EXPERIMENT ON PARAMETERS FOR WOOD VINEGAR BURNING PROCESS

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering Program in Mechanical and Process System Engineering

Suranaree University of Technology

Academic Year 2018

การทดสอบพารามิเตอร์ของกระบวนการเผาเพื่อผลิตน้ำส้มควันไม้

นายพิเนียท ทอน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมเครื่องกลและระบบกระบวนการ
มหาวิทยาลัยเทคโนโลยีสุรนารี
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EXPERIMENT ON PARAMETERS FOR WOOD VINEGAR BURNING PROCESS

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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งานวิจัยนี้มุ่งพัฒนาและทดสอบกระบวนการเผาเพื่อผลิตน้ำส้มควันไม้โดยใช้ไม้เป็นวัตถุดิบ เพื่อจะออกแบบและดำเนินการดังกล่าวจำเป็นต้องเข้าใจพารามิเตอร์ที่ส่งผลกระทบต่อสมรรถนะของระบบ งานวิจัยนี้อุปกรณ์ถูกออกแบบเพื่อปรับปรุงอัตราการกลั่นของน้ำส้มควันไม้ให้ดีขึ้น ระบบที่พัฒนาประกอบด้วยถังสองใบคือ ถังเผา และถังกลั่น ถังเผาทำจากเหล็กมีเส้นผ่าศูนย์กลาง 400 มิลลิเมตร ยาว 600 มิลลิเมตร สำหรับบรรจุไม้ได้ 15-20 กิโลกรัม มีช่องสำหรับต่อท่อส่งไอเสียสองตำแหน่งคือ ตัวบน และตัวล่าง ถังกลั่นขนาด 65 ลิตร บรรจุด้วยท่อกลั่นทำจากทองแดง ขนาดเส้นผ่านศูนย์กลาง 12 มิลลิเมตร ยาว 400 มิลลิเมตร จำนวน 24 ท่อ น้ำเย็นที่มีอุณหภูมิระหว่าง 30 – 40 องศาเซลเซียส ที่ใช้เป็นตัวกลางในการถ่ายเทความร้อนออกจากผิวท่อ ในการทดลองพารามิเตอร์ 4 ตัว ได้แก่ ไม้ 2 ชนิด อัตราการไหลของอากาศ 3 ค่า ความชื้นของเนื้อไม้ 3 ค่า และตำแหน่งท่อส่งควัน 2 ตำแหน่ง ถูกทดสอบการทดลองใช้ไม้ยูคาลิปตัสและไม้กระถิน 15 กิโลกรัม ทำการเผา 8 ชั่วโมง ซึ่งได้ปริมาณน้ำส้มควันไม้เฉลี่ย 6.39 ลิตร ผลการทดสอบพบว่าพารามิเตอร์ที่ศึกษาส่งผลกระทบต่อปริมาณของน้ำส้มควันไม้ที่ผลิตได้อย่างมีนัยสำคัญ โดยระบบที่นำเสนอและพารามิเตอร์ที่ออกแบบสามารถเพิ่มอัตราการกลั่นได้ 16 เท่า เมื่อเทียบกับอุปกรณ์กลั่นน้ำส้มควันไม้ที่พบเห็นทั่วไป

สาขาวิชา วิศวกรรมเครื่องกล ลายมือชื่อนักศึกษา ____________

ปีการศึกษา 2561 ลายมือชื่ออาจารย์ที่ปรึกษา ____________

PHINEATH THAN : EXPERIMENT ON PARAMETERS FOR WOOD VINEGAR BURING PROCESS. THESIS ADVISOR : ASST. PROF. KEERATI SULUKSNA, Ph.D., 78 PP.

WOOD VINEGAR/ BURNING/ EXPERIMENT

This research aims to develop a burning tank and experiment for the wood vinegar burning process using wood as raw material. To design and operation of such a burning tank require a detailed understanding of parameters that affect the system performance. In the research, the device has been designed for improving the distillation rate of wood vinegar. The developed system consists of two tanks, burning tank and distillation tank. Burning tank made from steel with 400mm diameter, 600mm long, and 15-20 kg containing capacity of wood. It has two positions for exhaust duct attached to top and bottom of the side of the tank. The 65L-distillation tank contain with condensing pipes. The condensing pipes made from 24 copper pipes a diameter of 12 mm, 400 mm long are installed in the distillation tank. Cooling water with a temperature of 30 ˚C to 40 ˚C, is used as media for removing the heat from those condensing pipes surface. In the experiment, four influent parameters are investigated; two kinds of woods, three fire conditions of airflow rate, three moisture contents in woods, and two positions of exhaust duct. The testing has been performed by using 15 kg of Eucalyptus and River tamarind wood within 8 hours burning. The experiment can produce average of 6.39L of wood vinegar. The experiment results shown that the interaction between the proposed designed and parameters are significantly effect to the yield percent of obtained wood vinegar. The proposed

device and designed parameters can increase the wood vinegar of 16 times compared to conventional system.

School of Mechanical Engineering

Academic Year 2018

Student's Signature________

Advisor's Signature________

ACKNOWLEDGMENT

Firstly, I would like to thank God for giving health and enabling me to do this work with the School of Mechanical Engineering, Suranaree University of Technology here in Thailand.

Secondly, I would thank my Advisor, Assistant Professor Dr. Keerati Suluksna for his guidance and support throughout my studies and to the accomplishment of this thesis. Also, special thanks should go to the committee members, Associate Professor Dr. Bundit Krittacom (Chairperson), Assistant Professor Dr. Keerati Suluksna (Thesis Advisor), Assist. Professor Dr. Atit Koonsrisuk (Member) and Dr. Pichitra Uangpairoj (Member) for their advice.

Additionally, I would also like to thank all graduates and staffs from the school of Mechanical Engineering and other schools in the University for supporting me as they were always willing to help me.

Finally, I must express my very profound gratitude to my parents and to my brothers and sisters for providing me with unfailing support and continuous spiritually encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you all.

Phineath Than

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Wood vinegar has been used daily and it has a long history in agriculture dates back at least two millennia (Tiilikkala, Fagernäs, and Tiilikkala, 2010). It is known as pyroligneous acid, mokusaku, liquid smoke was seen the most in some of the countries in Asia. Since 1930's, wood vinegar has been used as a fertilizer and growth promoting agent in the agriculture field. Although the wood vinegar has been mentioned in some document, it was hard to find good scientific evidence that state when wood vinegar used as a pesticide. Probably only few documents have been recorded in language and countries hard to reach via modern information retrieval (woodvinegar.org). In the conventional of making wood vinegar model, wood was burned under airless condition by slowly heating up to desire temperature. Lower process 400˚C and longer liquid smoke residence time favor the charcoal production (Wood Vinegar for Organic Agriculture). Now, this natural fertilizer is receiving much attention from researchers, organizations, and institutions in the region.

1.2 Wood Vinegar

Figure 1.1 Wood Vinegar (Food and Fertilizer Technology Center, 2005)

Wood vinegar is the wet smoke combined between vapor and hot dry air, generated from hot gas due to combustion of fresh wood burning in airless condition. When the gas is cooled, the vapor will condenses to be liquid that is called wood vinegar (Chalermsan, and Peerapan, 2009). Wood vinegar is a dark liquid, contains more than 200 natural compounds primarily acetic acid, methanol, phenols, and formaldehyde (Food and Fertilizer Technology Center Thailand, 2005; Giuffrida, Cassaniti, and Leonardi, 2014). Its principal components are acetic acid and methanol. Acetic acid is used as a soil disinfectant, and methanol is known to increase crop yield utilizing less water, whereas phenols are known as a natural source for antioxidants (Wood Vinegar Market Analysis, 2017). Such attributes of its ingredients make it a better choice for sustainable farming thereby increasing the crop yield.

There are many researchrs have been studies on wood vinegar. Most of the research has been undertaken in China and Japan (Food and Fertilizer Technology

Center Thailand, 2005). They studied that the liquid smoke improved soil quality, eliminate pests and control plant growth, accelerates the growth of roots, stems, tubers, leaves, flowers, and fruit. The organization also has shown that fruit trees produce increased amounts of fruit after applying wood vinegar in an orchard. It is safe to living matters in the food chain, especially insects that help pollinate plants. It is also widely used for pest repellent, bud opening for flowering plants, and soil improvement, as well as a natural animal feed that is resistant to infection, is increasing globally (Wood Vinegar Market Analysis, 2017).

Some works have also focused on using a compound of wood vinegar in a feed to improve animal health was reported by (Nakajima, et al,1993). Wood vinegar is used for animal food to improve meat quality, improve fertility rate, increase milk production substantially and improve feed efficiency reported by (Wood Vinegar Market Analysis, 2017). Pyroligneous is suitable for powltry and other livestock like cattle chicken, sheep, etc wood vinegar is an all nateral livestock deodorant derived from plant extracts. The skin-friendly plant chemicals bind themselves to odor-causing on the animal's body and wastes, effectively breaking down, absorbing and transforming them into a naturally acidic state and destroying and suppressing bacteria, viruses and other odor-causing pathogens. It effectively controls the production of odor-causing bacteria on the animal and the farm resulting in healthier livestock and increasing yield. Chae, Choi, Shinde et al, (2009), investigate the effect of wood vinegar on the performance, nutrient digestibility and intestinal microflora in weanling pigs. Wood vinegar made of broadleaf tree bark carbonized has the testing effect on red mites (Yamauchi, Matsumotoand, et al, 2016).

Moreover, Wood vinegar is also known as a medicine for human health. According to (Global Health Center), wood vinegar is used for blocking diarrhea, preventing vomiting, eliminating detail infection, lowering cholesterol, insect bites, pink eye, infected wounds, snake bites, ear infections, and pain relief.

1.3 Problem Statement

Wood vinegar was little known only a few decades ago. The current level of interest in this production as well as usage of this natural fertilizer in governmental organization, agriculture development agencies, farmers, and some universities in Southeast Asia is on the rise (An Introduction to Wood Vinegar, 2013).

Figure 1.2 Wood Vinegar making (An Introduction to Wood Vinegar, 2013).

Wessapanet et al, (2006) investigated undertaken to develop a pyrolysis oven for production of wood vinegar using charcoal residual as fuel. The oven was designed with an inside chamber for the heat to be evenly distributed throughout the oven and a lid covered the oven. Yang, Sharifi, and al, (2004) studied influent of airflow rate and the moisture of fuel on biomass burning behaviors and simulated municipal solid wastes in packed beds. Somsuk, Wessapan and al, (2009) investigated pyrolysis oven in wood vinegar production by developing a heat exchanger. Chalermsan, Peerapan et al, (2009) produced wood vinegar from a rural charcoal kiln and it used as plant protection. Enchen, Chenxi, and al, (2014) also carried out an experiment of wood vinegar produced from pine nut shell continuous pyrolysis.

However, there is still a lack of detailed or no supporting document on the experimental study of parameters for wood vinegar burning process and to develop the distillation rate of wood vinegar using wood as raw material. The advantage of an experimental study can improve the distillation rate of wood vinegar and lies in its ability to reveal the detailed behavior of parameters in the burning process inside. This research aims to contribute a better understanding, controlling of wood vinegar burning process.

1.4 Case Study Overviews

The two interrelated studies considered in this thesis are:

a) To establish of new model of wood vinegar burning system based on wood vinegar distillation rate.

b) To experiment on parameters that effect the wood vinegar burning process as followed:

i. Effect of exhaust duct positions.

ii. Effect of kind of woods.

iii. Effect of wood moistures.

iv. Effect of airflow rates into burning tank.

1.5 Objective

The main objectives of the thesis are;

a) To develop a wood vinegar burning system in order to use in the experiment on the wood vinegar burning process.

b) To test the parameters that effect on wood vinegar burning process.

1.6 Limitations of the Thesis

In the intended improvement studies, the experiment of parameters for wood vinegar burning processes, focused only burning kiln. The research has investigated with experiment methodology; two kinds of woods will be tested, three fire conditions of airflow rate and three moisture of woods are varied, and two positions of exhaust duct are investigated.

1.7 Thesis Structure

The outlines of this thesis are following:

Chapter 1 provides an introduction, benefit of wood vinegar, problem statement, case studies overview, objective, scope and thesis structure.

Chapter 2 explains a review of wood vinegar; including methods making wood vinegar, parameters that are important for heat exchanger for wood vinegar burning tank and distillation tank, wood moisture content, airflow rate and wood vinegar insight. This chapter gives the background of the wood vinegar burning system behind the method and related parameters.

Chapter 3 illustrate the methodology of wood vinegar burning system, including design concepts, operation and structure design, factorial diagram design and process for the experiments, techniques for experiment and its setup.

Chapter 4 exhibits and discusses the outcome from the experiment and performance of wood vinegar distillation, including the influent parameters in making wood vinegar.

Chapter 5 concludes the result of the experiments and drawn the parameters that effect on the wood vinegar distillation rate included future work.

1.8 Chapter Summary

This chapter explained the general introduction about wood vinegar that is included the general information of wood vinegar, the basic concept of making wood vinegar, wood vinegar substances, usage, and their various type of using as natural fertilizer. Also, it described in short about wood vinegar burning system and its components. Apart from that in the problem statement, it showed how to develop the distillation rate of wood vinegar and what the action included parameter should take to increase the efficiency of the system. Lastly, its direct to the case study overview, objective, and scope of research including an outline of the thesis have been mentioned in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviewed on wood vinegar, including the significant potential for the application of making wood vinegar. Such as wood vinegar, elements and characteristics of wood vinegar, method of making wood vinegar, kiln for charcoal production, heat exchanger, wood moisture content, air mass flow rate, exhaust duct position, wood application insight, wood vinegar concern and wood vinegar supplies remain impressive as agriculture and animal field. The wood vinegar is a natural fertilizer by generated from the smoke of incomplete combustion. It is used in agriculture or animal field to improve meat quality, fertility rate, increase milk production substantially effectively. Wood vinegar produced by the conventional method or pyrolysis method is used through the worlds. Since the last decade, technology innovation has been improved method and burning tank in order to obtain more efficiency of wood vinegar production. In order to increase efficiency, safety, desired environment and reliability of economic enhancement, a human being has demanded natural nor chemical fertilizer for healthy. As demonstrated in the (Food and Fertilizer Technology Center Thailand, 2005) wood vinegar is a natural fertilizer that is safe for human and animals life especially it safe for the environment.

2.2 Wood vinegar

Wood vinegar is a natural fertilizer, using in agriculture, the animal field as well as human medicine. This liquid smoke generated from the gas and combustion of fresh wood burning under airless condition. When the gas is cooled by outside air during passing through a chimney or exhausted pipe, it condenses into liquid. That is liquid called wood vinegar. The cooling of the vapor smoke effect causes condensation of wood vinegar when particularly the temperature of the liquid smoke produced by carbonization is about 120-430°C. The gape of this temperature could give the good quality of wood vinegar under the amount of airless condition. The limit-air was known as the incomplete combustion gases that are a mixture of volatile organic compounds. The temperature is raised at the carbonization stage of exothermic decomposition and is shown by the production of yellow smoke, acrid smoke (Food and Fertilizer Technology Center Thailand, 2005). In the conventional method (An Introduction to Wood Vinegar, 2013), if wood is burned for 12 to15 hours (or less, depending on the type and size of wood) in a 200-liter oil drum kiln, it should produce 2 to 7 littres, which is causing the price of wood vinegar highly in a market.

