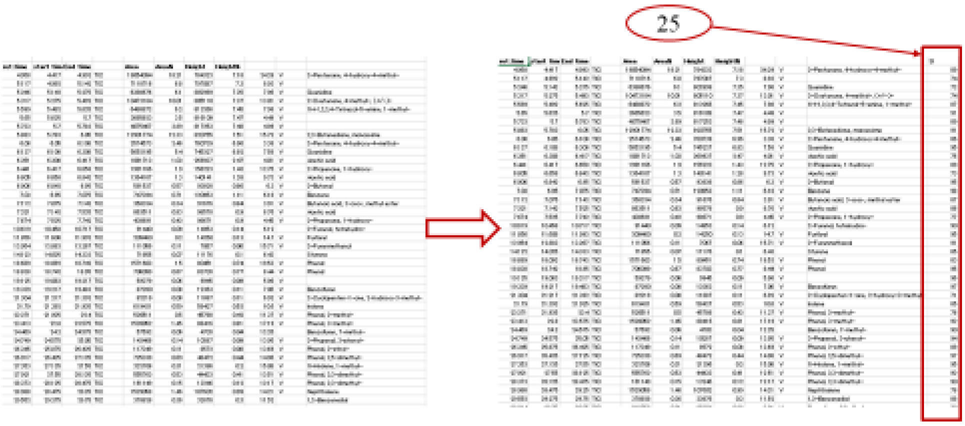
24.h. See spectrum process table, delete data if Hit more than 1 and leaving only value Hit = 1, only push "Run" button



3. Procedures to combine each data

25.Superimpose of Qualitative Analysis Result

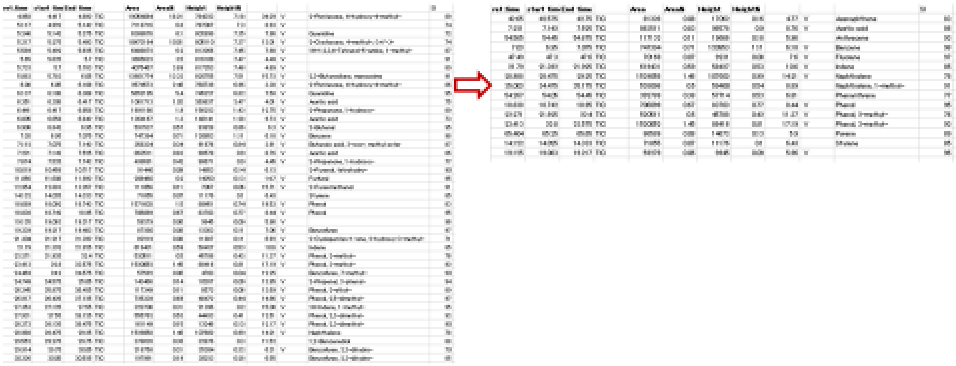
Superimpose value of similarity to produce result of qualitative analysis at calculation sheet



3. Procedures to combine each data

26.Selecting compounds

- Select compounds from the result of superimpose value of the similarity in calculation sheet
- Use compound with highest value of similarity between same compounds
- Use value of similarity more than 70, and do not use if the value less than 70



3. Procedures to combine each data

27. Calculation of concentration every compound

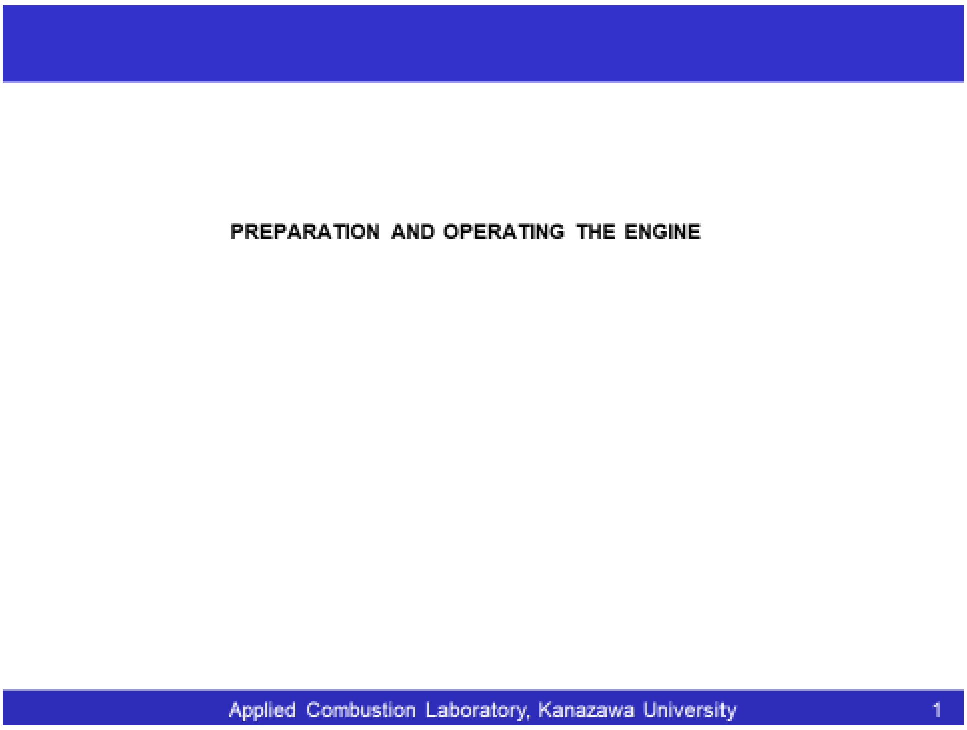
Concentration every compound calculated from value of Area I the extracted data

	Area
2-Pentanone	
Acenaphthene	81328
Acenaphthylene	
Acetic acid	863511
Anthracene	117132
Benzene	747394
Benzophenone	
Fluoranthene	
Fluorene	70169
Indene	619431
Naphthalene	1529058
Naphthalene, 1-methyl-	538098
Naphthalene, 2-methyl-	
o-Xylene	
Phenanthrene	392789
Phenol	706099
Phenol, 3-methyl-	1520062
Propanoic acid	
Pyrene	86589
Styrene	71855
Toluene	

Chemical	y	m	c	y	x
				Area	Conc.
2-Pentanone	4060x + 333	4060	3339.5	3339.5	0
Acenaphthene	15631x + 55	15631	55237	118952.41	4
Acenaphthylene	12196x + 39	12196	391472	391472	0
Acetic acid	1610.3x - 26	1610.3	-267.14	894951.71	556
Anthracene	14653x + 22	14653	22937	123649.71	7
Benzene	3989.6x + 28	3989.6	28992	621666.67	149
Benzophenone	14549x + 53	14549	53048	53048	0
Fluoranthene	13577x + 74	13577	74535	74535	0
Fluorene	14014x + 48	14014	48161	104351.96	4
Indene	27150x + 3E	27150	3.00E+06	3319141.9	12
m-Cresol	33027x + 2E	33027	2.00E+06	5510852.2	106
Naphthalene	11276x + 33	11276	331790	656931.92	29
Naphthalene, 1-methyl-	15690x + 70	15690	70417	70417	0
Naphthalene, 2-methyl-	28665x + 2E	28665	2.00E+06	2000000	0
o-Xylene	27496x + 13	27496	13329	599778.63	21
Phenanthrene	15405x + 46	15405	46375	1135666.2	71
Phenol	10633x - 51	10633	-51755	262962.75	30
Propanoic acid	1713.6x - 69	1713.6	-69505	-69505	0
Pyrene	12869x + 79	12869	79950	147992.28	5
Styrene	27496x + 13	27496	13329	69835.183	2
Toluene	4676.9x + 29	4676.9	290418	290418	0

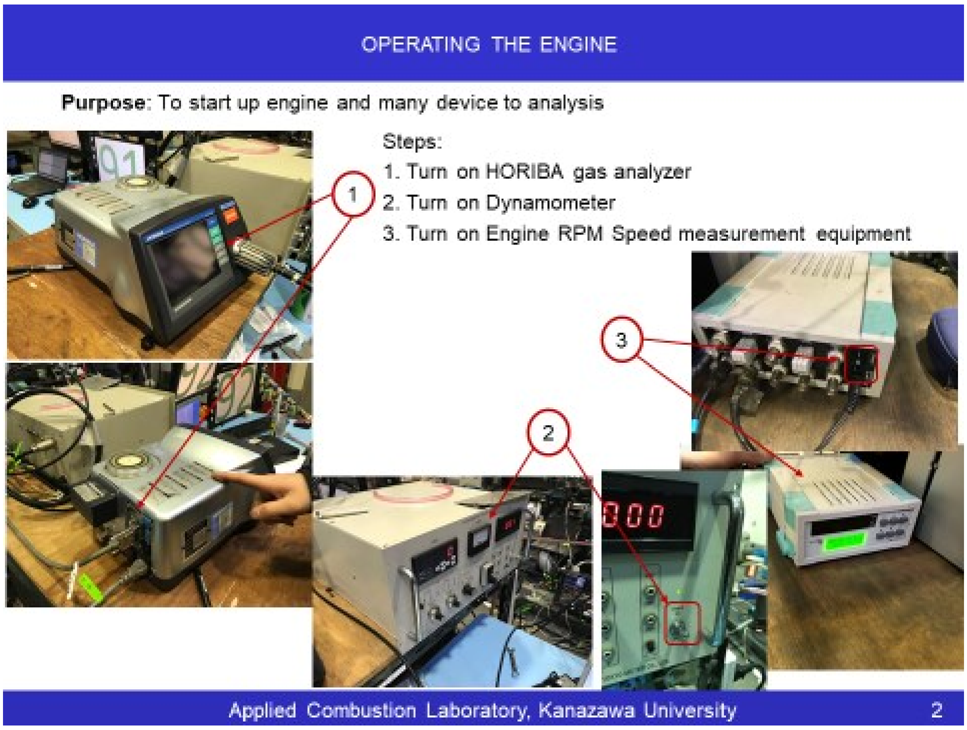
APPENDIX 9. OPERATING ENGINE

ENGINE EXPERIMENT OPERATING PROCEDURE



PREPARATION AND OPERATING THE ENGINE

Applied Combustion Laboratory, Kanazawa University 1



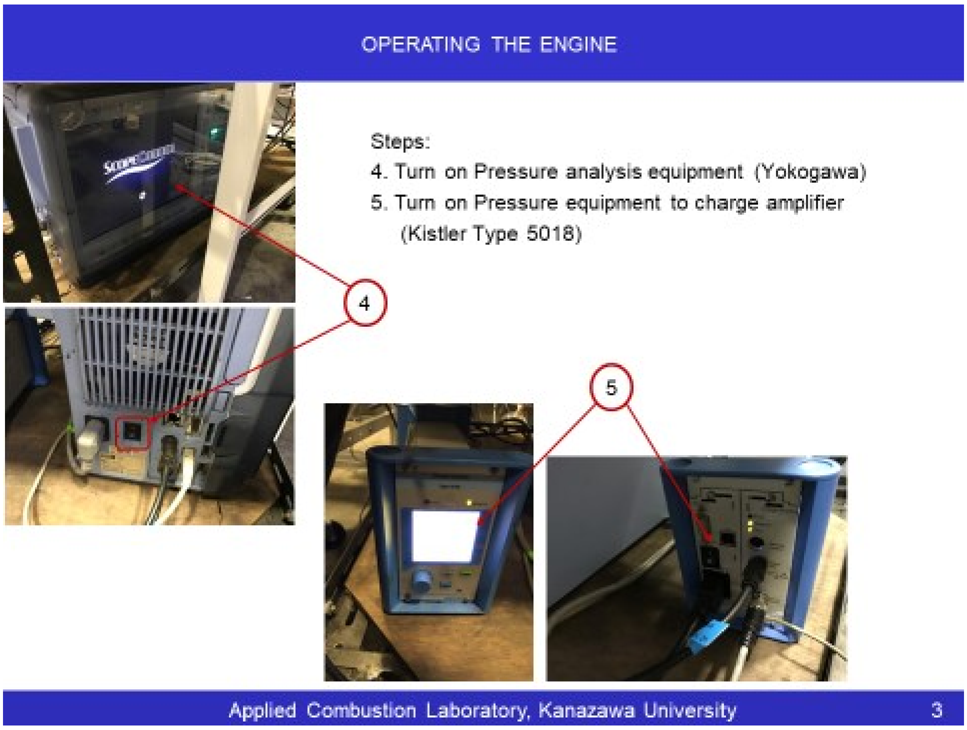
OPERATING THE ENGINE

Purpose: To start up engine and many device to analysis

Steps:

1. Turn on HORIBA gas analyzer
2. Turn on Dynamometer
3. Turn on Engine RPM Speed measurement equipment

Applied Combustion Laboratory, Kanazawa University 2

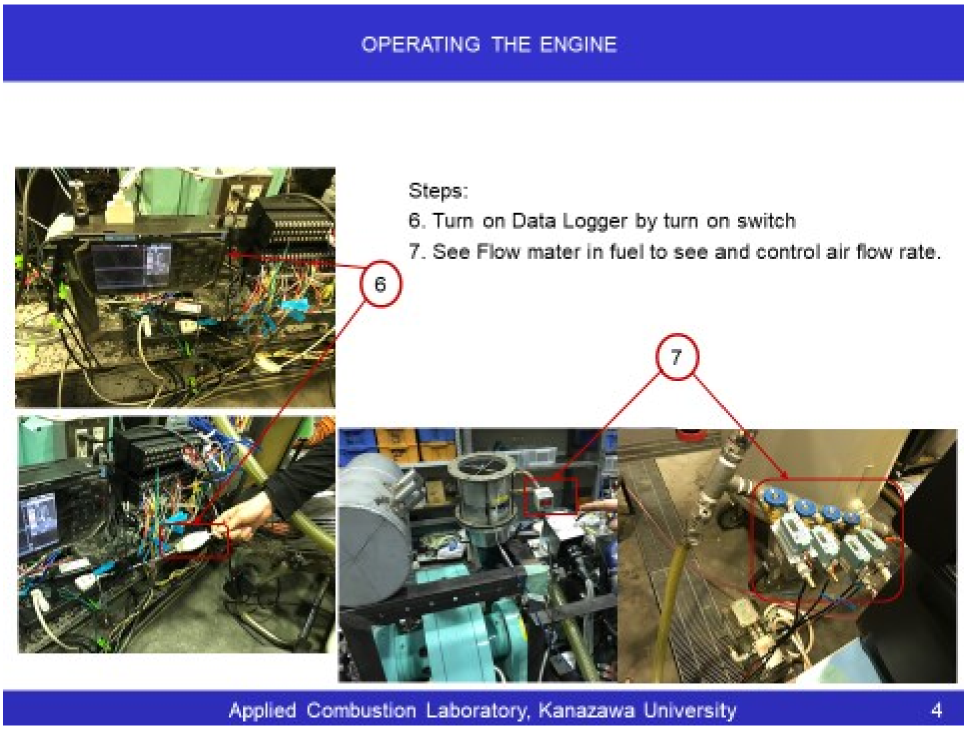


OPERATING THE ENGINE

Steps:

4. Turn on Pressure analysis equipment (Yokogawa)
5. Turn on Pressure equipment to charge amplifier (Kistler Type 5018)

Applied Combustion Laboratory, Kanazawa University 3

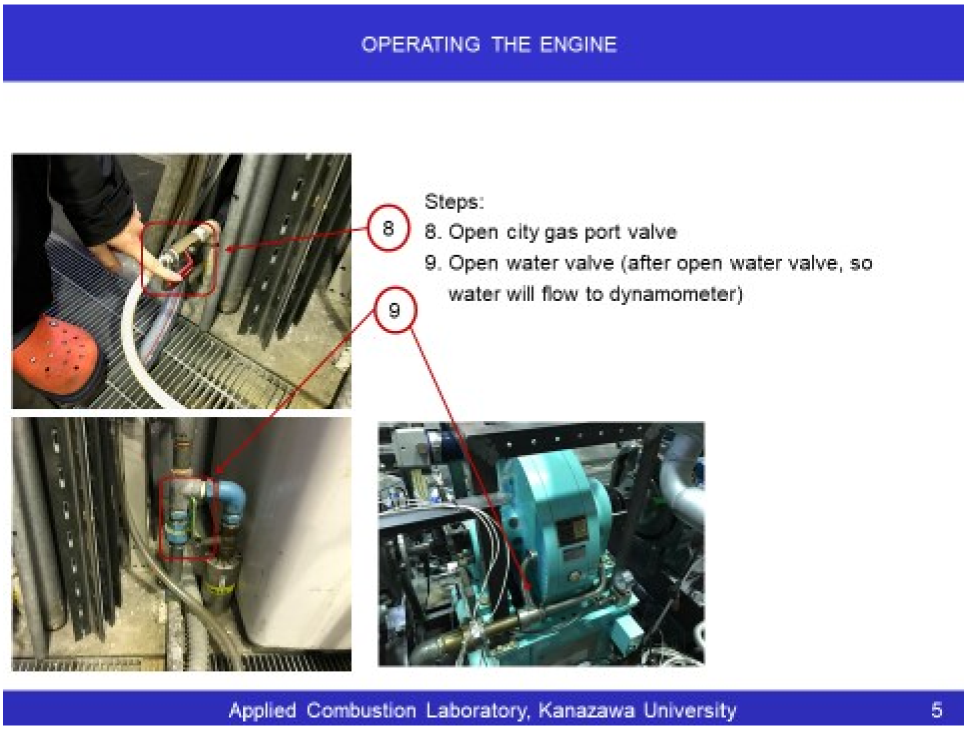


OPERATING THE ENGINE

Steps:

6. Turn on Data Logger by turn on switch
7. See Flow mater in fuel to see and control air flow rate.

Applied Combustion Laboratory, Kanazawa University 4



OPERATING THE ENGINE

Steps:

8. Open city gas port valve
9. Open water valve (after open water valve, so water will flow to dynamometer)

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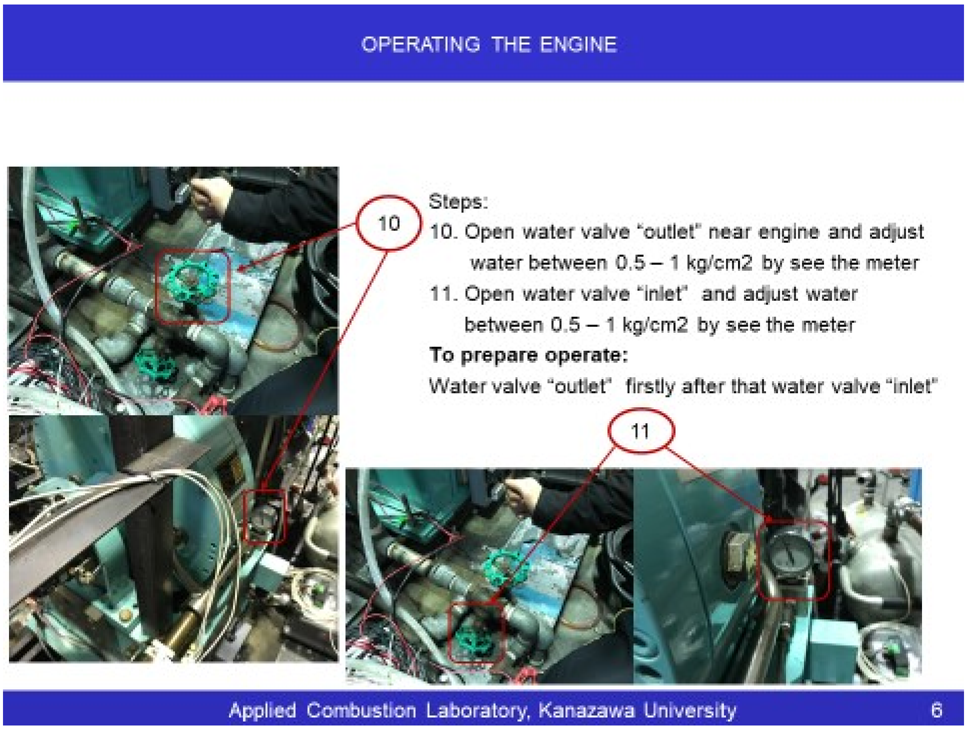


OPERATING THE ENGINE

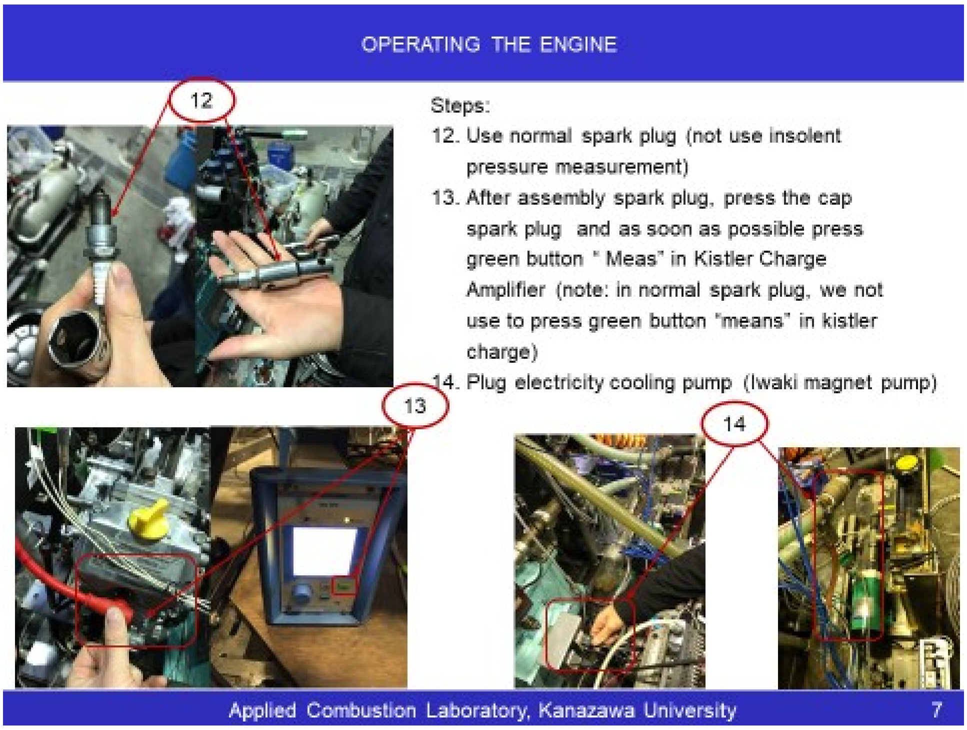
Steps:

10. Open water valve “outlet” near engine and adjust water between 0.5 – 1 kg/cm2 by see the meter
11. Open water valve “inlet” and adjust water between 0.5 – 1 kg/cm2 by see the meter

To prepare operate:

Water valve “outlet” firstly after that water valve “inlet”