2.2.1 Elements and characteristics of wood vinegar

Wood vinegar contains many kinds of substances that meet the requirement of plants, animal and human need. (An Introduction to Wood Vinegar, 2013, and Wood Vinegar Market Analysis, 2017) the substances exist approximately 200 components. These primarily include: Acid (acetic, formic, propionic, valeric) is used as a soil disinfectant, alcohol (methanol, butanol, and amyl alcohol) is known to increase crop yield utilizing less water, phenols (syringol, cresol, phenol) are known as a natural source for antioxidants and basic substances such as ammonia methylamine and pyridine. The good quality of wood vinegar was determined as having the following characteristics (An Introduction to Wood Vinegar, 2010):

- PH of approximately 3.0
- Specific gravity between 1.005-1.050
- Color ranging from pale yellow to bright brown
- Transparent
- Smoky odor
- Dissolved tar content: less than3 percent
- Ignition residue: less than 0.2 percent by weight

2.2.2 Opportunity for researching on wood vinegar

Wood vinegar is one of the useful natural fertilizers, which has many advantages for plants, animals, and humans. However, Wood vinegar was little-known only a few decades ago. The current level of interest in this production as well as usage of this natural fertilizer in governmental organization, agriculture development agencies, farmers, and some universities in Southeast Asia is on the rise (An Introduction to Wood Vinegar, 2010). Fortunately, now this natural fertilizer is receiving much attention from researchers, organizations, and institutions in the region, developing the distillation rate of wood vinegar condensing, increased understanding benefits of wood vinegar for a user and looking market for this production.

2.3 Method of making wood vinegar

Liquid smoke is produced when smoke from charcoal production is cooled by outside air while passing through a chimney or flue pipe. The cooling effect causes condensation of pyroligneous liquor, particularly when the temperature of smoke produced by carbonization ranges between 120ºC and 430 ºC this temperature is reached at the carbonization stage of exothermic decomposition and is indicated by the production of yellowish, acrid smoke (Keerati, and Phineath, 2018). (Burnette, 2013) was shown as the summary of key wood vinegar production steps as following:

Figure 2.1 Wood Arrangement (An Introduction to Wood Vinegar, 2013).

Wood Arrangement. Preparing a gate by placing at least 3 pieces of wood, about 25 cm long and 3 cm wide, crossways at the bottom of the burning tank to serve for burning. Then put the wood lengthways along the bottom of the kiln and arrange to follow up by stacking bigger wood in higher the burning tank until the biggest pieces of wood are placed lengthways on top in the kiln. Place the large ends toward of wood the front opening when arranging it into the kiln.

Figure 2.2 Sealing the cover of the kiln (An Introduction to Wood Vinegar, 2013).

Sealing the cover of the kiln. Seal it by placing the modified cover over the place for burning gate of the drum, keeping the square cut opening at the bottom when the tank is full of wood. Close the spaces along the edge of the cover with clay or sticky land and burnt rice husks. This crude seal will prevent liquid smoke would leakage and as well as not allow air outside flow entering the drum that causes the burning inside turn to completed combustion which is not good for wood vinegar condition.

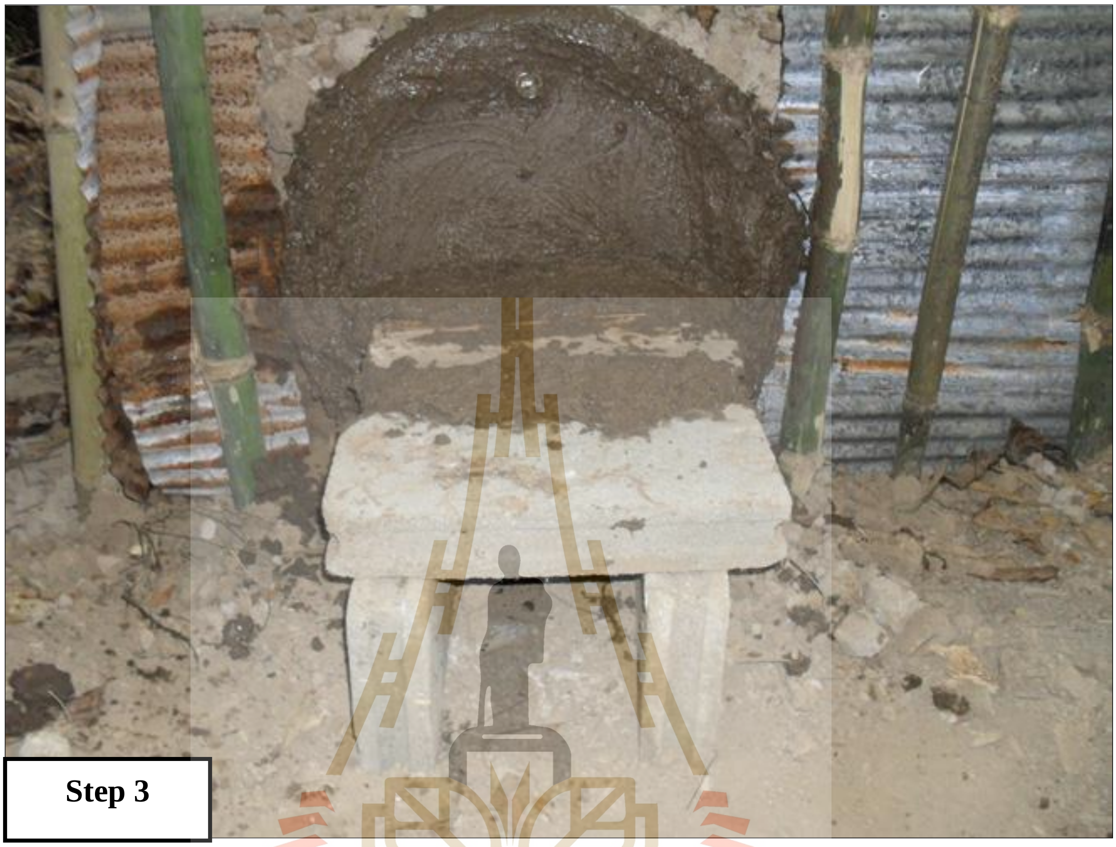

Figure 2.3 Preparing burning gate (An Introduction to Wood Vinegar, 2013).

Make an outer vent for burning gate in front of the hold of the square cut opening in the lid by standing two brick blocks lengthways toward of the hold with keeping a space hold as before. Cover by two more blocks crossways on the two blocks. To make the outer vent perfectly, seal the spaces along the edge of blocks and the space between the burning tank lid and the brick of the cover with clay or sticky land.

Figure 2.4 Burn a small fire in the brick block burning gate

(An Introduction to Wood Vinegar, 2013).

Burn a small fire in the brick block burning gate. Gradually insert wood for burning in the burning gate at the opening of the kiln. This initial small amount of heat will transfer into the kiln and drive moisture from the wood and flow out the moisture smoke from the kiln to the chimney. Time approximately needed to make evaporate the moisture from the wood inside will be at least around 1 to 2 hours it bases on the size of wood. When see the smoke releasing from the chimneys is very think and white, not need to add more wood to burn. This smoke shows that wood in the burning tank is getting burned for carbonization.

Figure 2.5 Wood vinegar collecting (An Introduction to Wood Vinegar, 2013).

Wood vinegar collecting. When the smoke turns from white to thick slightly yellowish after you stop feeding wood into the kiln, close off most of the burning gate with the sticky clay. Turn on a small crack hold which is approximately 3 cm wide, should remain open. Connected a hollow green bamboo pole with the angle around 45º from the flue pipe. Place the containers fastened below one to two holes with approximately 2cm and 30 cm from the connection with the flue pipe in order to obtain the drop of wood vinegar.

When the smoke releasing the flue is slightly thickness, reopen the burning gate around 5 to 10 minutes to make the wood inside remaining burning. For the raw material of wood is bigger, you can open the burning gate for 20 to 30 minutes. At this point, wood inside the burning tank will have become into pure charcoal. However, the presence of fresh air entering the kiln too much it will cause the combustion to turn to completed combustion and the wood will turn to ashes. Additionally, the cool down period stops up the end of the chimney and burning gate with clay.

Figure 2.6 Turned off process (An Introduction to Wood Vinegar, 2013).

After sealing the chimney and the burning gate, add more soil or sand on top of the burning tank over to the retaining wall to enable heat to dissipate from the tank. Keep the tank and contents to cool down around 12 to 15 hours. After that, the charcoal can be collected from the kiln for storage or packaging.

2.3.1 Wood vinegar by using gasoline tank as a kiln

Wood vinegar is made from burning fresh wood in a charcoal kiln, made from a 200-liter oil drum and 120-cm-tall concrete chimney with a 4-inch diameter. The kiln contains 63-83 kg of fresh wood. Wood good for vinegar must have a heartwood (Food and Fertilizer Technology Center, 2005).

1. Cure wood that has heartwood and bark for 5-15 days.
2. Pile wood in the kiln **Figure 2.7** Close the kiln and cover every hole with clay. Burn it at 120-430oC.
3. After 1 hour, put a tile at the top of the chimney **Figure 2.8.** If brown or dark brown drops appear on the tile, allow smoke to flow through a bamboo pipe so that the hot steam may be condensed into liquid.
4. Place a vessel to collect the vinegar drops from the bamboo pipe.
5. If wood is burned for 12-15 hours in a 200-liter oil drum kiln, it should produce 2-7 liters of wood vinegar. At this stage, it is called raw wood vinegar.
6. Leave the raw wood vinegar for 3 months to become silted. The vinegar will turn yellow like vegetable oil. After which, it will turn light brown and the tar will become silted. The top content will be a light, clear oil. Remove the tar and light oil, as well as the dark brown translucent oil and the remainder will be sour vinegar **Figure 2.9**.

Figure 2.7 Pile Wood in the Kiln (Food and Fertilizer Technology Center, 2005).

Figure 2.8 Collect the Vinegar Drops from the Bamboo

(Food and Fertilizer Technology Center, 2005).

Figure 2.9 The Wood Vinegar (Food and Fertilizer Technology Center, 2005).

2.3.2 Pyrolysis method

Wessapan, Sutthisong, and al, (2014) the pyrolysis is the method of combustion with no presence of gases that are volatile organic compounds pass through the air-cooled condenser to be condensed into pyroligneous acid.

Figure 2.10 Pyrolysis oven (Wessapan, Sutthisong, and al, 2014)

The pyrolysis method of making wood vinegar is conducted by some researcher in propose to increase the efficiency of distillation rate of wood vinegar and quality of charcoal. However, this method is quite complicated and costs highly budget to build this system moreover it is not so convenient for people in the countryside especially farmer to use. This method uses 60 kg of wood could produce wood vinegar 7.2 liters. It was the summary of key wood vinegar production steps as following:

Figure 2.11 The obtained charcoal (Wessapan, Sutthisong, and al, 2014)

1. Leave the Acacia wood after cutting for 3-4 days before doing an experiment.
2. Place 60 kg of the Acacia wood chips in the pyrolyzing tank, and place charcoal 20 kg residuals in the burning of the second tank. Close the cover of the pyrolyzing tank and then close the oven with a lid.
3. Start to burn the charcoal in the second tank. Start to time, measure the temperature every 1 hour at the pyrolyzing chamber.
4. Notice the color of the wood vinegar product from the condensing tank. If the color turns to red-brown liquid, which means it is becoming raw wood vinegar. Collection the vinegar drops from the wood vinegar drain.

5. If the color of wood vinegar turns to dark brown color, which means the moisture substance in those wood are all evaporated and the wood becomes good charcoals.

6. Stop to time after 10 hours. The period of timing since the beginning is the process time of producing wood vinegar. Leave the oven and the charcoal cool down for 1 night.

7. Measure the amount of obtained charcoal, wood vinegar, and ash.

9. Close the raw wood vinegar in the bottles or tanks for 3 months in order to separate light oil, sour vinegar, and tar. Remove the light oil and tar out by using sourwood vinegar only.

2.3.3 Design and development of pyrolysis system to produce liquid oil

Conte, Schmidt, and Cimò, (2016) recommendation on the nature of the biomass feedstock to be used for biochar production, and guidelines on the pyrolysis conditions to be applied. (Iberahim, 2013) designed and developed the manufacturing process to produce liquid oil and investigated on rice husk as a raw material.. In this study the author using slow Pyrolysis, characterized by the slow temperature around 500 C above. The major component of the system fabricated by stainless steel of grade AISI 304 due to its rationale properties. In this combustion, the heating rate usually less than 2 seconds for slows Pyrolysis. A cylindrical combustion was designed and fabricates using mild steel plate of the outer diameter is 45cm. The combustion volume and length were 56548 cm^3 and 40cm respectively.

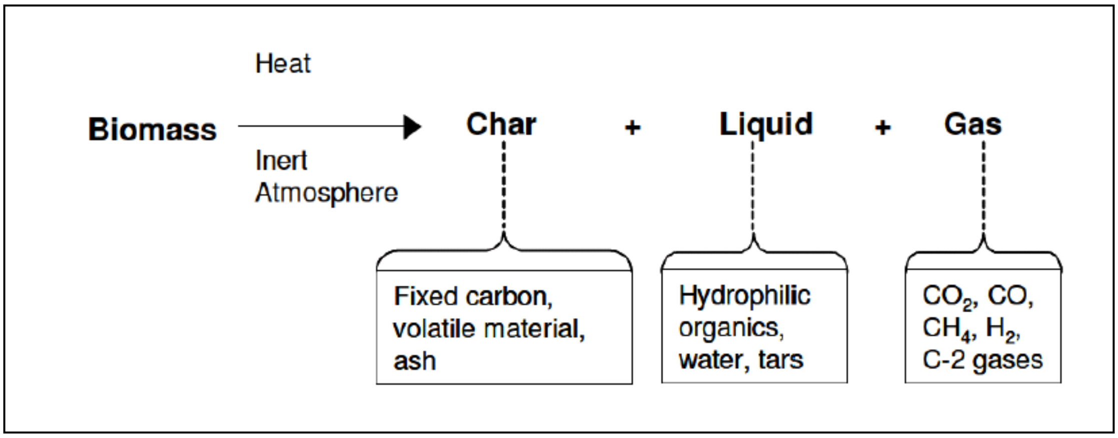

Figure 2.12 A simple representation of pyrolysis process (Iberahim, 2013)

2.4 Heat Exchanger Review

2.4.1 Thermal Conductivity

Kulkarni, and Goswami, (2015) studies and experimentation on cooling towers show that the thermal conductivity of materials, which are necessary for the research. (Biswas, and Mahanta, 2012) illustrate on design and experimental analysis of condenser for the production of bamboo vinegar by designing the condenser which is a modification of a shell and tube type heat exchanger. The condenser acts as a heat sink improving the yield and quality of bamboo vinegar produced. (Kleanthous, and Van Gorder, 2017) shows that Heat and mass transfer due to upstream fluid flow in a vertical pipe which is heated in some region due to an external heating element on the surface of the pipe is considered.