Applied Combustion Laboratory, Kanazawa University 6

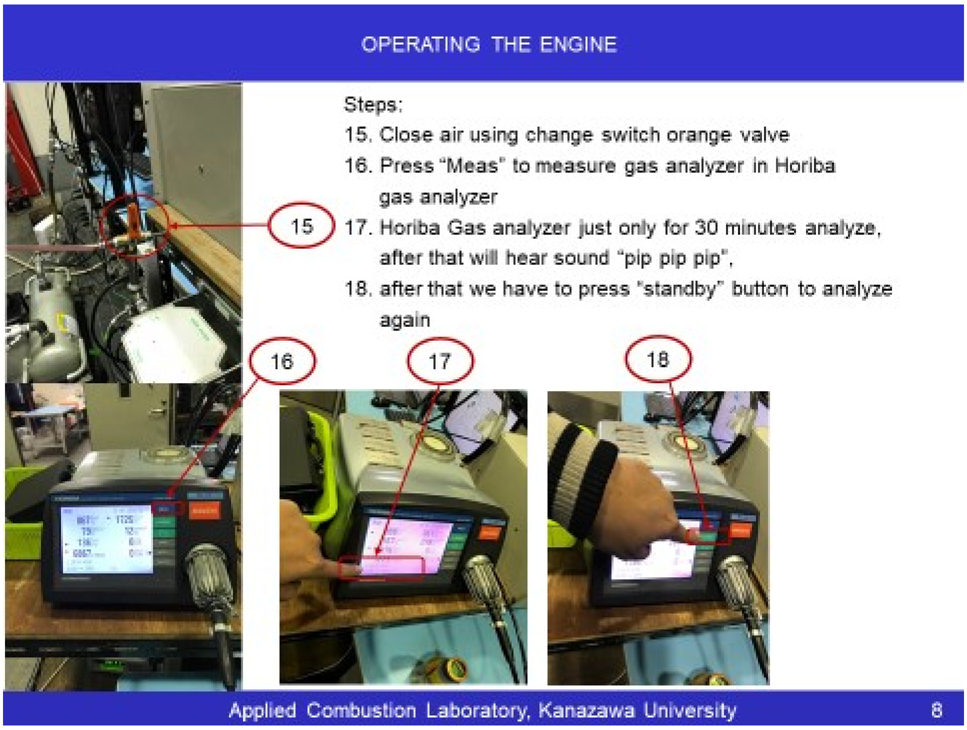


OPERATING THE ENGINE

Steps:

12. Use normal spark plug (not use insolent pressure measurement)
13. After assembly spark plug, press the cap spark plug and as soon as possible press green button " Meas" in Kistler Charge Amplifier (note: in normal spark plug, we not use to press green button "means" in kistler charge)
14. Plug electricity cooling pump (Iwaki magnet pump)

Applied Combustion Laboratory, Kanazawa University 7

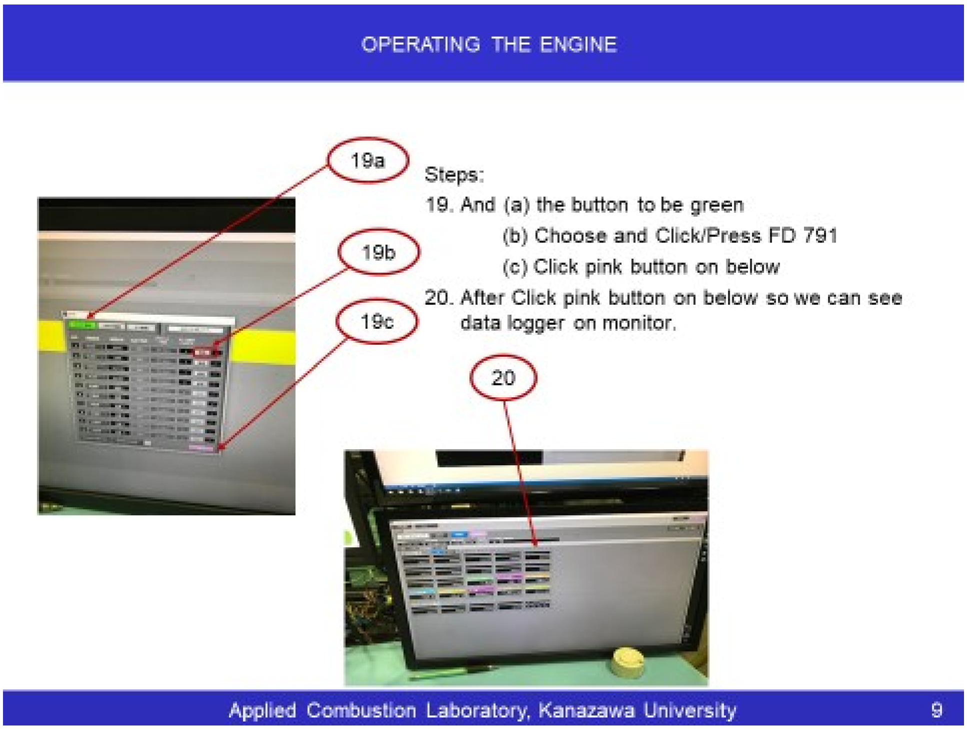


OPERATING THE ENGINE

Steps:

15. Close air using change switch orange valve
16. Press "Meas" to measure gas analyzer in Horiba gas analyzer
17. Horiba Gas analyzer just only for 30 minutes analyze, after that will hear sound "pip pip pip",
18. after that we have to press "standby" button to analyze again

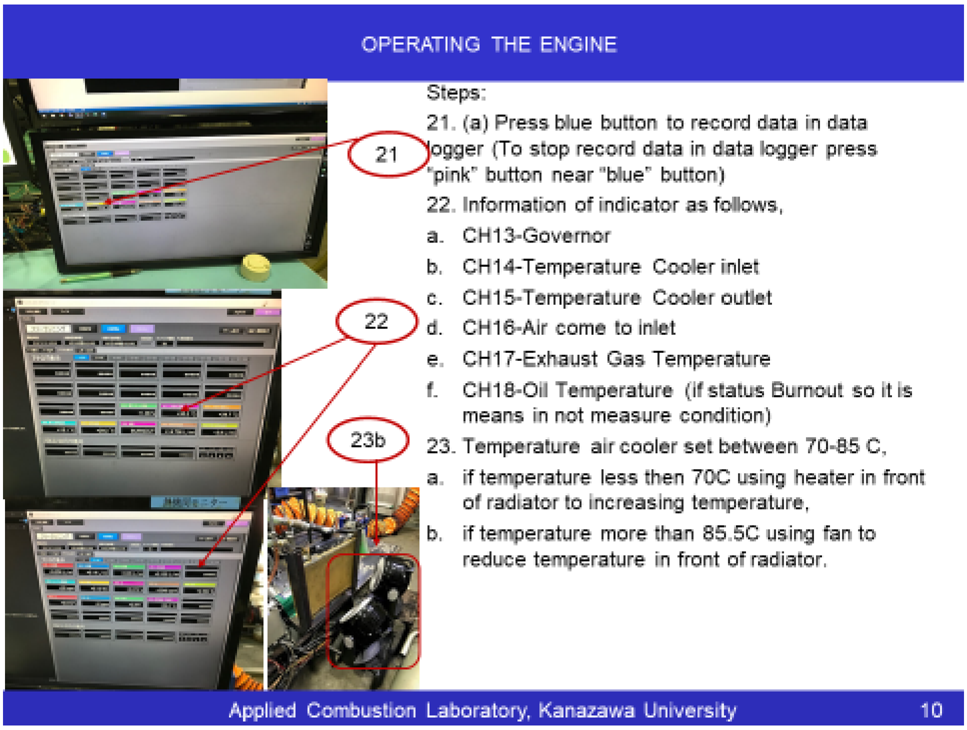
Applied Combustion Laboratory, Kanazawa University 8



OPERATING THE ENGINE

Steps:

19. And (a) the button to be green
    (b) Choose and Click/Press FD 791
    (c) Click pink button on below
20. After Click pink button on below so we can see data logger on monitor.

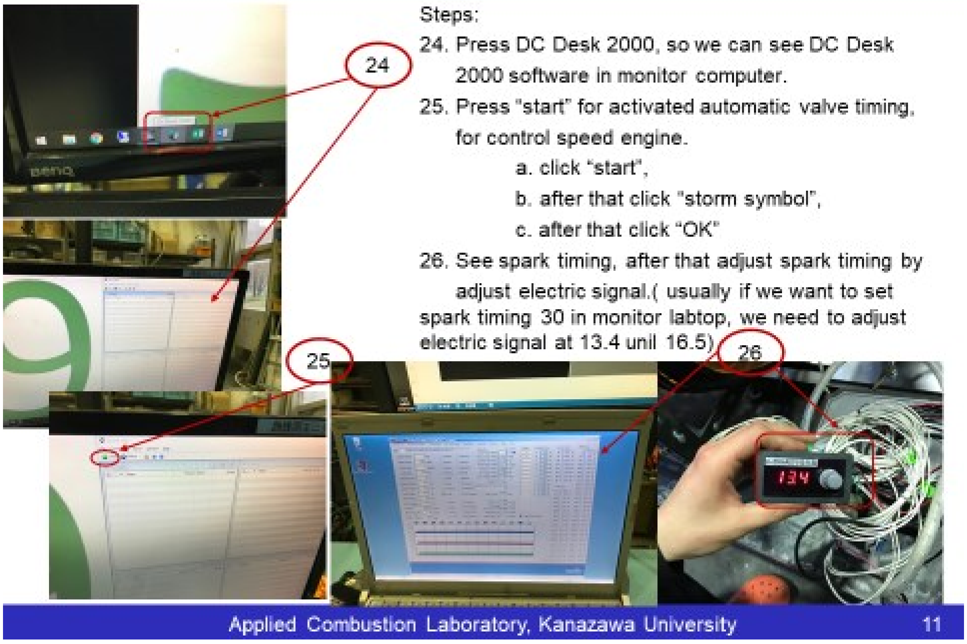


OPERATING THE ENGINE

Steps:

21. (a) Press blue button to record data in data logger (To stop record data in data logger press "pink" button near "blue" button)
22. Information of indicator as follows,
    a. CH13-Governor
    b. CH14-Temperature Cooler inlet
    c. CH15-Temperature Cooler outlet
    d. CH16-Air come to inlet
    e. CH17-Exhaust Gas Temperature
    f. CH18-Oil Temperature (if status Burnout so it is means in not measure condition)
23. Temperature air cooler set between 70-85 C,
    a. if temperature less then 70C using heater in front of radiator to increasing temperature,
    b. if temperature more than 85.5C using fan to reduce temperature in front of radiator.

OPERATING THE ENGINE



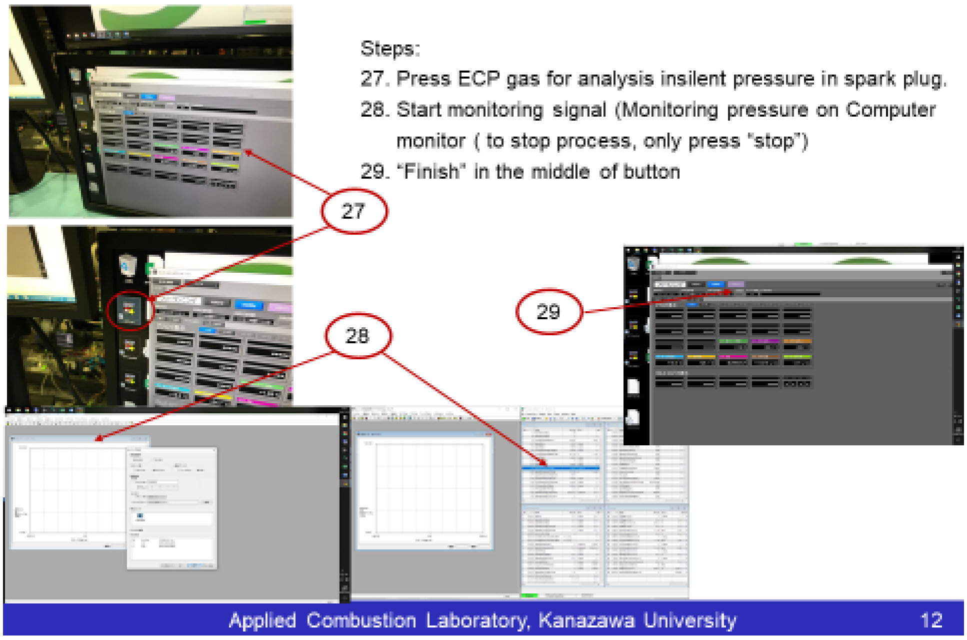
Steps:

24. Press DC Desk 2000, so we can see DC Desk 2000 software in monitor computer.
25. Press "start" for activated automatic valve timing, for control speed engine.
    a. click "start",
    b. after that click "storm symbol",
    c. after that click "OK"
26. See spark timing, after that adjust spark timing by adjust electric signal.(usually if we want to set spark timing 30 in monitor labtop, we need to adjust electric signal at 13.4 unil 16.5)

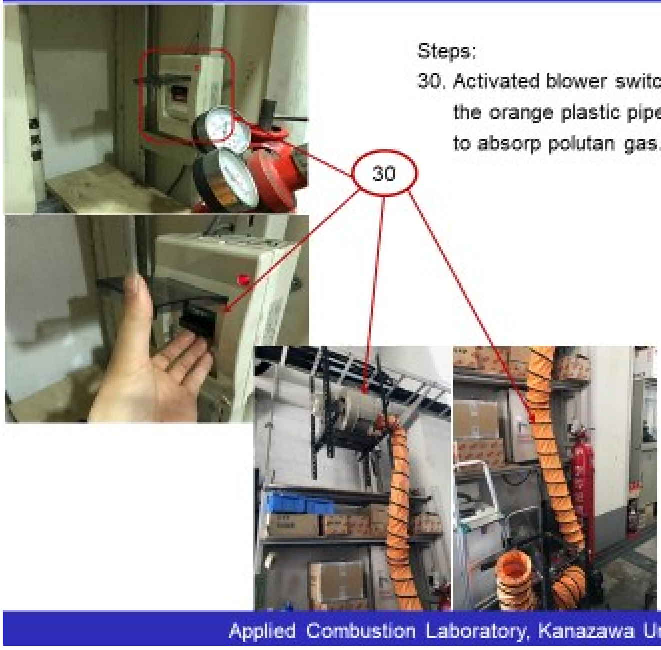
OPERATING THE ENGINE

Steps:

27. Press ECP gas for analysis insilent pressure in spark plug.
28. Start monitoring signal (Monitoring pressure on Computer monitor (to stop process, only press "stop")
29. "Finish" in the middle of button



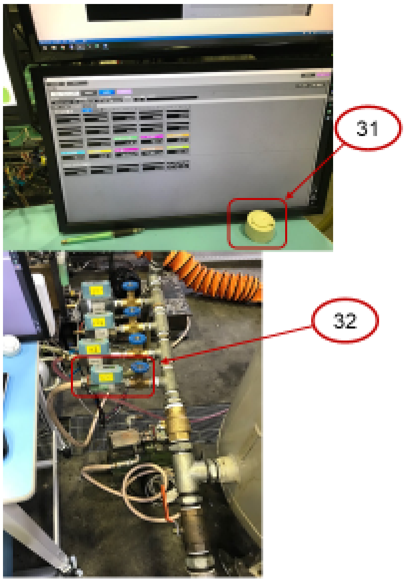
OPERATING THE ENGINE



Steps:

30. Activated blower switch by turn on switch and set the orange plastic pipe in front of exhaust engine to absorp polutan gas.

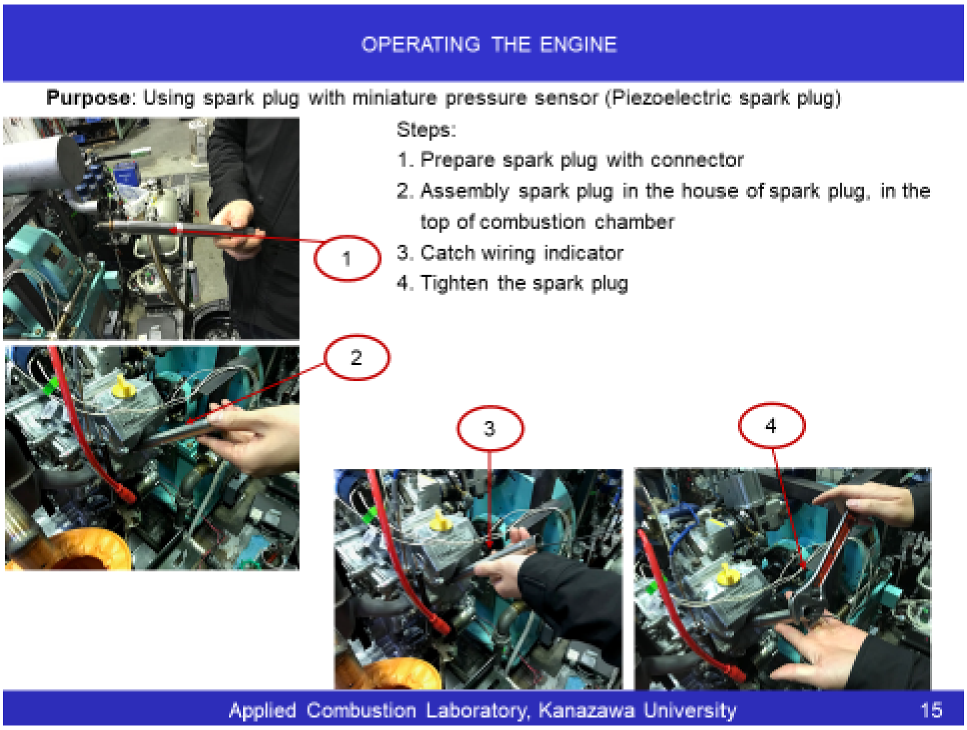
OPERATING THE ENGINE



Steps:

31. Start engine by press "start" button.

32. Adjust city gas flow by control flow meter.
(set city gas/fuel air flow rate for start engine at 14 L/min, and after that adjust to reach 1800 RPM at engine speed by load dynamometer and increase fuel air flow rate at 21.5 L/min)



OPERATING THE ENGINE

Purpose: Using spark plug with miniature pressure sensor (Piezoelectric spark plug)

Steps:

1. Prepare spark plug with connector
2. Assembly spark plug in the house of spark plug, in the top of combustion chamber
3. Catch wiring indicator
4. Tighten the spark plug

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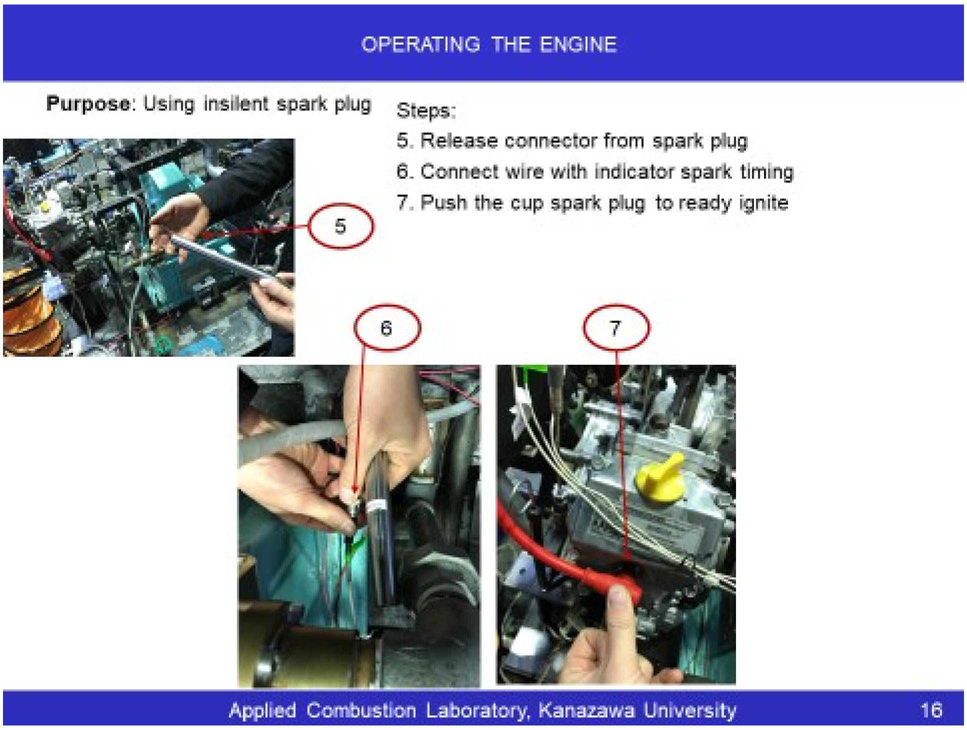

OPERATING THE ENGINE

Purpose: Using insilent spark plug

Steps:

5. Release connector from spark plug
6. Connect wire with indicator spark timing
7. Push the cup spark plug to ready ignite