Table 2.1 Thermal Conductivity

Materials	Thermal Conductivity (W/m K)
Copper	385
Steel	48
Stainless steel	22
Concrete	1.1
Water	0.65
Air	0.025
Brick	0.70–1.33
Dry sand	150– 0.25

2.4.2 Relation between Conduction and Convection

The relation between conduction and convection heat exchanger is shown:

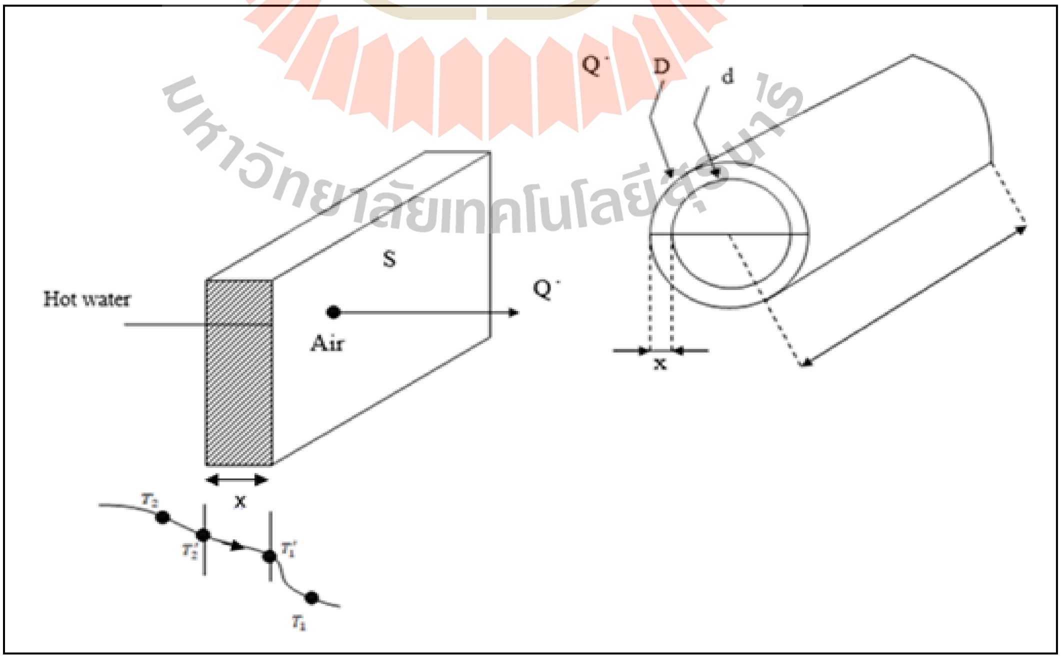

Figure 2.13 A relation between conduction and convection

$\dot{Q}$ Heat transfer rate total of conduction and conviction (kW)

S Surface area of the exchanger (m^2)

T_2 Temperature of hot water (°c)

T_2' Temperature around the tube (°c)

In practice, the heat transfer by conduction and convection is applied at the same time or simultaneously, for example, if the hot water has been circulated in a metal tube, we obtain:

- The internal convection of the tube
- Conduction through the wall of the tube
- External convection of the tube

For internal convection:

$$Q^o{}_{Ci} = h_i \times s \times (T_2 - T_2^{'}) \Rightarrow (T_2 - T_2^{'}) = \frac{Q^o{}_{Ci}}{h_i . s} \qquad eq-(1)$$

Where h_e - thermal conductivity of the tube $(w/m^2.k)$

- **Conduction through the wall of the tube**

$$Q^o = \frac{\lambda \times s \times (T_2^{'} - T_1^{'})}{x} \Rightarrow (T_2^{'} - T_1^{'}) = \frac{Q^o \times x}{\lambda \times s} \qquad eq-(2)$$

Where λ - thermal conductivity of the tube $(w/m.k)$

- **External convection of the tube**

$$Q^o{}_{Ce} = h_e \times s \times (T_1^{'} - T_1) \Rightarrow (T_1^{'} - T_1) = \frac{Q^o{}_{Ce}}{h_e \times s} \qquad eq-(3)$$

Where h_e - thermal conductivity of the tube $(w/m^2.k)$

Somme those equations $eq-(1)$, $eq-(2)$ & $eq-(3)$

$$(T_2 - T_2^{'}) + (T_2^{'} - T_1^{'}) + (T_1^{'} - T_1) = \frac{Q^o{}_{Ci}}{h_i \times s} + \frac{Q^o \times x}{\lambda \times s} + \frac{Q^o{}_{Ce}}{h_e \times s}$$

$$\Leftrightarrow (T_2 - T_1) = \frac{Q^o}{s}\left[\frac{1}{h_i} + \frac{x}{\lambda} + \frac{1}{h_e}\right] \qquad eq-(4)$$

We take $\frac{1}{k} = \frac{1}{h_i} + \frac{x}{\lambda} + \frac{1}{h_e}$

$$(T_2 - T_1) = \frac{Q^o}{s} \times \frac{1}{k}$$

$Q^o = k \times s \times (T_2 - T_1)$ $\qquad eq-(5)$ $\qquad$ In general $\qquad \frac{1}{k} = \frac{1}{h_i} + \frac{\sum x}{\lambda} + \frac{1}{h_e}$

2.5 Wood moisture content

Water in wood can be defined as "water content" and "humidity". In practice, the terms "water content" and "humidity" are often confused or even equated with one another. However, this is inaccurate. Water content (M) expresses the mass of water present in relation to the mass of fresh wood. This value describes the quantity of water in the entire moist biomass (fresh mass). This measure is used in the marketing of wood fuels (Krajnc, and Nike, 2015, and ASTM D 2974-87, 1993).

The formula for calculating water content (M) is:

$$M = \frac{W_w - W_0}{W_w} x100 \qquad eq-(6)$$

Where is:

W_w = wet weight of wood

W_0 = oven-dry weight of wood

A practical example of calculation of water content– wherein total 100 kg of wood water represents 20 kg

2.6 Air flow rate

Yang, Sharifi, and al, (2004) who studied influent of airflow rate and the moisture of fuel on biomass burning behaviors. The result from this research shows that primary air has a significant effect on the moisture evaporation, devolatilisation, and char burning. Increasing primary airflow initially increasing each of the process rates but it causes a decrease in the rates beyond a certain point (the critical airflow rate). Moreover, higher moisture in the fuel results in higher moisture evaporation rate. (Shen, Xue et al, 2013) who observed on the influent of oxygen supply and burning rate on emission factor as a result state that a fast burning or the burning with a low air supply amount could result in oxygen deficient atmosphere. In addition, increased air supply may cool the combustion temperature, both of which could lead to the change in the formation and emission of carbonaceous particulate matter

$$\text{Air mass flow rate} = \text{Air density} \times \text{Duct section area} \times \text{Air flow speed} \qquad eq-(7)$$

Where

Air mass flow rate (kg/s)

Air density (kg/m^3)

Duct section area (m^2)

Air flow speed (m/s)

2.7 Exhaust duct

The exhaust duct is a structure that provides ventilation for hot flue gases or smoke from a burning tank or fireplace to the outside atmosphere. Exhaust ducts are typically vertical, horizontal or as near as possible to vertical, to ensure that the gases flow smoothly, drawing air into the combustion in what is known as the stack, or chimney effect (Ingham, and Wen, 1995).

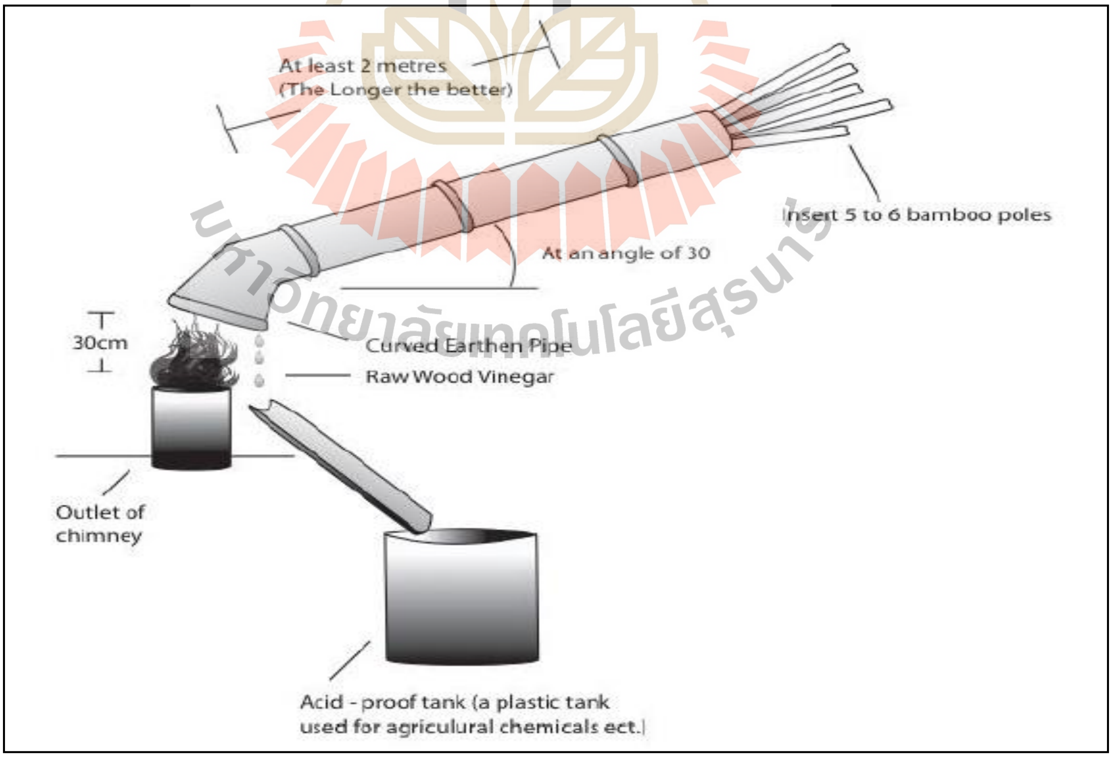

Figure 2.14 An exhaust duct for collecting wood vinegar (Joseph, 2014).

The length of a chimney influences its ability to transfer flue gases to the external environment via stack effect. Additionally, the dispersion of pollutants at higher altitudes can reduce their impact on the immediate surroundings. In the case of chemically aggressive, particle output, a sufficient exhaust duct can allow for partial or complete self-neutralization of airborne chemicals before they reach ground level. The dispersion of pollutants over a greater area can reduce their concentrations and facilitate compliance with regulatory limits. (Keerati and Phineath, 2018) Investigated on Effect of Exhaust Duct Position on Wood Vinegar Burning Process. From the experiment, results show that the interaction between the positions of exhaust duct is significantly effect on the yield percent of wood vinegar collected.

2.8 Application Insights

Agriculture emerged as the largest application industry and accounted for 43.7% of the global revenue (Wood Vinegar Market Analysis, 2016).

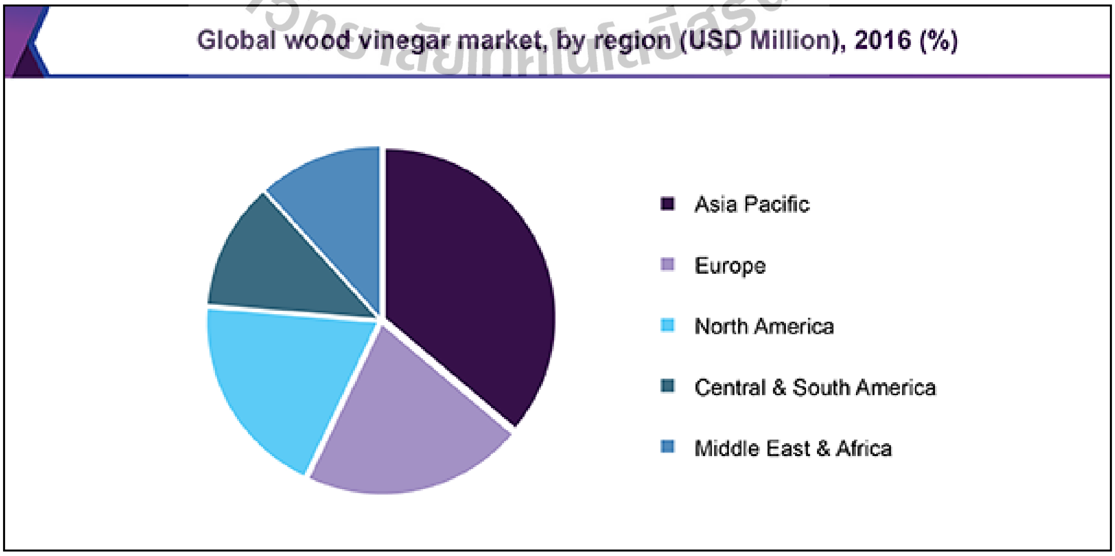

Figure 2.15 Global wood vinegar market (Wood Vinegar Market Analysis, 2016).

It was followed by animal feed as the second largest segment, in terms of revenue. When applied to soil and mixed in high concentrations, inhibits soil diseases and eelworms. When pyroligneous acid is mixed with agricultural chemicals, it increases the overall efficacy. It enhances the development of stronger roots for plants, and crop yield. The Asia Pacific was followed by North America in terms of revenue and expected to grow at a rate of 5.8% over the forecast period. The application segment is dominated by the use of the wood vinegar as a food additive and in animal feed. Genetically modified organisms are used to increase the yield in the poultry, which pose several health risks. The demand for non-Genetically Modified Organism (non-GMO) animal feed is increasing in this region.

2.9 Wood vinegar concern

Thailand's department of agriculture claims that wood vinegar is safe in the food chain living matters, including pollinating. Nevertheless, they also indicate that the composition of the fertilizer is slightly toxic to fish and harmful to plants if applied excessively reported by (An Introduction to Wood Vinegar, 2013). Research at Mae Jo University also reveals that wood vinegar with high amounts of tar kill the plants.

2.10 Chapter summary

This chapter has reviewed on wood vinegar; including the history of wood vinegar elements and characteristics of wood vinegar, usage, the opportunity for researching on wood vinegar. Furthermore, with significant potential for the application method of making wood vinegar. Four parameters for wood vinegar experiment were discussed. Two kinds of woods will be used to test. Fire conditions of air mass flow rate and moisture of woods are varied are discussed. The heat exchanger of operation of wood vinegar experiment is also discussed. In the improvement and optimization techniques review, it has been observed that most of the studies in wood vinegar production made the focus on the method of making wood vinegar and usage of wood vinegar without considering the development of distillation rate of wood vinegar and systematically theoretical and testing on parameters for wood vinegar burning. The advantage of the theoretical and experiment are in its ability to reveal characteristically detailed of wood moisture, mass air flow rate, kind of wood and gas emission position that effect to wood vinegar burning process inside.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research aims to develop a burning tank and experiment for a wood vinegar burning process using wood as raw material. Operation and design of such burning tank require a detailed understanding of parameters that affect the system performance. In the research, the device designed for testing and developing a burning system that can improve the distillation rate of wood vinegar. The developed system consists of two tanks; burning tank, and distillation tank. In the research, it is a factorial design of experiments with two replicating has been investigated in order to study of those influence parameters. Testing are performed based on yield percentage of obtained wood vinegar, and the optimal those parameters for producing wood vinegar are determined. The burning tank is developed for production of wood vinegar by using LPG as fuel. A by-product from the process is charcoal, which can be used as a solid fuel.

3.2 Design Concepts

Schematic of wood vinegar processing system shown in **Figure 3.1** The system consists of five parts: (1) burning gate, (2) burning kiln, (3) pipe connecting between burning tank to distillation tank, (4) distillation tank, and (5) condensing tubes. The wood vinegar burning device designed to contain 15-20 kg of wood. It provides a gate for flowing the air into the tank for burning process. The burning tank uses Liquid Petroleum Gas (LPG) as fuel in order to maintain the accuracy of experiment and provides high temperature to burning tank. The required temperature to heat the wood is about 120-430°C to give the good quality of wood vinegar under the amount of airless condition. The limit-air known as the incomplete combustion gases that are a mixture of volatile organic compounds pass through the connection pipe to the distillation tank. This has 24 copper pipes used as a condensing tube to be condensed into wood vinegar resulting in a condensing surface area of 0.362 m^2. The condensing pipes installed in a 65 liter-tank contains with cool water, which is used as media for removing the heat from those pipe surfaces.

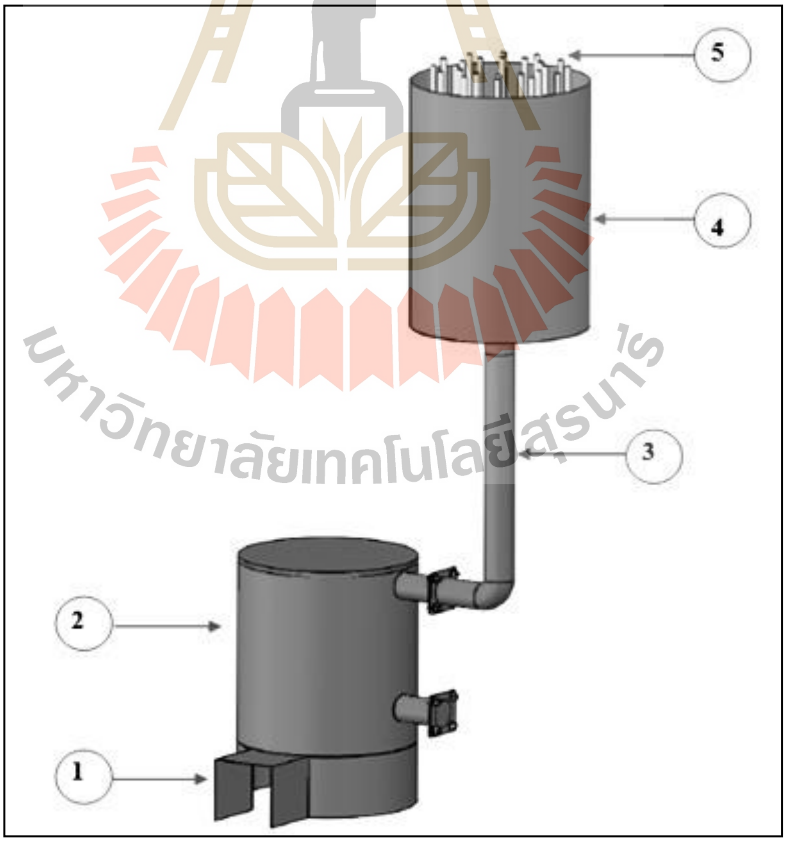

Figure 3.1 Schematic of wood vinegar producing.

3.2.1 Operation and Structure Design

The burning system consists of two main components: burning tank **Figure 3.2** and distillation tank **Figure 3.3** the burning tank has 400 mm diameter, 600 mm tall and 1.5 mm thickness. The sand residual is used as isolation to protect the heat loss from inside, shown in **Figure 3.11.** It is designed for wood burning under the airless condition and obtains the heat from the burning gate. The tank made of sheet metal. The burning hood at outside tank used for LPG fuel heating as shown in **Figure 3.12**. The capacity of the tank is 0.075 m^3 for wood. Two exhaust ducts with a 60 mm diameter and 150 mm long, attached to the tank side for more smooth ventilation and experiment investigated.

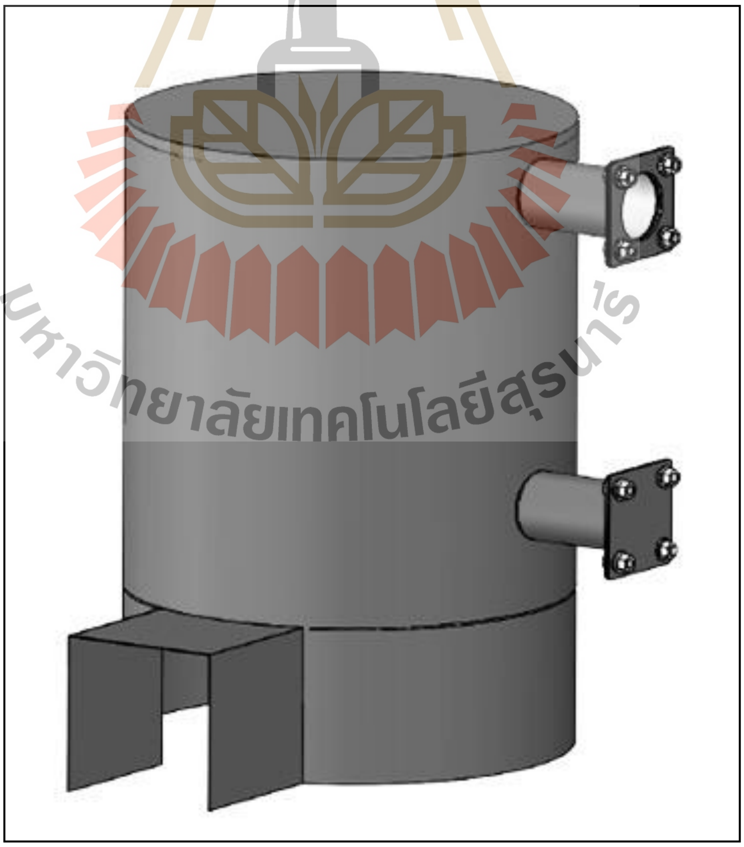

Figure 3.2 the burning tank

The distillation system used in the extraction process for raw wood vinegar collection. The burning tank designed for the concept; the experiment of parameters for a wood vinegar burning process using wood as raw material and thermal decomposition of organic substances harmful gases pass through the copper tube. Cool water used as a media for removing the heat from those pipe surfaces. The vapour condenses to be wood vinegar **Figure 3.3.** The concept helps to increase performance and decrease the greenhouse effect.

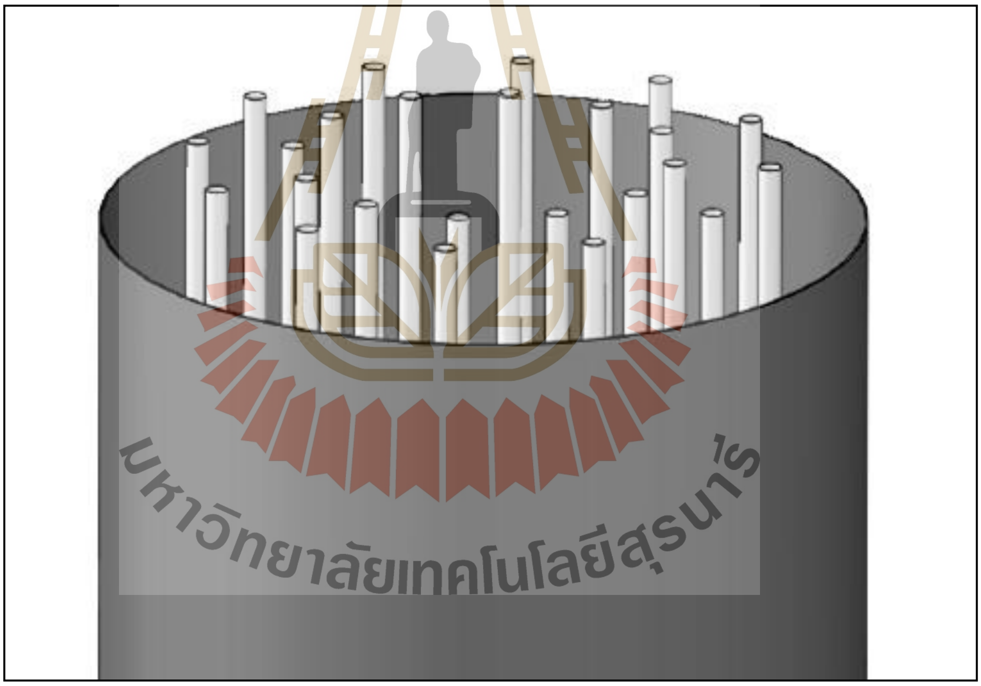

Figure 3.3 The distillation tank

3.3 Experiment

In this research, the experiment process has been analysed base on factorial design. The two replicating have been employed in order to study the influence parameters; two kinds of woods, three fire conditions of airflow rate, three moisture contents and two positions of exhaust duct. Testing conditions are set based on yield percent of obtained wood vinegar. In order to determine the optimal conditions for producing the wood vinegar. In the experiments, two kinds of woods, River tamarind and Eucalyptus will be tested. Three fire conditions of airflow rate are varied no fan, 4.2L/s, and 6.2L/s testing. The moisture conditions of tested woods are 0kg, 1kg, 2kg removed-moisture. The effect of exhaust duct positions; top position and bottom are investigated testing.

In each cases, 15 kg of wood is used and the yield percentages of wood vinegar production from those two kind of tested wood are performed.

3.3.1 Factorial diagram design for the experiment

1. Experiment on exhaust duct positions: factorial diagram design for exhaust duct position experiments is revealed in **Figure 3.4**. The experiment is conducted by test on the top 500mm from bottom and bottom 100mm from the bottom positions of the exhaust duct. The position which can maximize the producing of wood is able to produce wood vinegar maximum will be selected to be the setup condition for two kinds of wood experiment.

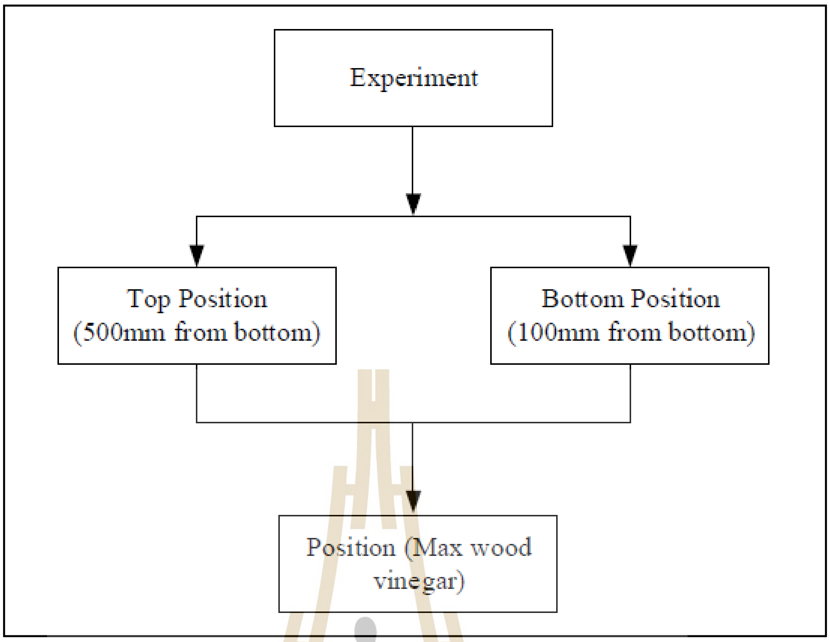

Figure 3.4 Factorial diagram experiment for exhaust duct position.

2. Experiment on Eucalyptus and Revier tamarind wood: factorial diagram design for Eucalyptus and Revier tamarind wood experiments is displayed in **Figure3.5**. The experiment is conducted by test on the kind of woods. The wood is able to produce wood vinegar maximum will be selected to be the setup conditions for wood moisture experiment in the next step.

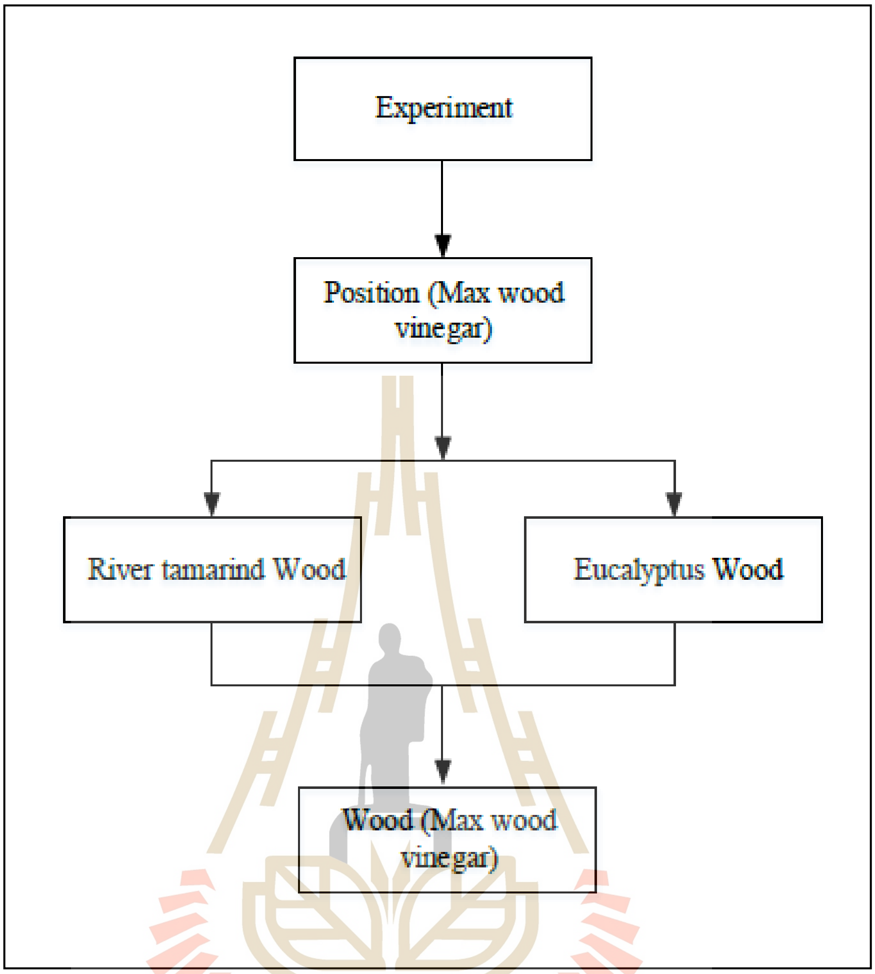

Figure 3.5 Factorial diagram experiment for kind of wood.

3. Experiment on wood moistures: factorial diagram design for wood moistures experiments is shown in **Figure 3.6**. The experiment is conducted by test on three kinds of wood moisture in sense of moisture removed from wood, no-moisture removed, 1kg moisture-removed, and 2kg moisture-removed. The wood moisture weight can produce a maximum wood vinegar will be selected to be the test condition for the air flow rate experiment.

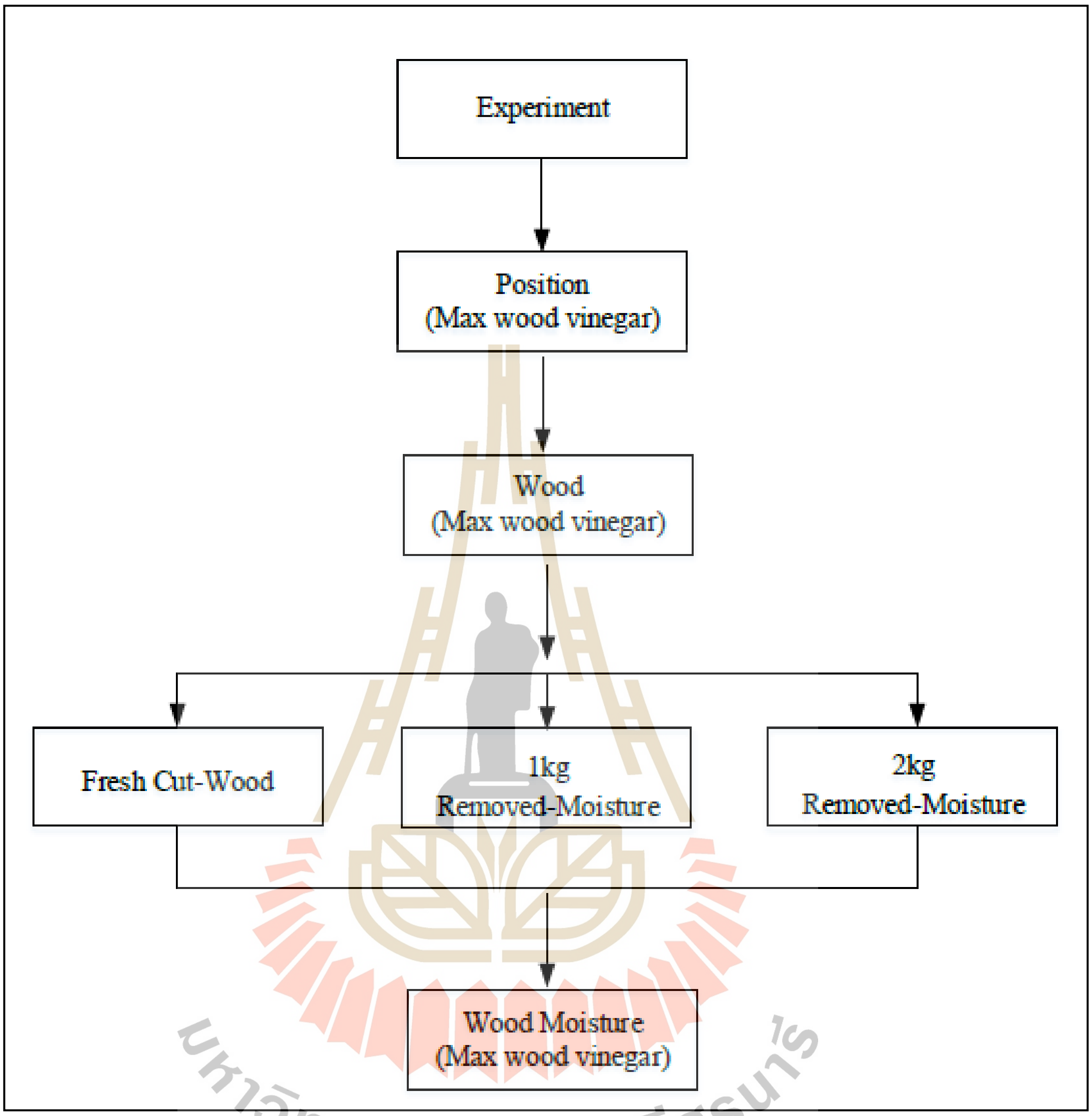

Figure 3.6 Factorial diagram experiment for air mass flow rate experiments.