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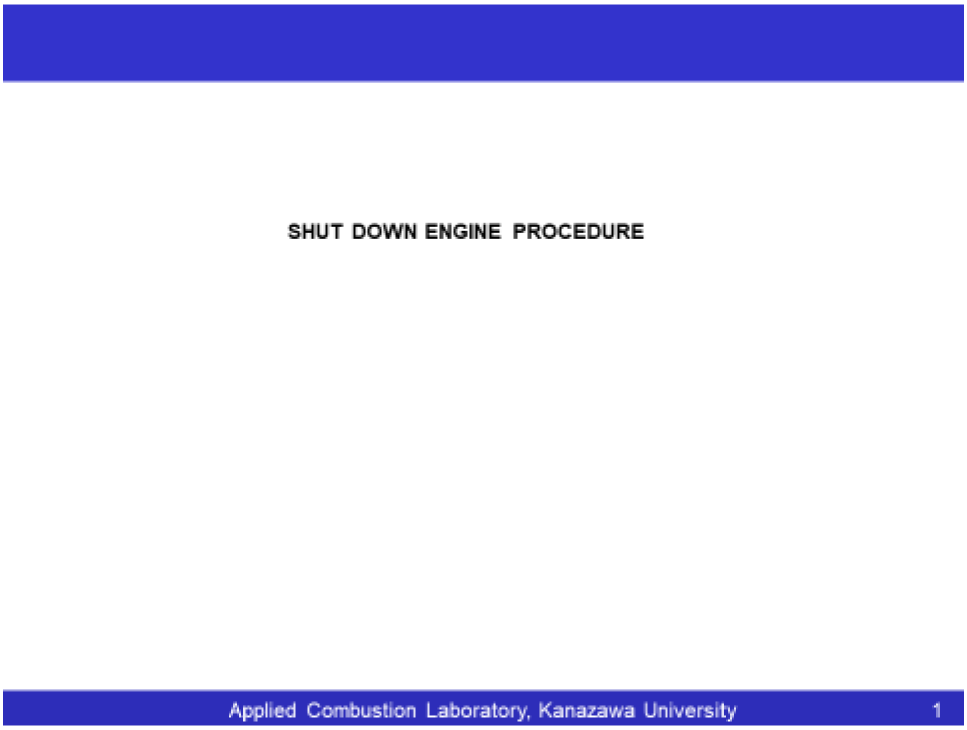
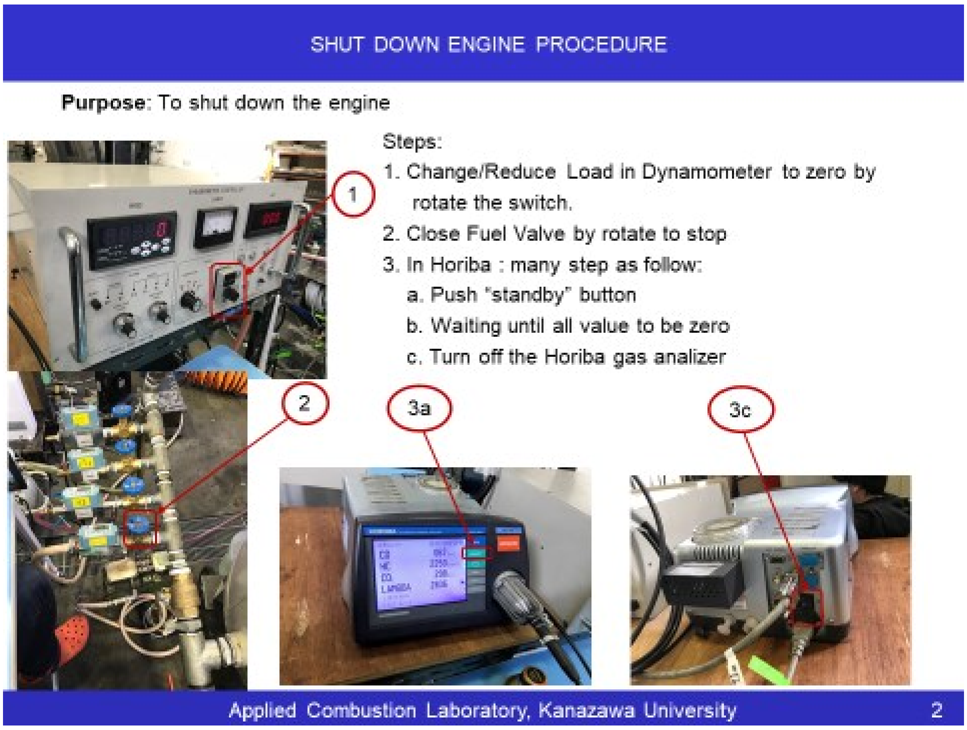
APPENDIX 10. OPERATING ENGINE

SHUTDOWN ENGINE EXPERIMENT PROCEDURE



SHUT DOWN ENGINE PROCEDURE



SHUT DOWN ENGINE PROCEDURE

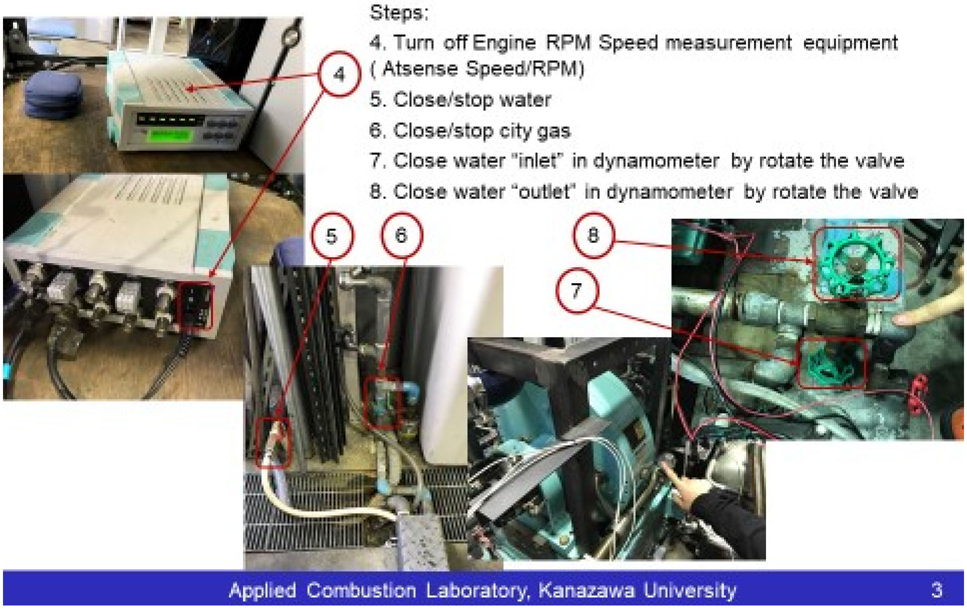
Purpose: To shut down the engine

Steps:

1. Change/Reduce Load in Dynamometer to zero by rotate the switch.
2. Close Fuel Valve by rotate to stop
3. In Horiba : many step as follow:
   a. Push "standby" button
   b. Waiting until all value to be zero
   c. Turn off the Horiba gas analizer

SHUT DOWN ENGINE PROCEDURE

Purpose: To shut down the engine

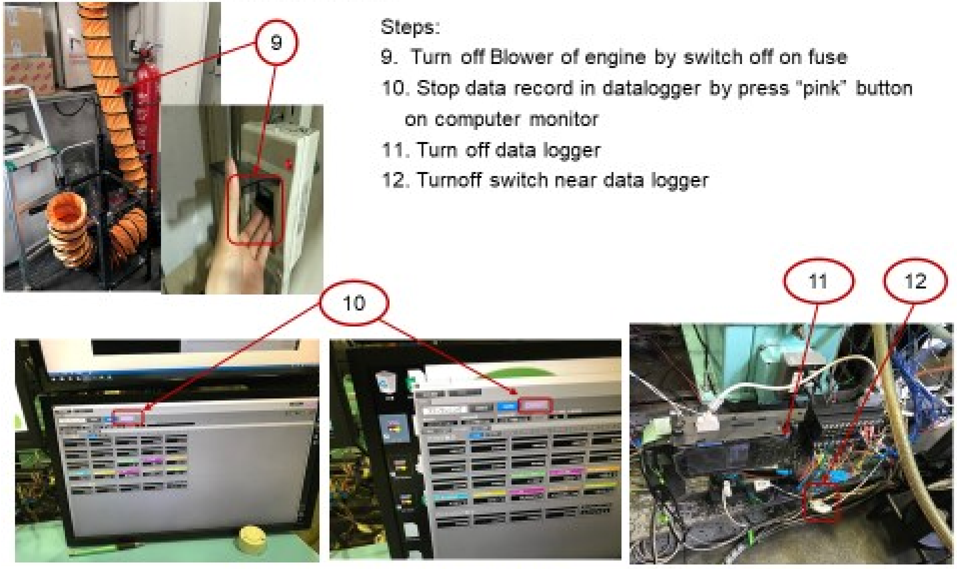


Steps:

4. Turn off Engine RPM Speed measurement equipment (Atsense Speed/RPM)
5. Close/stop water
6. Close/stop city gas
7. Close water "inlet" in dynamometer by rotate the valve
8. Close water "outlet" in dynamometer by rotate the valve

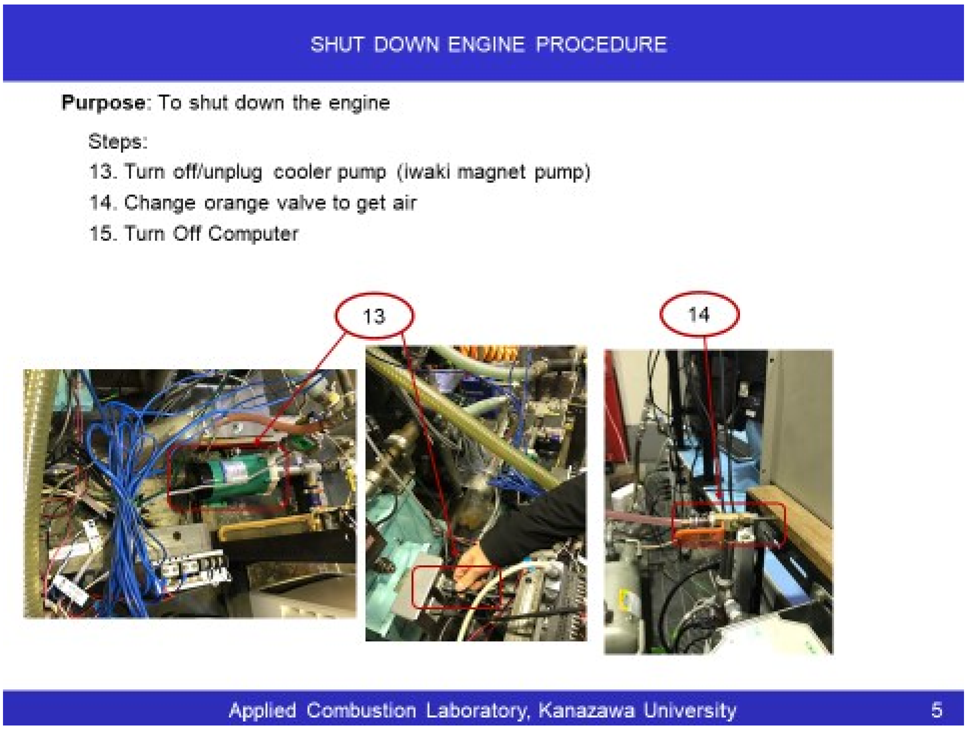
SHUT DOWN ENGINE PROCEDURE

Purpose: To shut down the engine



Steps:

9. Turn off Blower of engine by switch off on fuse
10. Stop data record in datalogger by press "pink" button on computer monitor
11. Turn off data logger
12. Turnoff switch near data logger



SHUT DOWN ENGINE PROCEDURE

Purpose: To shut down the engine

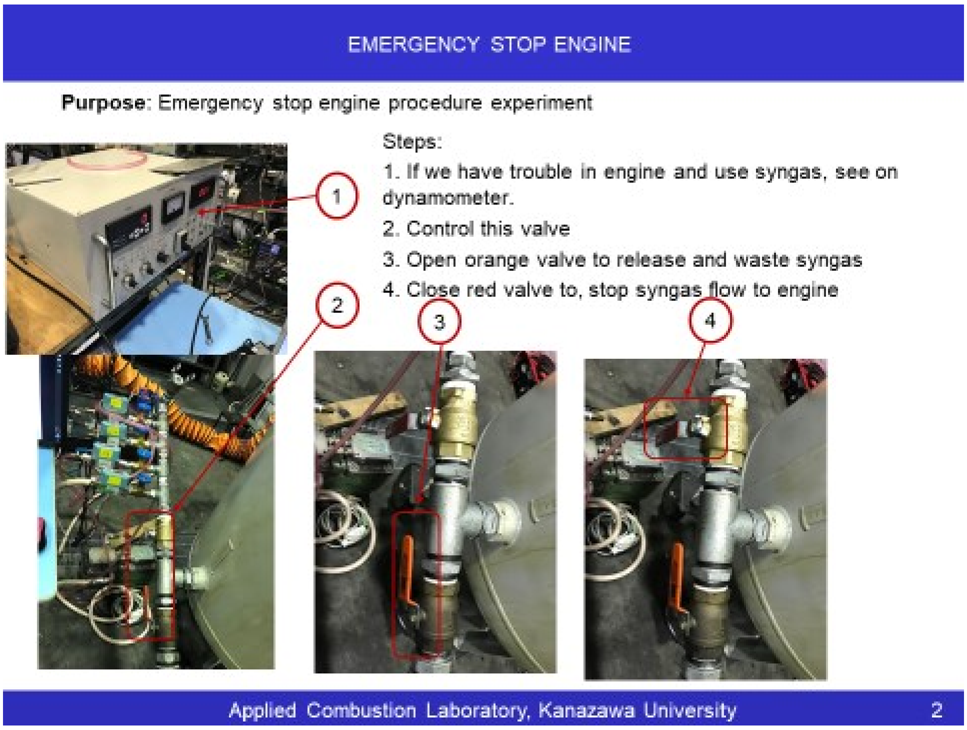
Steps:

13. Turn off/unplug cooler pump (iwaki magnet pump)
14. Change orange valve to get air
15. Turn Off Computer

APPENDIX 11. OPERATING ENGINE

EMERGENCY STOP ENGINE

EMERGENCY STOP ENGINE



EMERGENCY STOP ENGINE

Purpose: Emergency stop engine procedure experiment

Steps:

1. If we have trouble in engine and use syngas, see on dynamometer.
2. Control this valve
3. Open orange valve to release and waste syngas
4. Close red valve to, stop syngas flow to engine

APPENDIX 12. METHOD AND APPARATUS FOR REPAIRING TAR JP 2009-40885 (2007)

Hiroaki Ohara, Katsuaki Matsuzawa, Method and Apparatus for Repairing Tar, JP 2009-40885 (2007)

https://www.j-platpat.inpit.go.jp/p0200

Bibliography:

(19) [Issuing country] Japan Patent Office (JP)

(12) [Gazette classification] Published patent gazette (A)

(11) [Publication number] JP 2009-40885 (P2009-40885A)

(43) [Date of publication] February 26, 2009 (Feb. 26, 2009)

(54) [Title of Invention] Method and apparatus for collecting tar

(51) [International Patent Classification]

C10J 3/46 (2006.01)

C10J 3/02 (2006.01)

C10J 3/54 (2006.01)

C10J 3/84 (2006.01)

[FI]

C10J 3/46 Z

C10J 3/02 Z

C10J 3/54 Z

C10J 3/84

[Request for Examination] Unclaimed

[Number of Claims] 10

[Application] Form: OL

[Total number of pages] 9

(21) [Application number] Japanese Patent Application No. 2007-207391

(P2007-207391)

(22) [Application date] August 9, 2007 (2007.8.9)

(71) [Application] Person]

[Identification number] 0000000099

[Name] IHI Corporation

(74) [Agent]

[Identification number] 110000512

[Name] Yamada Patent Office

(72) [Inventor]

[Name] Hiroaki Ohara

(72) [Inventor]

[Name] Katsuaki Matsuzawa

Wrap Up:

(57)[Summary]

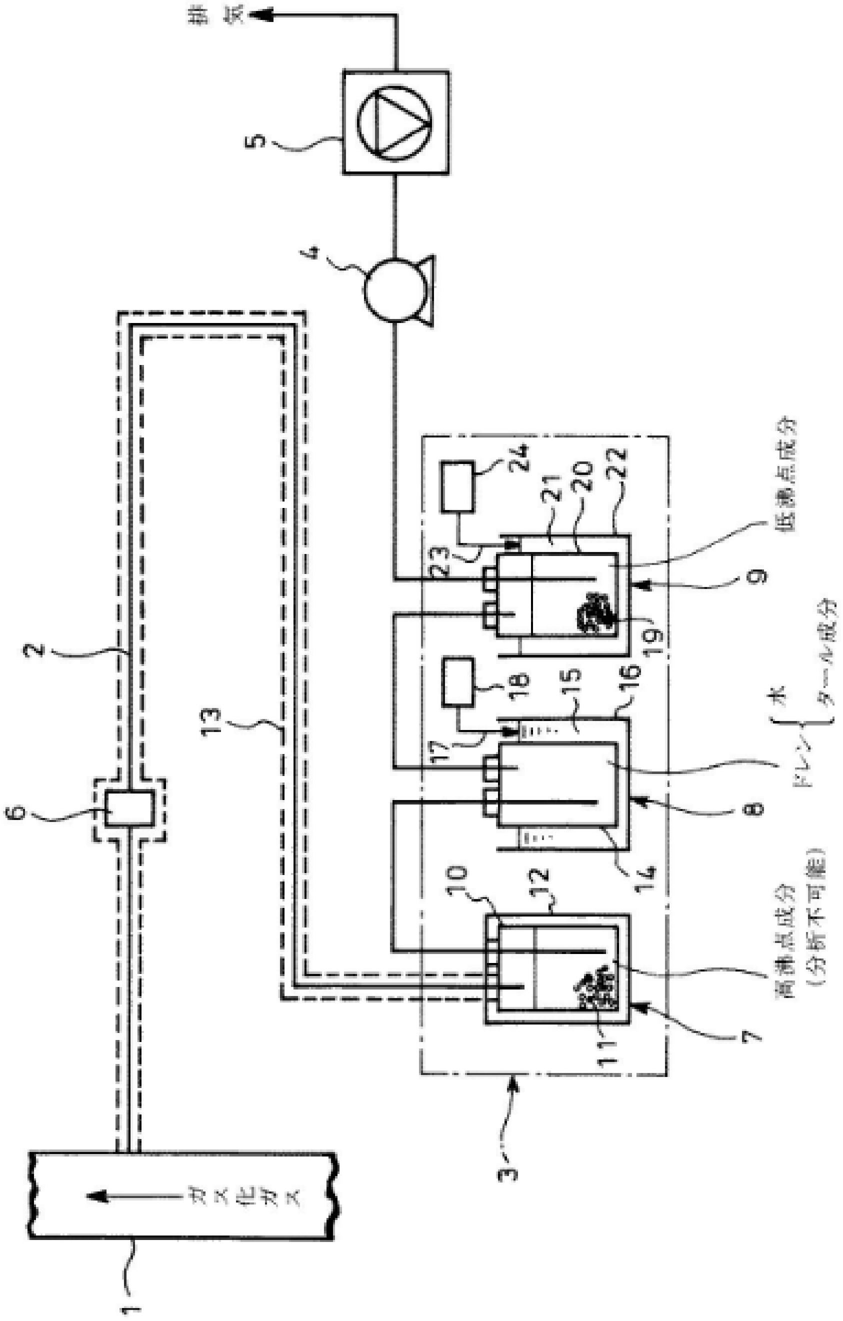
[PROBLEMS] To collect tar present in a gas at a wide range of boiling points effectively and in consideration of analysis. A drain for introducing a sampling gas, and a drain for collecting a drain condensed by cooling the sampling gas to a coagulation temperature of water with water (15) supplied with dry ice (17) from outside of the cleaning bottle. A collecting device 8, a gas washing bottle 20 for introducing the sampling gas from the drain collecting device 8, an outer container 22 surrounding the outside of the gas washing bottle 20 and containing acetone 21, and an acetone 21 of the outer container 22. And a low-

boiling-point component collecting device 9 for collecting low-boiling-point components condensed by cooling to a temperature at which carbon dioxide in the sampling gas does not solidify.

[Selection diagram]

FIG.

FIGURE



The Scope of The Claims:

Claims

[Claim 1]

1. A first step of sampling gas for collecting drain water condensed by cooling to a solidification temperature of the water, the sampling gas from the first step and acetone dry ice is supplied and cooling the mixture to a temperature at which carbon dioxide in the sampling gas does not solidify to collect low-boiling components. 2. The method for collecting tar according to claim 1, wherein in the second step, the sampling gas is cooled to a temperature of -70 ° C. to −78.9 ° C. close to the temperature of dry ice to collect low boiling components.

3. The method according to claim 1, wherein in the first step, the sampling gas is cooled by heat exchange with water cooled with dry ice. Wherein said drain is water, tar collecting method according to claim 1 which is tar components which can be analyzed by the analyzer are collected with a boiling point above 0 ° C.

5. In front of the first step, capturing high-boiling components analysis to collect the high-boiling components cannot by keeping the maximum temperature in the sampling gas and the boiling point of the tar which can be analyzed by analyzer. The method for collecting tar according to any one of claims 1 to 4, further comprising a collecting step.

6. A maximum temperature of the boiling point of the tar which can be analyzed by the spectrometer tar collecting method according to claim 5 which is 0.99 °C.

7. A gas washing bottle for introducing a sampling gas, and a drain collecting device for collecting the drain condensed by cooling the sampling gas to a solidification and contraction temperature of water by a cooling fluid from outside the gas washing bottle. , A washing bottle for introducing the sampling gas from the drain collection device, an outer container surrounding the outside of the washing bottle and containing acetone, and

a dry ice supply device for supplying dry ice to acetone in the outer container And a low-boiling-point component collector that collects low-boiling components condensed by cooling to a temperature at which carbon dioxide in the sampling gas does not solidify.

8. The drainage trap has an outer container with water surrounds the outside of the gas washing bottles, according with dry ice supply device for supplying a dry ice water of the outer container Item 7. A tar collecting device according to Item 7.
9. A high boiling point for collecting a high boiling point component which cannot be analyzed by maintaining the temperature of the sampling gas at the maximum boiling point of the tar which can be analyzed by an analyzer at a stage preceding the drain collecting device. The tar collecting device according to claim 7, further comprising a component collecting device, and a heater for keeping a temperature of a sampling pipe for introducing a sampling gas to the high boiling component collecting device at a temperature equal to or higher than the maximum temperature.
10. A tar collecting device according to claim 9 having a solids separator to said sampling tube.

Detailed Description:

Description:

BACKGROUND OF THE INVENTION

1. Field of the Invention. The present invention relates to a tar trap for collecting tar present in a gas having a wide range of boiling points effectively and in consideration of analysis. And a collection method.
2. Description of the Related Art. In recent years, natural gas prices have soared, and carbon monoxide CO, hydrocarbons C_nH_m, and hydrogen H_2 have been produced by gasifying low cost carbon-based materials such as biomass, sludge, and coal. and carbon dioxide CO_2 and a gasified gas as a main component is generated, and the purified gas

obtained by purifying the gasified gas is used as a fuel for combustion, used as a raw material for producing ammonia, or activated carbon, carbon black, carbon It has been increasingly used as a raw material for producing carbon-based functional materials such as nanotubes and carbon nanofibers.

[0003]

However, as described above, tar is mixed in the gasified gas generated by gasifying a carbon-based raw material. Therefore, when purifying the gasified gas, the tar is supplied to equipment of a purification facility. There is a problem that adhesion causes blockage and other troubles. Also, since tar contains components with a wide range of boiling points, components with low boiling points are supplied as raw materials for the production of functional materials without being separated by purification equipment. Problem.

[0004]

Therefore, when purifying the refining facilities gasified gas as described above, and to provide a purified gas from refineries as a raw material for producing functional materials, the removal of tar in the gasified gas. That is being done.

[0005]

However, when the carbon-based raw material to be gasified changes, the amount and properties of the tar in the gasification gas change, and in order to effectively remove such tar, a method of removing tar, and It is necessary to determine the scale and the like of the tar removing device in advance, but in order to determine the tar removing method and the scale of the tar removing device in this way, what kind of tar of the gaseous gas has It is necessary to know what the concentration is.