4. Experiment on air mass flow rate: factorial diagram design for wood airflow rate experiments as illustated in **Figure 3.7**. The experiment is conducted by test on three kinds of airflow rate; free flow rate, 4.2L/s flow rate, 6.4 L/s flow rate. The wood moisture which can be produce the maximum wood vinegar will be point as the optimze condition as shown in **Figure 3.8.**

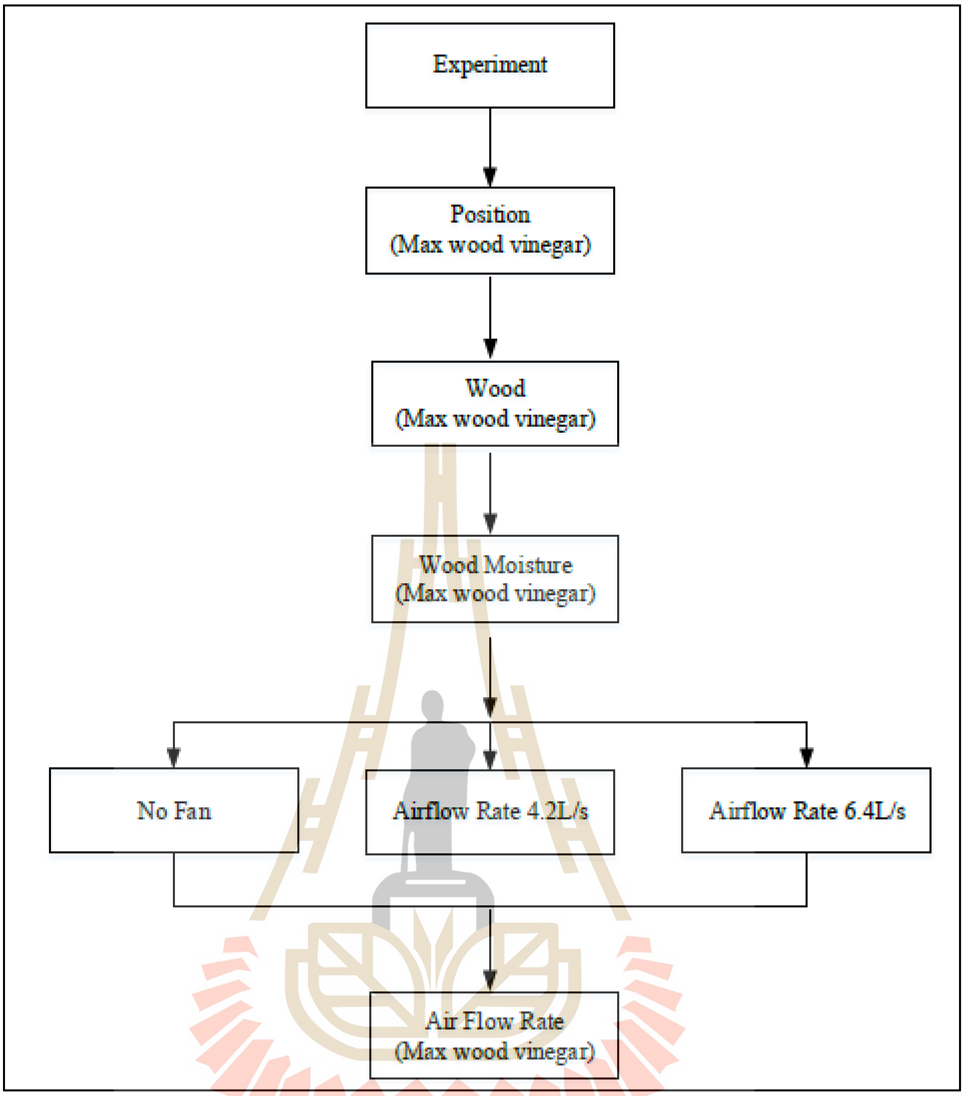

Figure 3.7 Factorial diagram experiment for airflow rate.

5. Experiment on overall:

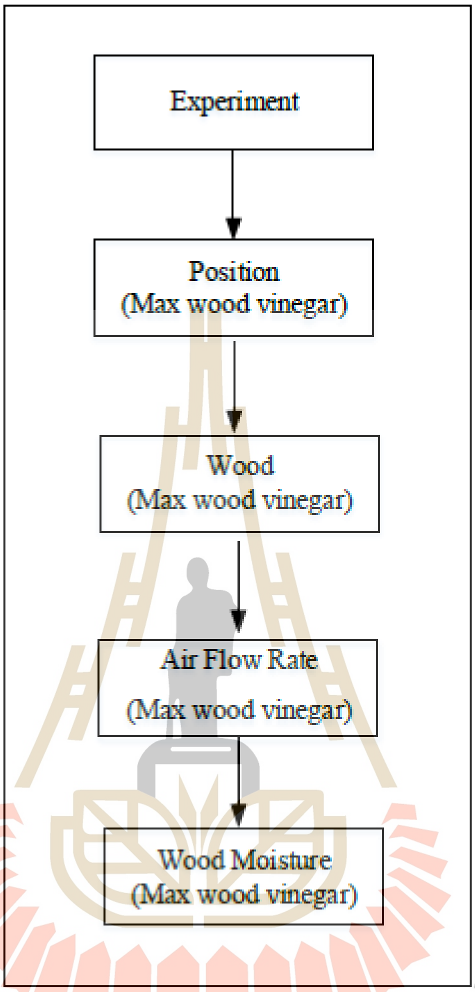

Figure 3.8 Factorial diagram designs for the overall testing.

3.3.2 The steps of the experiment

1. Leave the fresh River tamarind wood for 25-30 days (depend on condition of moisture to be removed) before conducting an experiment step, (**step 1**).

Figure 3.9 Eucalyptus wood.

Figure 3.10 River Tamarind wood.

2. Set up the device and fill wood river tamarind 15 kg to the burning tank, and set up LPG in the burning gate, (**steps 2, 3 and 4**).

Figure 3.11 Fill wood in the burning tank and set up the device.

3. Burn the LPG. Start to time, measure the temperature every 1 hour in the buring tank, (**steps 4 and 5).**

Figure 3.12 Liquid petroleum gas set up and temperature measurement.

4. Notice the color of the wood vinegar product from the distillation tank. If the color turns to red-brown liquid, which means it is becoming raw wood vinegar. Collection the vinegar drops from the wood vinegar drain, (**steps 6 and 7).**

Figure 3.13 Wood vinegar collecting.

5. If the color of wood vinegar turns to dark brown color, which means the moisture substance in those wood are all evaporated and the wood becomes good charcoals.

6. Stop to time after five hours. The period of timing since begining is the process time of producing wood vinegar. Leave the burning tank and the charcoal cool down for 6 hours.

7. Measure the amount of obtained charcoal, wood vinegar, and ash.

8. Repeat the step 1-7, with more replicating by changing conditions.

9. Close the raw wood vinegar in the bottles or tanks for 3 months in order to separate light oil, sour vinegar, and tar. Remove the light oil and tar out by using sour wood vinegar only, as shown in **Figure 3.14**.

Figure 3.14 Charcoal and wood vinegar obtained from the experiment.

3.4 Chapter summary

Implementation of the relevant parameters in this experiment has been finished in this chapter. Typical values of parameters are described and provided for each experiment. In the experiment, the temperature of the burning tank, cooling tank, wood vinegar, and color of smoke are usually observed. A complete of the wood vinegar experiment is a combination of every model of the parameters. The following chapter contains the results of the experiment in this chapter and then be discussed to get the conclusion in wood vinegar experiment.

CHAPTER 4

EXPERIMENT RESULTS AND DISCUSSION

4.1 Introduction

This chapter demonstrates the result of the experiments influent parameters are investigated and different cases are discussed according to the behavior and characteristics of wood vinegar performance as following sections; two positions of exhaust ducts are varied, two kind of woods, three moisture contents in woods, and three fire condition of airflow rates. Those experiments were tested by using 15 kg of River tamarind and Eucalyptus wood within duration 5 hours. Amount 0.5kg LPG is used to burn for each cases. The result of the interaction between those parameters is significant to show the behaviour and effect on the yield percentage of obtained wood vinegar collected.

4.2 Experiment results on Exhaust duct position

The burning system constructed and tested its operation on positions of exhaust ducts by using River tamarind wood. The result from the operation tested is shown in **Table 4.1**:

Table 4.1 Productions from testing.

Products	Unit	Amount of Products		Percentages (%)
		Bottom Position	Top Position	
Wood vinegar	mL	3,392	4,215	24%
Charcoal	kg	8.1	6.2	31%
Ash	kg	0.1	0.2	50%

The average interval temperature in the burning tank process is about 68-410°C that meets the desired temperature. Exhaust duct on the yield of wood vinegar with respect to time collected, with two replicates. The experiment results are shown in **Table 4.2**.

Table 4.2 Amount of wood vinegar with respect to time on each exhaust duct positions.

Time (h)	Burning tank temperature (˚C)				Amount of distillated wood vinegar (mL)			
	Bottom Position		Top Position		Bottom Position		Top Position	
	Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2
1	124	136	71	65	8	12	0	0
2	176	154	89	99	287	253	321	349
3	228	252	144	132	840	910	1,242	1,198
4	336	316	332	348	1,240	1,180	1,409	1,431

5	419	401	337	339	1,087	967	1,273	1,207

From **Figure 4.1,** the top exhaust duct position gives the higher yield of raw wood vinegar for the production of wood vinegar by using the burning system. The distillation rates of wood vinegar of these two position are shown in **Figure 4.2**. At initial, the bottom position gives wood vinegar 10 mL in the first hour while the top position gives no condensed wood vinegar. It is seen that the bottom position started to evaporate moisture from the wood in the first stage.

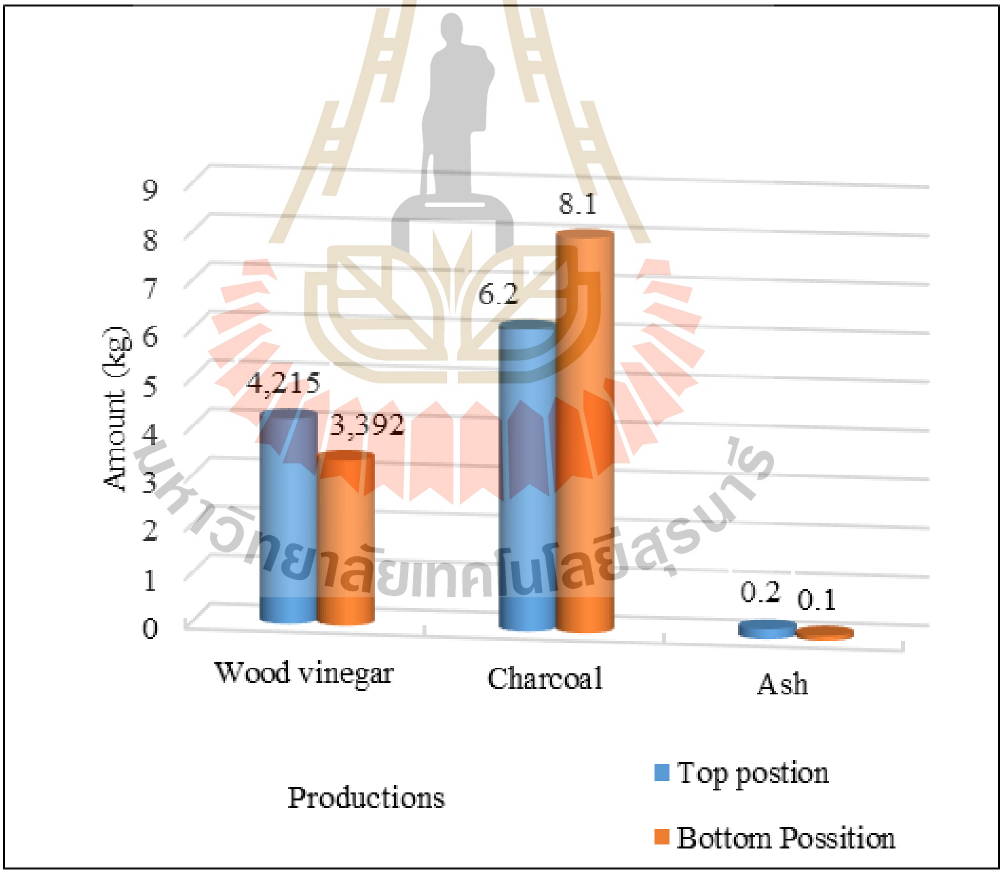

Figure 4.1 Comparison of product amount obtains from different position of exhaust ducts.

From second to third hour, the temperature of the bottom position and top position were increased rapidly, but the top position was able to produce wood vinegar much more than the bottom position. During the third to fourth hour, the temperature of the bottom position and top position reached to 326 ˚C and 340 ˚C respectively. In this stage, it is found that the wood was strongly self-burning which could produce wood vinegar maximum. The wood vinegar began slightly fall distillation. After the tank was cold down, the bottom position was fill with many wood vinegar stuck to the burning surface while the top position there was lesser. This is because the hot gas in the bottom zone was hard to flow out the exhaust duct which leads to some of the wood vinegar condensed in the burning tank and remain the temperature increasingly. The top position allowed more smooth the gas flow at the exhaust duct to the distillation tank to condense into wood vinegar.

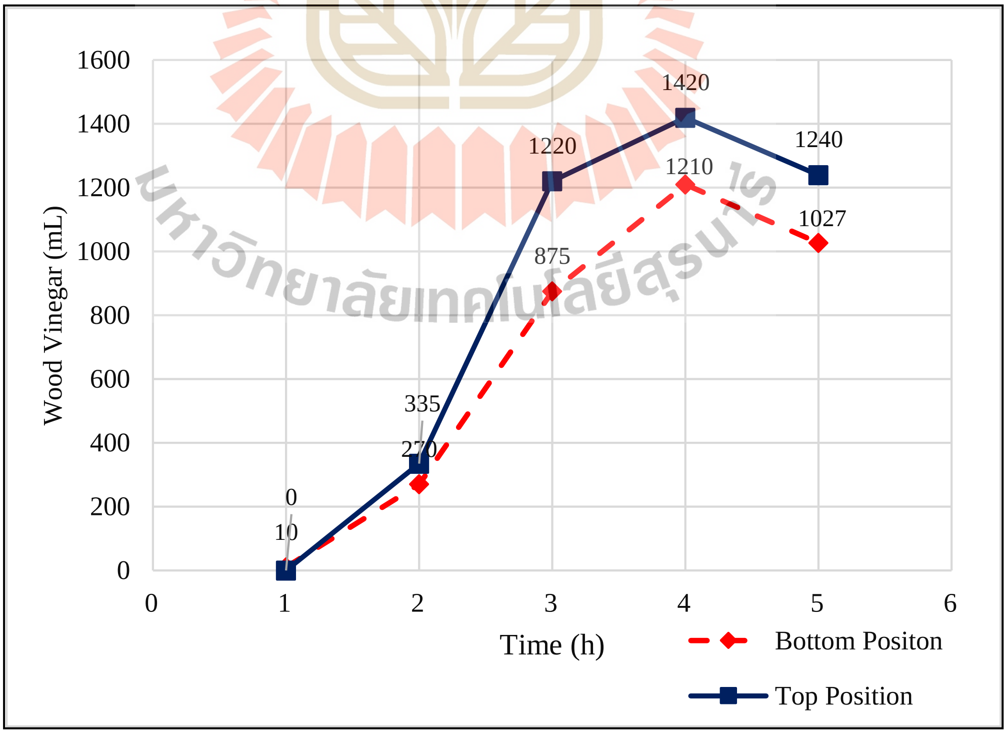

Figure 4.2 Wood vinegar distillation rate based on position of exhaust ducts.

4.3 Experiment result on kind of woods

The burning system has been tested on two kind of woods; Eucalyptus, and River tamarind wood, to find the yield percentage of obtained wood vinegar.

The results from the experiment are shown in **Table 4.3**.

Table 4.3 Productions from testing.

products	Unit	Amount of products		Percentages (%)
		Eucalyptus	River tamarind	
Wood vinegar	mL	4,505	4,215	6.44%
Charcoal	kg	6	6.2	3%
Ash	kg	0.2	0.2	0%

Results from the effect of kind of woods with two replicates are shown in **Table 4.4**.

Table 4.4 Amount of wood vinegar with respect to time based on kind of wood experiments.

Time (h)	Burning Tank Temperature (˚C)				Amount of Distilled Wood Vinegar (mL)			
	Eucalyptus		River tamarind		Eucalyptus		River tamarind	
	Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2
1	61	67	71	65	0	0	0	0

2	219	231	89	99	755	683	321	349
3	359	381	144	132	1,248	1,272	1,242	1,198

Table 4.4 Amount of wood vinegar with respect to time based on kind of wood experiments (Cont.).

4	398	418	332	348	1,331	1,309	1,409	1,431
5	439	451	337	339	1,218	1,200	1,273	1,207

Figure 4.3 shows the comparison of product amount between Eucalyptus and River tamarind woods. The by-production got from this experiment are charcoal and ash. The the amount of charcoal and ash obtain from both wood experiments are quite similar. Nevertheless, the observation on the results in **Table 4.4** revealed that the interaction of temperature between the Eucalyptus and River tamarind woods, in which the temperature in the burning tank of Eucalyptus case is higher than the River tamarind case in every hour. This is mean that the Eucalyptus wood has high heating power than the River tamarind wood. The heating power increase the temperature in the burning tank meets the temperature of wood vinegar desired (120-430°C) faster. In this case, the wet smokes happen in the burning tank are flow into the distillation tank. The smokes go up through condensing tube and then condense to be wood vinegar. In the second hour, 721 mL of wood vinegar was distillated from this wood. This obtained amount is higher than the use of River tamarind. However, in the fourth hour, the amount of wood vinegar condense turns to slightly drop down even the temperature in the burning tank of the wood was remain increasing. On this condition, It cause from the number of liquid substances in those woods are slightly evaporated.

The temperature of River tamarind wood is 68-340°C, which is lower than the temperature of Eucalyptus case. In initial time, the wood produced wood vinegar is slower than the Eucalyptus wood case. Until the third-fourth hour, the temperature in the burning tank rises up and meets the temperature of wood vinegar desired. The wood vinegar distillation rate trend to produce faster and higher than Eucalyptus wood case. That it may cause from the number of liquid substances in those woods remain evaporating higher than the Eucalyptus wood case. Within 5 hours, the amounts of wood vinegar obtained from both of the wood were different. That is the Eucalyptus wood was able to produce wood vinegar more than River tamarind wood about 6.44% (see the **Table 4.3**). The experiment shows the type of wood is significantly affect the yield percentage of raw wood vinegar. That is, the Eucalyptus wood case can increase the wood vinegar about 6.44 % compared to the River tamarind wood case.

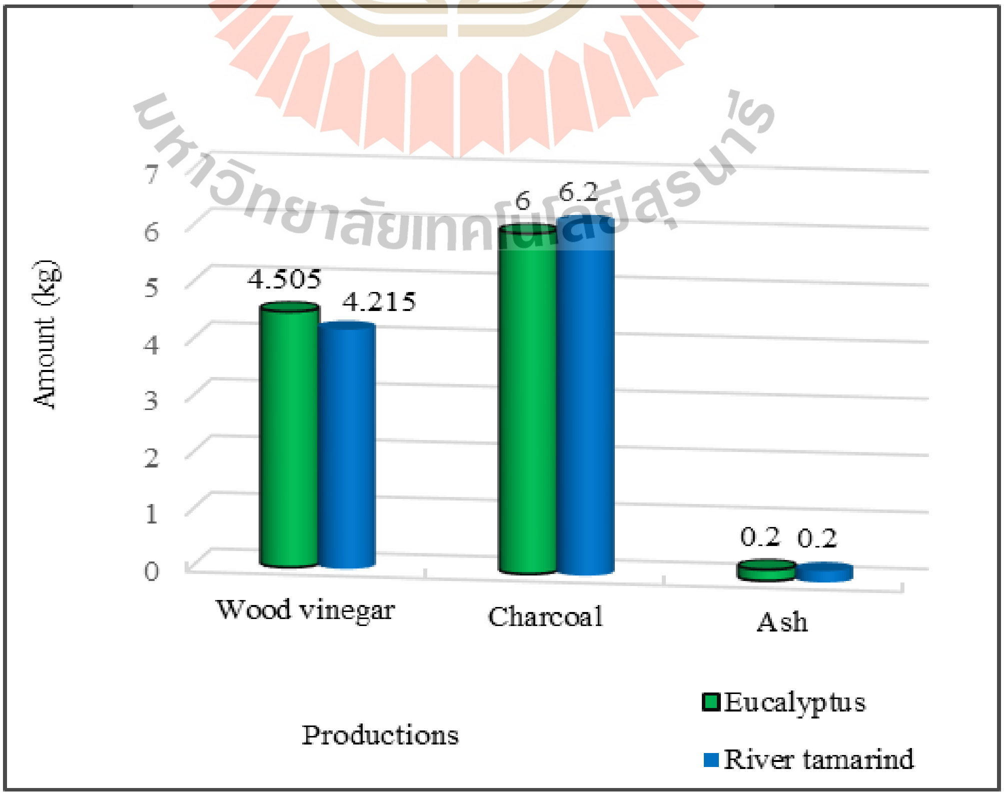

Figure 4.3 Comparison of product amount obtains from two kind of woods experiments

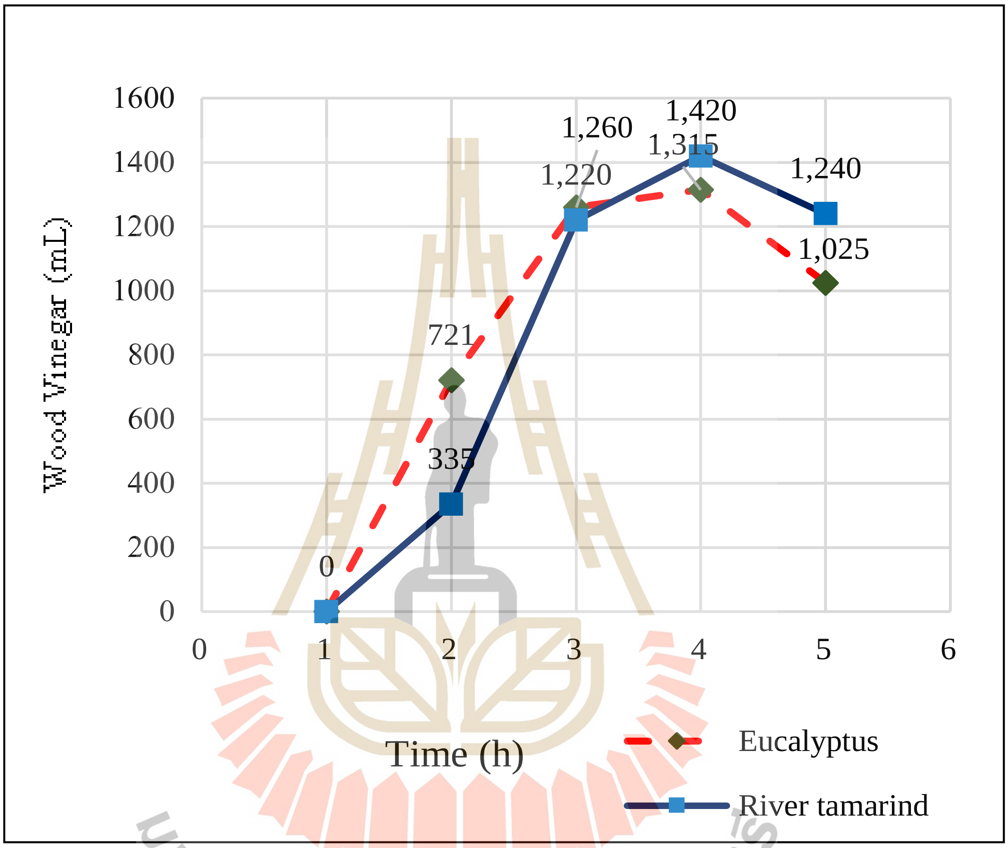

Figure 4.4 Wood vinegar distillation rate.

4.4 Experiment results on wood moisture contents

In this research, the affect of wood moisture contents on distillation rate have been tested based on the conditions; fresh cut wood, 1kg and 2kg removed moisture respectively. The experiment results shown in **Table 4.5**.

Table 4.5 Productions from testing.

Testing	Unit	Removed-Moistures Contents			Percentages (%)
		Fresh Cut -Wood	1kg -Removed Moisture	2kg -Removed Moisture	
Wood vinegar	mL	4,215	3,178	2,915	44.6%
Charcoal	kg	6.2	6	5.4	13%
Ash	kg	0.15	0.2	0.3	50%

With two replicated testing, the experiment results on wood moisture contents with respect to amount of wood vinegar are shown in **Table 4.6**.

Table 4.6 Amount of wood vinegar with respect to wood moisture contents.

Time (h)	Burning Tank Temperature (˚C)			Amount of Distillated Wood Vinegar (mL)		
	Fresh Cut - Wood	1kg Removed Moisture	2kg Removed Moisture	Fresh Cut - Wood	1kg Removed Moisture	2kg Removed Moisture

	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
1	71	65	108	112	118	130	0	0	0	0	0	0
2	89	99	174	188	201	187	321	349	496	556	690	750
3	144	132	354	352	365	359	1,242	1,198	921	949	778	822
4	332	348	407	422	406	400	1,409	1,431	1,079	1,097	856	834
5	337	339	440	464	449	449	1,273	1,207	624	636	568	532

From **Figure 4.5**, it is found that the lesser moisture removed, the higher wood vinegar condensed. The by-product got from this experiment is charcoal and ash. The charcoal obtained from fresh cut wood condition. The result in the **Table 4.6** shown that the temperature of fresh cut wood is lower than the temperature of high removed-moisture condition. It is also found that the wood with fresh cut wood condition is not good for making higher temperature and its effect on the charcoal quality. However, the temperature of the wood meets the temperature of wood vinegar desired (120-430°C). Thus, the moisture substance in those woods started to evaporate to the liquid smoke and then pass through to condense tank to condense into raw wood vinegar in the third-fifth hours. At the fourth-fifth hour, the amount of wood vinegar just started to fall slightly condense. This cause from the number of liquid substances in those woods is still evaporating. Moreover, the distillation rate of wood vinegar is increased when the temperature of the burning tank reach to the temperature of wood vinegar need. But in the period of last third hour the distillation rate of wood vinegar was drop down quickly even the wet smoke temperature in the burning tank remain increasing. This is because the moisture content inside those woods is mostly diffused out as wet smoke. As a result, amount of wood vinegar from burning process, it is necessary to use the raw wood with more moisture content. However, the most moisture content it reduces of wood vinegar quality. Besides, the moisture content in the wood is also prevent the combustion turn to completed combustion. The complete combustion condition is not good for the wood vinegar as well as the charcoal production process. As ending of experiment it is found that the charcoal obtained from the wood with fresh cut wood are almost completed. The quality of the wood vinegar is pH=3.6. While the charcoal obtained from the wood with higher moisture content, the charcoal produce from the process are also perfect charcoals as well. The quality of the wood vinegar is pH=3.1. In the experiment, it is seen that the moisture content in the woods is strongly effects to the amount of raw wood vinegar and wood vinegar quality obtained from the distillation process.