[0006]

In order to analyze the composition and concentration of tar contained in a gas such as the above-mentioned gasified gas, a predetermined amount of gas has been sampled, and the tar is concentrated and collected from the sampled gas. A way to do that has been proposed. As a method for collecting tar, as described in Non-patent Document 1 and Non-Patent Document 2, a method in which an affinity solvent (anisole, isopropyl glycol, acetone, dichloromethane) absorbs tar in a sampling gas. Alternatively, a method of collecting tar in a sampling gas by cooling the temperature as shown in Non-Patent Document 3 and a method of using liquid nitrogen as a method of cooling the temperature of the sampling gas as shown in Patent Document 1 It is considered.

[Non-patent document 1]

Sampling and analysis of particles and tars from biomass gasifiers, Philipp Hasler, Biomass and Bioenergy 18 (2000) 61-66.

[Non-patent document 2]

The development of a draft protocol for the sampling and analysis of particulate and Organic contaminants in the gas from small biomass gasifiers, Nick Abatzoglou, Biomass and Bioenergy, 18 (2000) 5-17.

[Non-Patent Document 3]

Control of Molecular Composition of Tar by Secondary Reaction in Fluidized-Bed Pyrolysis of a Subbituminous Coal, Jun-ichiro Hayashi , Energy and Fuels, 1993, 7, 57-66.

[Patent Document 1]

Japanese Patent Application Laid-Open No. 7-82564 [Disclosure of the Invention]

[0008]

However, as described in Non-Patent Documents 1 and 2, the method of absorbing tar in a sampling gas with a solvent and collecting the same is a method of collecting tar as a target of collection. If a solvent having a boiling point higher than that of the components is not used, the solvent heated by the sampling gas evaporates during sampling, and there is a problem that tar cannot be collected for a long time. In addition, when the solvent is evaporated to separate and concentrate the tar, the collected tar is also evaporated and scattered, so that there is a problem that the collecting accuracy is low.

Further, as shown in Non-patent Document 3 and Patent Document 1, the temperature is cooled to reduce. The method of condensing tar is to cool the gas washing bottle into which the sampling gas has been introduced by using a cooling tank filled with ice water, or to cool the gas washing bottle by using a deep cooling tank in which the temperature is lowered by adding liquid nitrogen to acetone. According to this method, tar can be collected according to the boiling point of tar.

[0010]

However, the collection of the tar by gas sampling must be performed continuously for a predetermined time, and therefore, the cold bath containing ice water, it is necessary to add the appropriate ice to maintain the cooling temperature However, when the ice is added, the melted amount becomes water, and the water level in the cold storage tank rises. Therefore, there is a problem that an operation of draining the water is required, and the operation becomes complicated. Also, in a deep-cooled cooling tank that cools acetone with liquid nitrogen, there is a possibility that acetone may be rapidly cooled to its freezing point (-95 ° C) with liquid nitrogen at −210 ° C. to solidify the acetone. When the gas contains carbon dioxide CO_2, carbon dioxide having a freezing point of −78.9 ° C is also condensed, so that a further operation of separating the tar component and carbon dioxide from the trapped component is required. There is for this reason, it is necessary to carefully control the supply amount of liquid nitrogen with respect to acetone so that the temperature of acetone is always kept constant, and there is a problem that this operation is very troublesome and complicated.

Further, as described above, the conventional method of collecting tar in the sampling gas does not collect the tar in consideration of analyzing the composition and concentration of the collected tar, so that the tar is not collected. It has a problem that it cannot be used effectively when accurately determining the composition and concentration of collected tar and determining the tar removal method and the scale of the tar removal device when purifying gasified gas.

[0012]

The present invention has been made in view of the above circumstances, and has a tar collecting method and apparatus capable of effectively collecting tar existing in a gas having a wide boiling point in consideration of analysis. It is intended to provide.

SUMMARY OF THE INVENTION

[0013]

The present invention includes a first step and, wherein the acetone dry ice was fed first for collecting drainage sampled gas was condensed by cooling to a solidification temperature of the water. A second step of exchanging heat with the sampling gas from the step and cooling the sample gas to a temperature at which carbon dioxide in the sampling gas does not solidify to collect low-boiling components.

In the above method of collecting tar, it is preferable that in the second step, the sampling gas is cooled to a temperature of -70 ° C. to −78.9 ° C., which is close to the temperature of dry ice, to collect low boiling components.

In the above method for collecting tar, it is preferable that in the first step, the sampling gas is cooled by heat exchange with water cooled by dry ice.

In the above method for collecting tar, the drain is a tar component which is collected with water and having a boiling point of 0 ° C. or higher and can be analyzed by an analyzer.

Further, in the above-mentioned method of collecting tar, in the preceding stage of the first step, by keeping the sampling gas at the maximum temperature of the boiling point of tar which can be analyzed by an analyzer, high boiling components which cannot be analyzed are removed. It is preferable to have a high boiling point component collecting step of collecting.

[0018]

In the above method for collecting tar, the maximum temperature of the boiling point of tar which can be analyzed by the analyzer is 150 ° C.

[0019]

The present invention includes a washing gas bottle to introduce a sampling gas, the cooling fluid from the outside of the wash gas bottle. A drain collection device that collects drain condensed by cooling the sampling gas to the coagulation temperature of water, a gas washing bottle that introduces the sampling gas from the drain collection device, and surrounds the outside of the gas washing bottle. And a dry ice supply device for supplying dry ice to the acetone in the outer container, and cools to a temperature at which carbon dioxide in the sampling gas does not solidify to capture low-boiling components condensed. And a collecting device for collecting low-boiling components.

In the above tar collecting device, the drain collecting device has an outer container surrounding the outside of the air-cleaning bottle and containing water, and supplies dry ice to the water in the outer container. It is preferred to have a feeding device.

In the above-mentioned tar collecting apparatus, the sample gas is maintained at the highest boiling point of the tar gas which can be analyzed by the analyzer and the high boiling point which cannot be analyzed before the drain collecting apparatus. It is preferable to provide a high-boiling-point component collecting device for collecting components, and to provide a heater for keeping the temperature of a sampling tube for guiding a sampling gas to the high-boiling-point component collecting device at a temperature equal to or higher than the maximum temperature.

Further, in the above tar collecting apparatus, it is preferable that the sampling tube is provided with a solid separator. Advantageous Effects of the Invention.

According to the present invention, a drain collection device that collects drain condensed by cooling the sampling gas to the coagulation temperature of water, and subsequently, carbon dioxide in the sampling gas is collected by acetone supplied with dry ice. Has a low-boiling-point component collector that cools to a temperature that does not coagulate and collects low-boiling components, so that in the drain collector, tar components that condense at a temperature equal to or higher than the coagulation temperature of water are collected, Since the low-boiling components that condense at a temperature at which carbon dioxide in the sampling gas does not coagulate are collected in the boiling component collection device, tar components with a wide range of boiling points are effectively separated and separated at the coagulation temperature of water. There is an effect that can be collected.

[0024]

Further, since the low-boiling component collecting device to cool the acetone dry ice, is easy task carbon dioxide in sampling gas to adjust the temperature of the acetone to a temperature not solidified, long sampling there is an effect that work becomes easy.

[0025]

Furthermore, high-boiling component collected in front of the drain trap, the high-boiling component analysis is not possible by keeping the maximum temperature in the sampling gas and the boiling point of the tar which can be analyzed by analyzer A tar component that condenses at a temperature equal to or higher than the solidification temperature of water from a sampling gas from which high-boiling components that cannot be analyzed by the high-boiling components collecting device have been removed because it has a collecting device Has the effect of being able to collect satisfactorily.

[0026]

Therefore, high-boiling components that cannot be analyzed by the analyzer collected by the high-boiling component collection device, tar components that condense at a temperature higher than the solidification temperature of water collected by the drain collection device, and low-boiling components. The low-boiling components condensed at a temperature below the freezing temperature of water collected by the collecting device and at a temperature at which carbon dioxide does not coagulate are measured. Further, the tar component in the drain collecting device and the low-boiling component collecting device are measured. The low boiling point component in the above has an effect that the composition and concentration of the tar component having a wide range of boiling point existing in the sampling gas can be efficiently measured by performing the analysis with the analyzer.

BEST MODE FOR CARRYING OUT THE INVENTION

[0027]

Hereinafter will be described the embodiments of the present invention with reference to the accompanying drawings.

[0028]

FIG. 1 is a flowchart illustrating an example of an embodiment of the present invention. In FIG. 1, reference numeral 1 denotes a duct for introducing a gas containing tar such as a gasified gas generated in a gasification furnace. Reference numeral 2 denotes a duct connected to the duct 1 to transfer a sampling gas to a tar collecting device 3 of the present invention. The gas is a sampling pipe that guides the gas. The gas from which the tar is collected by the tar collecting device 3 is sucked by the suction pump 4, and the flow rate is measured by the flow meter 5 to be exhausted.

The sampling pipe 2 is provided with a solid separator 6 for removing a solid content in the sampling gas due to the gasified gas from the duct 1. The solid separator 6 includes silica, SUS, or the like. A filter composed of a combination, a cyclone, or the like can be used.

The tar collecting device 3 includes a high-boiling component collecting device 7 (high-boiling component collecting step) for collecting high-boiling components from the sampling gas, and subsequently, a temperature higher than the solidification temperature of water from the sampling gas. A drain collecting device 8 (first step) for collecting tar components condensed at a temperature and a low boiling component collecting device 9 (second step) for collecting low boiling components from the sampling gas are provided. are doing.

[0031]

The high-boiling-point component collecting device 7 (high-boiling-point component collecting step) has a heat-retaining container 10 into which a sampling gas is introduced from the sampling pipe 2. Glass beads 11 of about 1 mm to 5 mm are inserted, and a temperature controller 12 composed of an electric heater or the like is provided outside the heat retaining container 10. The temperature controller 12 keeps the temperature of the sampling gas supplied to the heat retaining container 10 at, for example, 150 °C., which is the maximum temperature of the boiling point of tar that can be analyzed by the analyzer. Here, chromatography, which is commonly used for the analysis of substances, has a maximum detectable temperature of 150 °C., and therefore cannot be measured by the high-boiling-point component collecting device 7 at a temperature of 150 °C. or higher, which cannot be measured by chromatography. High boiling components are collected from the sampling gas. The temperature of the high-boiling-point component collecting device 7 can be arbitrarily set according to the detectable temperature of the analyzer.

[0032]

Further, the outside of the sampling tube 2 and the solid separator 6, made of a ribbon heater or the like which sampling gas leading to the high-boiling component collecting device 7 is heated to maintain a temperature higher than the 0.99 °C. A heater 13 is provided. Therefore, in the high-boiling-point component collecting device 7, high-boiling-point components having a boiling point of 150 °C or higher in the sampling gas are collected so as to adhere to the glass beads 11 in the heat-retaining container 10.

[0033]

The drain collection device 8 (first step) includes a washing bottle 14 for introducing the sampling gas from the high-boiling-point component collection device 7, and a cooling system including water 15 surrounding the outside of the washing bottle 14. An outer container 16 containing a fluid, and a dry ice supply device 18 for supplying dry ice 17 to water 15 in the outer container 16 are provided. Is cooled to the solidification temperature (0 °C.), and the condensed water and the drain composed of the tar component are collected in the air-washing bottle 14. The dry ice 17 supplied to the outer container 16 solidifies the water 15 in the outer container 16 when it is put in a large amount, and when the water vapor concentration in the sampling gas is high and the sampling time is long, the dry ice 17 is therefore, the supply amount of the dry ice 17 is adjusted so that the water 15 does not freeze and is kept at around 0 °C. In the illustrated example, the case where the water 15 is cooled to 0 °C by the dry ice 17 is illustrated, but other cooling fluids and cooling methods may be used as long as the sampling gas can be cooled to 0 °C.