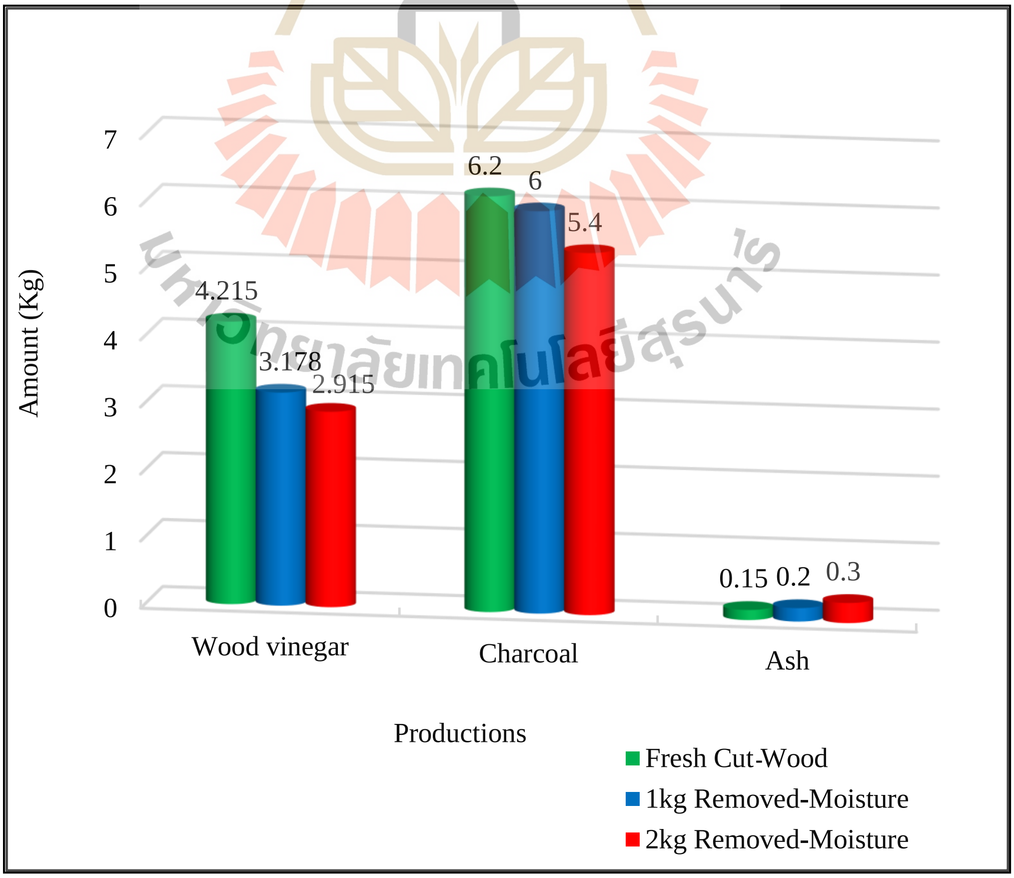

Figure 4.5 Comparison of product amount obtains based on wood moisture experiment

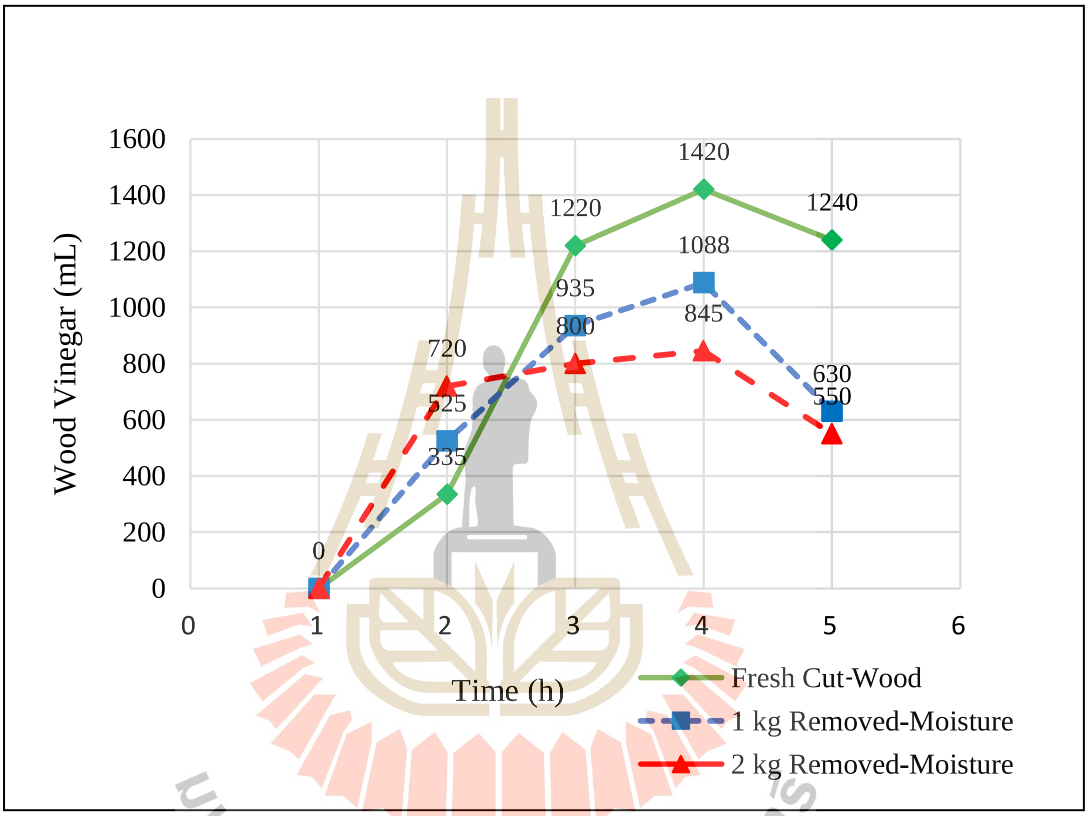

Figure 4.6 Wood vinegar distillation rate based on moisture content condition of woods.

4.5 Results and Discussion on Airflow Rate Effect

As previous mentioned the airflow rate is one of important parameter that effect to the wood vinegar burning process. In this research, the experiments on airflow rate are on no fan, 4.2L/s of airflow rate and 6.4L/s airflow rate. Results from the experiment shown in the following **Table 4.7**:

Table 4.7 Productions from testing.

Testing	Unit	Airflow rate			Percentage (%)
		No Fan	4.2L/s	6.4L/s	
Wood vinegar	mL	4,235	4,21	4,175	1.42%
Charcoal	kg	4.7	6.2	6.3	24.2%
Ash	kg	0.4	0.2	0.2	50%

During perform experiment, the temperature of wet smoke inside the burning tank is varies within the range 68-430°C and with two replicates. The experiment results are shown in **Table 4.8**.

Table 4.8 Amount of distilled wood vinegar with respect to airflow rate.

Time (h)	Burning Tank Temperature(˚C)						Amount of Distillated Wood Vinegar (mL)					
	No Fan		Airflow 4.2L/s		Airflow 6.4L/s		No Fan		Airflow 4.2L/s		Airflow 6.4L/s	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2

1	69	71	71	65	72	80	192	268	0	0	0	0
2	268	280	89	99	98	106	1,026	974	321	349	455	529
3	374	354	144	132	132	120	1345	1,335	1,242	1,198	1,298	1,372
4	380	412	332	348	305	329	918	932	1,409	1,431	1,250	1,300
5	422	438	337	339	324	332	722	758	1,273	1,207	1018	1,125

Figure 4.7 shows that all tested conditions of airflow rate give the quite similar amount of wood vinegar. The products obtained from the experiment are remarkable. The charcoal and ash from a no fan experiment are higher than the other rest cases. Base on the **Table 4.8**, the temperature of no fan experiment is higher than the other rest cases. It is seen that with no fan condition, the burning tank is able to remain the temperature increase rapidly. The temperature in the burning tank meets the temperature of wood vinegar desired. Thus, the evaporation of the liquid smoke happen in the burning tank and flow to the distillation tank bypass through the condensing tube. The temperature of those tubes which surrounded by cool water is too low compared to the temperature of the vapor. That causes the temperature of the wet smoke drop down and distillated as liquid in early hour of the experiment (see the **Figure 4.8**). The temperature keeps remaining at the third-fifth hour, but the amount of wood vinegar start to drop down. This is because the moisture content of those woods are almost diffused out. Therefore, the airflow rate into burning process is significant effect to increase the heat transfer between wet smoke and condensing tube. It helps to push the wet smoke from inside burning tank to the distillation. Furthermore, this can avoid the condensed smoke within the burning tank during the process. However, the heat in the burning tank will transferred out the wet smoke

flow through distillation tank. Therefore, the temperature of airflow obtained from experiments is lower than the no fan condition. That is the temperature did not match with the desired temperature of the wood vinegar. Thus, the amount of distillated wood vinegar in this period is less as well (see **Table 8**). As ending of the experiment, it is seen that the no fan experiment give a lot of wood vinegar distillated on the wall of the burning tank than other cases. The more woods closed to the fire the more charcoals and ashes become. From this experiment, in order to increase the yield of raw wood vinegar and to obtain a good charcoal, the airflow should be supplied when the temperature in the burning tank meet the wood vinegar desired temperature (120-430°C).

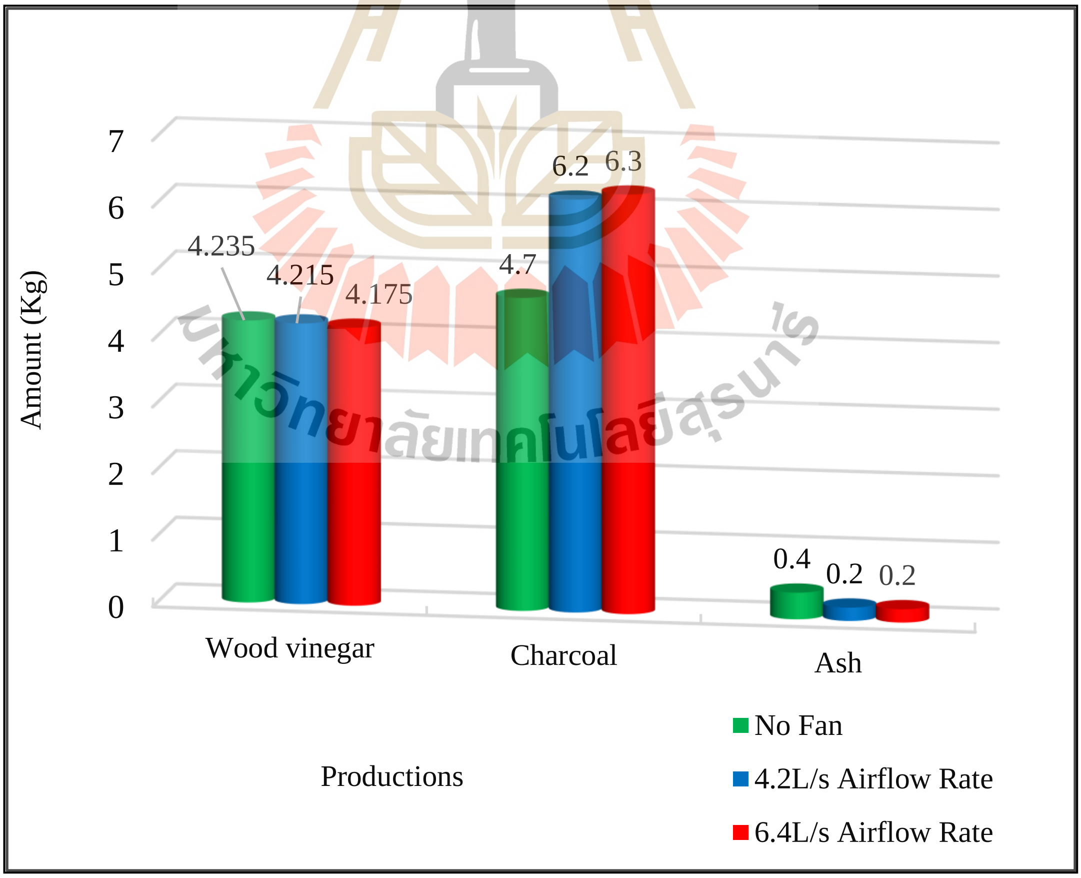

Figure 4.7 Comparison of product amount obtains based on airflow rate experiment

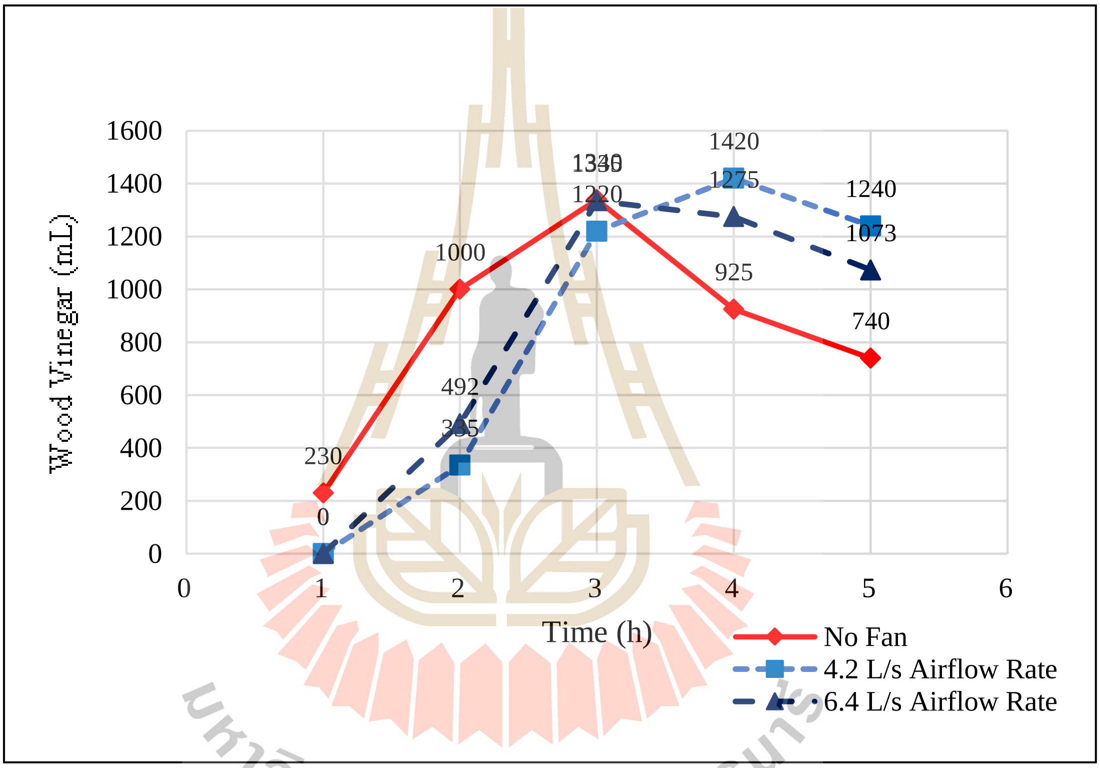

Figure 4.8 Wood vinegar distillation rate with various airflow.

4.6 Overall Result and discussion

The burning system has been constructed and tested its operation on hold experiment. The tests are performed with various moisture contents, airflow supplied as the temperature in the burning tank meet the wood vinegar desired temperature. The experiment has been investigate on 15 kg of River tamarind wood and the position of exhaust duct has been tested. The duration of this experiment is about 8 hours. The average interval measured temperature of the burning tank is varied within the range of 65-419°C. Results from the experiment based on the amount of distillate wood vinegar collected are shown in **Tables 4.9**, and **4.10**.

Table 4.9 Conditions and output of the test based on hold experiment condition.

Wood (kg)	15
Time (h)	8
Fuel (kg)	0.5
Wood vinegar (mL)	6,390
Charcoal (kg)	3.3
Ash (kg)	0.4

Table 4.10 Amount of wood vinegar with respect to time based on hold experiment.

Time (h)	Burning Tank Temperature(˚C)	Distillate Wood Vinegar (mL)
1	65	181
2	293	1,163
3	326	1,244
4	420	1,085
5	426	744
6	432	715

7	426	665
8	419	593

Figure 4.9 The obtained charcoal

Figure 4.10 The obtained wood vinegar.

rs with the quality of pH=3.4. The measured temperature at burning tank while the wood vinegar burning process is about 65-452°C that meets the desired temperature. If the temperature below about 120°C the wood vinegar will consist mainly of water. In the other hand, if the temperature is above 400°C, it will consist mainly of tar. The product of the designed burning tank is wood vinegar and the by-products are charcoals as shown in **Figure 4.10** and **Figure 4.9**, respectively. The wood vinegar is very valuable for agriculture. The charcoal can be used as solid fuel for cooking or can be sold. The first investment of the burning tank is about 5000 Baht. It is a simple burning tank structure, low investment but makes a high gain.

4.7 Chapter summary

This chapter has exhibited and discussed the results from the previous of the experiment chapter. The amount of wood vinegar by using the proposed model as well as the studies on parameters result is able to increase 16 times compare to the conventional model. The optimum parameters of the wood vinegar experiment have also been enforced by wood vinegar performance. The proposed and the designed parameters were seemed to be reasonable with developing distillation rate of wood vinegar. For conclude interpreted results, the next chapter has been finalized for general predictions.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In this research, experiment has been investigated on parameters for wood vinegar burning process. The applicability of the proposed system in replacing the conventional system for wood vinegar production is determined. The experiment based on four parameters studies as explained in the case study overview have been examined. The effect of the parameters as following conclusion can be drawn:

(a) The interaction between the positions of the exhaust duct significantly affects the yield of the obtained wood vinegar. The results shown that the top position of exhaust duct can increase the wood vinegar 24 % compared to the bottom position.

(b) The type of wood significantly affects the yield of the obtained wood vinegar. From experiment, the Eucalyptus wood can increase the wood vinegar about 6.44 % more than the River tamarind wood.

(c) The moisture content in the woods is strongly affect on the yield of obtained wood vinegar. The wood with moisture content is able to produce wood vinegar much more than the 2kg removed- moisture 44.6%.

(d) The rate of airflow affects the amount of obtained wood vinegar when the burning tank meets the desired temperature within the range of 120-430°C.

Finally, the proposed methodology of the experiment, is suitable for wood vinegar production. To eliminate or minimize the total wet smoke lost caused by a burning tank. The developed design new model can be used in wood vinegar production.

5.2 Future work

Wood vinegar has great potential for plant, animal, and human. The current level of interest in this production as well as usage of this natural fertilizer in governmental organization, agriculture development agencies, farmers, and some universities in Southeast Asia is on the rise. The primary considerations for the future works should include the following:

(a) Assessing the optimum size and shape of wood for making higher efficiency of wood vinegar distillation. For the further to reduce the deforestation, the biomass scrap such as corn stalk, coconut shell, rice husk, palm kernel shell etc. are encouraged and conduct more experiments.

(b) Further research should also consider on the cooling tank that is also the main media removing heat and increasing amount of wood vinegar distillation. As the future plan in organic farm turn to use natural fertilizer, the study on how to improve the quality of wood vinegar and usage are recommended. Additionally, the application of such an experiment should not be limited only to this field but can be expanded into any area.

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APPENDIX

LIST OF PUBLICATION

List of Publications

ARTICLES IN JOURNALS

Phineath, T., Keerati, S. (2018). **Effect of Exhaust Duct Position on Wood Vinegar Burning Process**, Accepted to be published by International Journal of Materials, Mechanics and Manufacturing (IJMMM) Vol. 6, No. 5, pp. 348-351.

ARTICLES IN CONFERENCES

Phineath, T., Keerati, S. (2018). **Effect of Exhaust Duct Position on Wood Vinegar Burning Process**: International Conference on Automation, Mechanical and Design Engineering (ICAMD), Malaysia.

Phineath, T., Keerati, S. (2018). **Experiment on Influent of Parameters on Wood Vinegar Burning Process**: by International Conference on Mechanical Engineering (TSME-ICoME 2018), Thailand.

International Journal of Materials, Mechanics and Manufacturing, Vol. 6, No. 5, October 2018

Effect of Exhaust Duct Position on Wood Vinegar Burning Process

Phineath Than and Keerati Suluksna

***Abstract*—This research aims to develop a burning tank and experiment for wood vinegar burning process using wood as raw material. To design, and operation of such burning tank require detailed understanding of parameters that affect the system performance. In the research, the device is designed for testing and developing a burning system that can improve the distillation rate of wood vinegar. The developed system consists of two tanks; burning tank and condensing tank. Burning tank made of steel with 400mm diameter and 600mm long for 15-20 kg of wood, provides tight airflow and has two exhaust ducts attached to top and bottom of the tank side. The condensing tank has 24 copper pipes with diameter of 12mm, and 400mm long, resulting in a condensing surface area of 0.36 m2. The condensing pipes are installed in a 65 liters tank contains cool water with temperature from 30 °C to 40 °C which is used as media for removing the heat from those pipe surfaces. In the experiments, two kind of woods will be used to test, fire conditions of air flow rate and moisture of woods are varied and two positions of exhaust duct are investigated. This developed system was tested on exhaust duct positions by using 15 kg Leucaena leucocephala wood with 5 hours, producing 3.39L and 4.21L by bottom and top duct positions respectively. The experiment results show that the interaction between the positions of exhaust duct is significantly effect on the yield percent of wood vinegar collected. That is the top position can increase the wood vinegar 24 % compare with the bottom position.**

***Index Terms*—Exhaust duct, wood vinegar, experiment, parameters, burning tank.**

I. Introduction

In rural area, charcoal was made from wood by using an earthen kiln. The woods are often dead wood collected from the forest or sometimes bamboo is used. In addition, the charcoal is then sold or is used for cooking. Traditional kilns release very harmful smoke and pollution into the environment. Recently, newer style of burning tank have been studied to made good quality charcoal and is suitable for adaption wood vinegar during a gasification process.

Wood vinegar or pyro-ligneous acid is distilled liquid obtained from the charcoal burning process. It is a dark brown liquid produce by the combustion of wood under airless conditions. When the vapor is cooled, it condenses into wood vinegar, which contains the principal components are acetic acid, acetone, methanol, wood oils and tars. Wood vinegar is used to improve soil quality, eliminate pests and control plant growth. It is causally growth of stems, tubers, leaves, roots, flowers, and fruit. Food and Fertilizer Technology Center [1] showing that fruit trees produce increased amounts of fruit after applying wood vinegar in an orchard. It is also safe in the food chain living matters, especially insects that help pollinate plants. There have been many researches into wood vinegar. China and Japan were known as the place has been undertaken research on wood vinegar, while some researchers have also focused on improving animal health by using a compound of wood vinegar mixing in animal food reported by Nakajima, *et al.* [2]. Design and development of pyrolysis system to produce wood vinegar by using rice husk as a raw material was investigated by Suzilawati [3]. Other researchers include Yamauchi, *et al.* [4] who investigated wood vinegar made of broadleaf tree bark carbonized has testing effect on red mites by injection into their bodies and Yang, *et al.* [5] who studied influent of air flow rate and the moisture of fuel on biomass burning behaviors and simulated municipal solid wastes in packed beds. Somsuk, *et al.* [6] who investigated pyrolysis oven in wood vinegar production by developing heat exchanger. Chalermsan, *et al.* [7] who produced wood vinegar from rural charcoal kiln and it is used as plant protection. Experiment of wood vinegar produced from pine nut shell continuous pyrolysis was also carried out by Jiang, *et al.* [8].

However, there is still a lack of detailed or no supporting documents on experimental study of parameters for wood vinegar burning process and develop the distillation rate of wood vinegar using wood as raw material. The advantage of experimental study can improve the distillation rate of wood vinegar and lies in its ability to reveal the detailed behavior of parameters in burning process inside. The research investigates on two positions of exhaust duct. Leucaena leucocephala wood is used as a materiel for the production process. This research contributes better understanding and controlling of the wood vinegar burning process and the performance of parameters in processes.

II. Methodology

A. Design Concepts

The schematic of wood vinegar processing system is shown in Fig. 1. The system consists of five parts: (1) burning gate, (2) burning tank, (3) Pipe connecting between burning tank to condensing tank, (4) condensing tank, and (5) condensing tubes.

The wood vinegar burning device is designed to contain 15-20 kg of wood, provides one gate for tight airflow as well as burning. The burning tank uses Liquid Petroleum Gas (LPG) as fuel. The required temperature to heat the

Manuscript received June 15, 2018; revised August 27, 2018.

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doi: 10.18178/ijmmm.2018.6.5.405

wood is about 120-430°C to give the good quality of wood vinegar, under amount of airless condition. The limit-air known as the incomplete combustion gases that are a mixture of volatile organic compounds pass through the connection pipe to condensing tank which has 24 copper pipes use as condensing tube to be condensed into wood vinegar resulting in a condensing surface area of 0.362 m2. The condensing pipes are installed in a 65 liters tank contains with cool water which is used as media for removing the heat from those pipe surfaces.

B. Operation and Structure Design

The burning system consists of two main components; burning tank Fig. 2 and condensing tank Fig. 3. The burning tank has 400 mm diameter, 600 mm tall and 1.5 mm thickness, which uses sand residual as isolation are shown in Fig. 2 is designed for wood burning under airless condition and obtain the heat from the burning gate. The tank is made from sheet metal. The rectangle cubic space at outside tank is used for LPG fuel heating Fig. 4.The capacity of the tank is 0.075 m^3 for wood. Two exhaust ducts with a 60 mm diameter and 150 mm long, attached to the tank side for more smooth ventilation and experiment investigated.

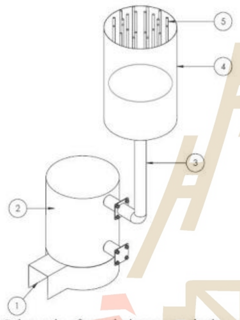

Fig. 1. Schematic of wood vinegar producing system.

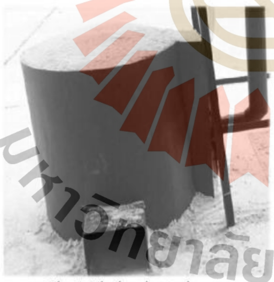

Fig. 2. The burning tanka.

The condensing system is used in the extraction process, allows for raw wood vinegar collection. The burning tank is designed for a concept; by experiment of parameters for wood vinegar burning process using wood as raw material and thermal decomposition of organic substances harmful gases will pass on through the copper tube, cool water with temperature from 30 °C to 40 °C is used as media for removing the heat from those pipe surfaces Fig. 3. It increases the performance of condensing and also reduces the greenhouse effect.

Fig. 3. The condensing tank.

III. Experiment

In this research, a factorial design of experiments with seven replicates, has been developed in order to study the influence of positions of exhaust duct, fire conditions of air mass flow rate, moisture of woods and two kind of woods are used to test based on yield percent of wood vinegar collected, and to determine the optimal exhaust duct position for producing wood vinegar.

In this research, the burning tank is developed for the production of wood vinegar, by using LPG as fuel. A by-product from wood vinegar production is charcoals which can be sold or use as a solid fuel. The influences of exhaust duct positions is investigated by testing two replicates, fire conditions of air mass flow rate are varied to test with 3 replicates, moisture of woods inside are removed 0kg, 1kg, 2kg and two kind of woods are used to test. Two kinds of wood; Leucaena leucocephala and Acacia are used in the experiment as raw materials to produce the wood vinegar. In each experiment 15 Kg of wood is used. Finally, the yield percent of wood vinegar production is performed.

Fig. 4. Operation testing

The steps to perform testing are following:

1) Leave the fresh Leucaena leucocephala wood for 25-30 days before conducting an experiment.
2) Put 15 kg of the Leucaena leucocephala wood in the

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burning tank, and set up LPG in the burning gate.

3) Burn the LPG. Start to time, measure the temperature every 1 hour in burning tank.
4) Notice the color of the wood vinegar product from the condensing tank. If the color turns to red-brown liquid, which means it is becoming raw wood vinegar. Collection the vinegar drops from the wood vinegar drain.
5) If the color of wood vinegar turns to dark brown color, which means the moisture substance in those wood are all evaporated and the wood become a good charcoals.
6) Stop to time after five hours. The period of timing since beginning is the process time of producing wood vinegar. Leave the burning tank and the charcoal cool down for 6 hours.
7) Measure the amount of obtained charcoal, wood vinegar and ash.
8) Repeat the step 1-7, with more replicates by changing conditions.
9) Close the raw wood vinegar in the bottles or tanks for 3 months in order to separate light oil, sour vinegar and tar. Remove the light oil and tar out by using sour wood vinegar only.

IV. Results and Discussion

The burning system is constructed, and tested its operation.

Results from the operation test with positions of exhaust duct on Leucaena leucoceph wood, are following Table I below:

TABLE I: Productions from Testing

Testing	Unit	Exhaust Duct Position		Percent
		Bottom	Top	
Wood (Dn 5-8cm)	Kg	15	15	0%
Time	h	5	5	0%
Fuel	kg	0.5	0.5	0%
Wood vinegar	ml	3392	4215	24%
Charcoal	Kg	8.1	6.2	31%
Ash	Kg	0.1	0.2	50%

The average interval of the measured temperature at the burning tank while happening the wood vinegar process is about 68-410°C that meets the desired temperature.

Fig. 5. The obtained charcoal.

Results from study the influence of position exhaust duct on the yield percent of wood vinegar collected, with 2 replicates. In each experiment uses 0.5 kg of LPG as fuel. The experiment results are shown in Table II.

Fig. 6. The obtained raw wood vinegar.

TABLE II: Amount of Wood Vinegar with Respect to Time at Each Exhaust Duct Position

Time (h)	Burning tank (°C)		Wood Vinegar (ml)	
	Bottom	Top	Bottom	Top
1	130	68	10	0
2	165	94	270	335
3	240	138	875	1220
4	326	340	1210	1420
5	410	338	1027	1240

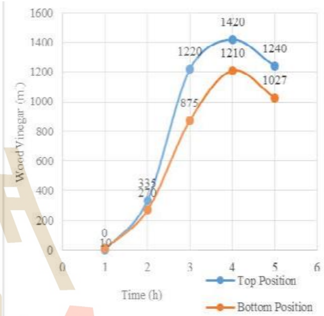

Fig. 7. Wood vinegar condensation performance vs. time.

Fig. 7 shows the condensing performance of wood vinegar in each position, top and bottom of exhaust duct vs. time for the 15kg of wood Leucaena leucoceph by using 0.5 kg of LPG fuel. The initial, the bottom position produced wood vinegar 10ml in the first hour while the top position there is no wood vinegar condensed. It seen that the bottom position started evaporate moisture from the wood in the first stage. From 2nd-3rd hour the temperature of bottom and top is increasing rapidly, but the top position is able to produce wood vinegar much more than the bottom position. During the 3rd -4th hour the temperature of bottom and top jump to 326 °C and 340 °C. In this stage, it seen that the wood is strongly self-burning which can produce wood vinegar maximum. The wood vinegar began to slight fall condensation. After the tank is cold down, the bottom position there is many wood vinegar stuck to the burning surface while the top position there is less than. It also seen that the current of gasification flow in the bottom position is hard to flow the hot gas out by the exhaust duct, so some of wood vinegar condensed in the tank and remain the temperature increasingly. The top position allowed more smooth gasification flow to condensing tank to condense into wood vinegar and release heat as well.

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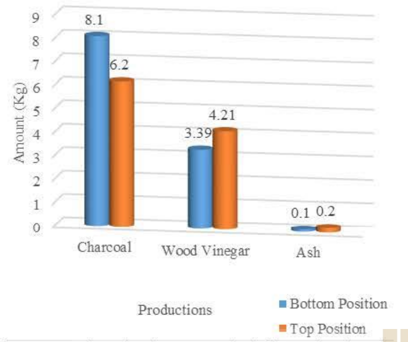

Fig. 8. Comparison of product amount obtain from each exhaust duct position.

Fig. 8 shows that top exhaust duct position gives the highest yield percent of raw wood vinegar for the production of wood vinegar by using this burning system. It is also interesting to note the development of the wood vinegar as time goes on. The first distillate is almost entirely water and it is not until about the 2nd hour that the liquor slowly darkens and contains increasing amounts of acid. The measured temperature at the burning tank is about 68-410°C that meets the desired temperature as prior design. If the temperature is below about 150°C, the wood vinegar will consist mainly of water. And if the temperature is above 400°C, it will consist mainly of tar.

The product of the designed burning tank is wood vinegar Fig. 6 and the by-products are charcoals Fig. 5 and the non-condensable wood gases. The wood vinegar is very valuable for agriculture. The charcoal can be used as solid fuel for cooking or can be sold.

The wood vinegar and the charcoals, produced by this burning system will make income for the investors. The first investment of the burning tank is about 5000 Baht. It is a simple burning tank structure, low investment but make high gain.

V. Conclusions

In the paper, the applicability of new system in replacing traditional system for wood vinegar production can be determined. From the experiment results show that the interaction between the positions of exhaust duct is significantly effect on the yield percent of wood vinegar collected.

The wood vinegar has great potential in many fields especially in agriculture. Further research is important in assessing the optimum size and shape of wood for making higher condensing of wood vinegar. The households' incomes are expected to increase when the investor use the burning system.

Acknowledgment

The author would like to thank Suranaree University of Technology (SUT) for the financial support of this research.

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