The low-boiling-point component collecting device 9 (second step) introduces the sampling gas from the drain collecting device 8 and has a washing vessel in which glass beads 19 having a diameter of about 1 mm to 5 mm are inserted. The air bottle 20, an outer container 22 surrounding the outside of the air washing bottle 20 and containing acetone 21, and a dry ice supply device 24 for supplying dry ice 23 to the acetone 21 of the outer container 22. The sampling gas is cooled by the acetone 21 supplied with the dry ice 23 to a temperature at which the carbon dioxide CO_2 does not solidify. That is, the temperature is cooled to a temperature close to the temperature of dry ice which is the solidification temperature of carbon dioxide CO_2 -78.9 °C., for example, about −70 °C to −78.9 °C. Therefore, in the low-boiling-point component collecting device 9, low-boiling components such as tar and benzene having a boiling point of −70 °C to −78.9 °C or more in the sampling gas are attached to the glass beads 11. Collected.

[0035]

Next, the operation of the illustrated embodiment. In FIG. 1, by driving the suction pump 4, a part of the gasified gas in the duct 1 is sucked into the sampling pipe 2 as a sampling gas, and after the solid is separated by the solid separator 6, the tar is collected. It is led to the device 3. At this time, the flow rate of the gas sucked by the suction pump 4 is measured by the flow meter 5.

The sampling gas is supplied to a heat-retaining container 10 of the high-boiling-point component collecting device 7 (high-boiling-point component collecting step), and the heat-retaining container 10 can be analyzed by an analyzer using an external temperature controller. Since the tar is kept at the maximum temperature of the boiling point, for example, 150 ° C., the high-boiling components having a high boiling point of

150 ° C. or more in the sampling gas are collected so as to adhere to the glass beads 11 inside the heat retaining container 10. Is done.

[0038]

The sampling gas from which the high-boiling-point components have been collected by the high-boiling-point components collection device 7 is subsequently supplied to the air-washing bottle 14 of the drain collection device 8 (first step). Outside the gas washing bottle 14, an outer container 16 surrounding the gas washing bottle 14 and containing a cooling fluid composed of water 15 is provided. Further, dry ice 17 is supplied to the water 15 in the outer container 16. Since the dry ice supply device 18 is provided, the sampling gas in the washing bottle 14 is cooled to the solidification temperature of water (0 ° C.) by the water 15 to which the dry ice 17 is supplied, and the drain is collected. This drain is collected with the condensed water in the sampling gas from which the high-boiling-point components are collected by the high-boiling-point component collecting device 7 and has a boiling point of 0 ° C. or more, and can be analyzed by an analyzer. It consists of tar components.

In the drain collecting device 8, since the water 15 is cooled by the dry ice 17, the amount of water does not change. Therefore, the amount of water is adjusted as in the conventional cooling method using ice water. Operation can be omitted. The sampling gas from which the drain has been collected by the drain collecting device 8 is subsequently supplied to the air-washing bottle 20 of the low-boiling-point component collecting device 9 (second step). An outside container 22 is provided outside the air-cleaning bottle 20 and surrounds the air-cleaning bottle 20 and accommodates acetone 21, and further supplies a dry ice 23 to the acetone 21 in the outer container 22. Since the sample gas 24 is provided, the sampling gas in the gas washing bottle 20 is cooled to a temperature at which carbon dioxide CO_2 does not coagulate, for example, about −70 °C. to −78.9 °C., by the acetone 21 to which the dry ice 23 is supplied. Boiling point components (low boiling point tar, benzene, etc.) are collected so as to adhere to the glass beads 19.

[0041]

At this time, in the low-boiling-point component collecting device 9, since the acetone 21 is cooled by the dry ice 23 which is a coagulated product of carbon dioxide, the temperature of the acetone 21 is adjusted to a temperature at which the carbon dioxide in the sampling gas does not coagulate. The operation can be very easily performed, and a long-time sampling can be easily performed.

[0042]

According to the above-mentioned embodiments, to collect the tar components condense in the drain collecting device 8 (first step) at a solidification temperature above the temperature of the water, followed by a low-boiling component collecting device 9 (first In step (2), the low-boiling components condensed at a temperature at which the carbon dioxide in the sampling gas does not solidify are collected. Therefore, tar components having a wide range of boiling points can be collected effectively and separated at the solidification temperature of water.

[0043]

Further, in front of the drain trap 8, since with high boiling component collecting apparatus 7 Analysis by spectrometer to collect high-boiling components cannot (high-boiling components absorption step), The drain collecting device 8 effectively collects tar components that condense at a temperature higher than the solidification temperature of water and that can be analyzed by an analyzer.

The high-boiling component collected by the high-boiling component collecting device 7, the tar component collected by the drain collecting device 8, and the washing low-boiling point collected by the low-boiling component collecting device 9. The components are each measured by washing and separating with methanol, acetone, or the like. At this time, since the flow rate of the gas supplied to the tar collection device 3 is measured by the flow meter 5, the components in the sampling gas are measured. The concentration of the high-boiling component, tar component, and low-boiling component can be determined. Further, since the tar component in the drain collecting device 8 and the low boiling component in the low boiling component collecting device 9 can be analyzed by an analyzer such as chromatography, the tar component present in the sampling gas can be analyzed. It will be possible to determine the concentration of each composition.

[0045]

Thus, the composition of the tar component in the gasification gas obtained as described above, concentration is effectively in determining the size and the like of the tar removal process and tar removal device in purifying gasified gas can be used.

It should be noted that the method and apparatus for collecting tar of the present invention are not limited to the above-described embodiment, and it is needless to say that various changes can be made without departing from the spirit of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046]

is a flow chart illustrating an example of FIG. 1 forms of implementing the present invention.

[Description of Signs]

1. Gas from Gasifier

2. Sampling tube

3. Tar collecting device

6. Solid separator

7. High boiling component collecting device (high boiling component collecting process)

8. Drain collecting device (first process)

9. Low boiling component collecting Collector (second step)

10. Inside Impinger bottle

11. Glass beads

12. Impinger bottle

13. Heate

14. Air-wash bottle

15. Water

16. Outer container

17. Dry ice

18. Dry-ice supply device

20. Air-wash bottle

21. Acetone

22. Outer container

23. Dry ice

24. Dry-ice supply device

Drawing:

FIG.

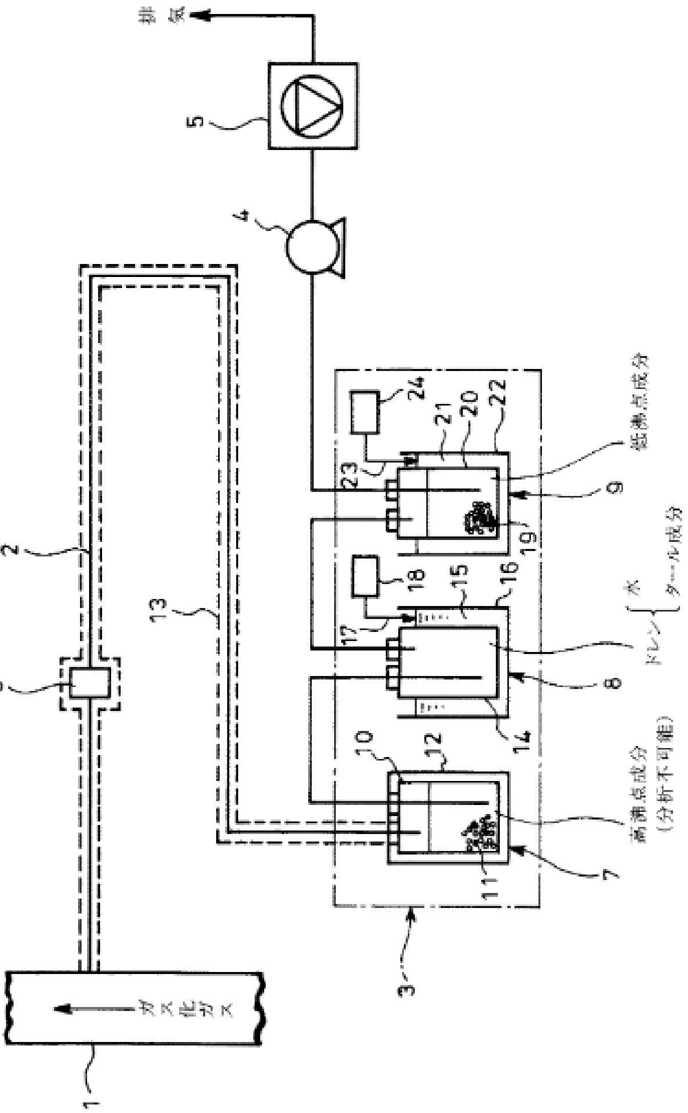
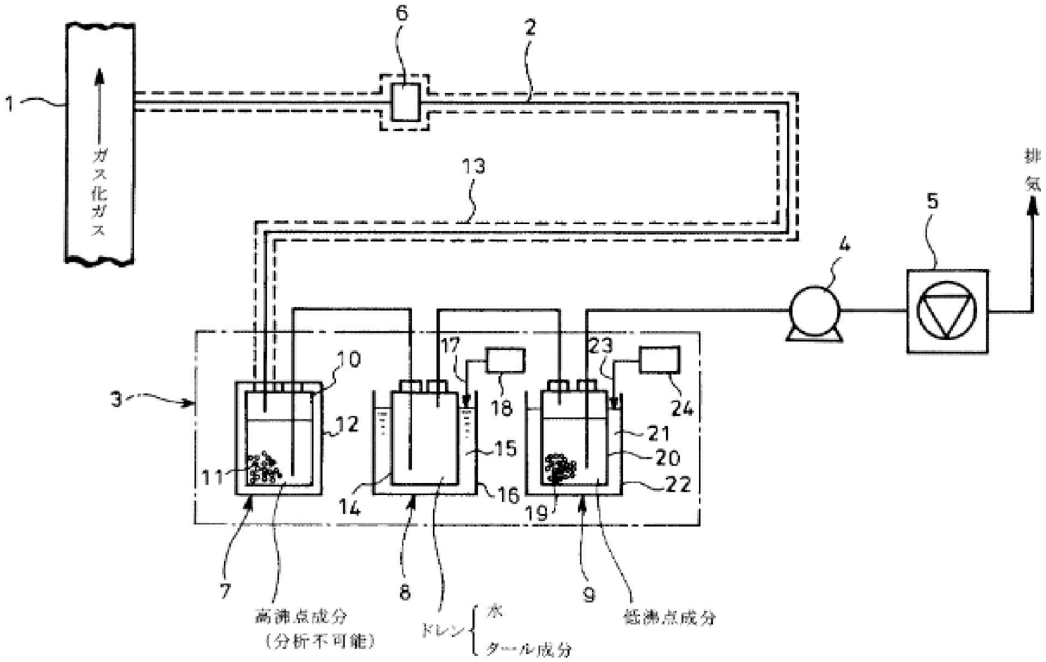

排気
5
4
2
6
13
24
21
20
22
23
低沸点成分
9
19
18
15
16
17
水
ドレン
タール成分
8
14
10
12
高沸点成分
(分析不可能)
7
11
3
ガス化ガス
1

FIG.


1
ガス化ガス
6
2
13
3
10
12
11
7
17
18
15
14
16
8
23
24
21
20
22
19
9
4
5
排気
高沸点成分
（分析不可能）
ドレン
水
タール成分
低沸点成分