A Development of Pyrolysis Oven for Wood Vinegar Production

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Abstract

This research was undertaken to develop a pyrolysis oven for the 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. The hollow space between the inner oven wall and the chamber wall was used for containing fuel, and the hollow space of the chamber was used for containing the pyrolyzing wood chips. The pyrolyzing chamber's capacity for wood chips was 0.2 m^3 and a chimney was attached to the burning chamber for smoother ventilation. An air cooled condensing system was used for the extraction process allowing for raw wood vinegar collection. The oven was made of refractory brick lining, rendered by refractory concrete with the pyrolyzing chamber made of metal sheets. In this research, a factorial design of experiments with 3 replicates and 5% significant level was developed. Objective was to study the influence of the kind and weight of pyrolyzing wood chips on the yield percent of the wood vinegar collected. Furthermore, it aimed to determine the optimal conditions for producing wood vinegar. Three kinds of pyrolyzing wood were used in this study namely Eucalyptus, Rubber wood and Acacia chips, and three levels of wood chip weights of 20, 40, and 60kg were selected

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for the experiment. Finally, the economic analysis of the wood vinegar production was performed. The results showed that the oven was economically attractive and its payback period was short.

Keywords: wood vinegar, pyrolysis, oven, design of experiments, economic analysis

บทคัดย่อ

งานวิจัยนี้ได้พัฒนาเตาอบสำหรับผลิตน้ำส้มควันไม้โดยใช้เศษถ่านเป็นเชื้อเพลิง เตาอบนี้ได้ออกแบบให้มี ห้องอบซ้อนอยู่ภายในอีกชั้นหนึ่งเพื่อให้มีการกระจายความร้อนที่ดี โดยเตาอบจะมีฝาปิดอยู่ทางด้านบน ช่องว่าง ระหว่างผนังห้องอบด้านในและผนังเตาด้านนอกใช้สำหรับใส่เศษถ่านที่เป็นเชื้อเพลิง ส่วนห้องอบภายในนั้นใช้ สำหรับใส่ชิ้นไม้สำหรับอบโดยมีปริมาตรห้องอบ 0.2 m³ ใช้ปล่องควันหนึ่งปล่องในการระบายควันจากการเผาไหม้ เครื่องควบแน่นชนิดใช้อากาศระบายความร้อนถูกนำมาใช้ในการดักเก็บน้ำส้มควันไม้ ตัวเตาผลิตขึ้นจากอิฐทนไฟ ฉาบด้วยคอนกรีต ผนังห้องอบทำจากแผ่นเหล็ก ออกแบบการทดลองแบบซ้ำ 3 ครั้ง ที่ระดับนัยสำคัญ 5% เพื่อศึกษา อิทธิพลของชนิดและน้ำหนักของชิ้นไม้ที่มีผลต่อปริมาณน้ำส้มควันไม้ที่ได้เพื่อหาสภาวะที่เหมาะสมในการผลิต น้ำส้มควันไม้ ได้ทำการศึกษาไม้ 3 ชนิด ได้แก่ไม้ยูคาลิปตัส ไม้ยางพารา และไม้กระถิน โดยใช้ปริมาณที่ทำการ ทดลองคือ 20 kg, 40 kg และ 60 kg ตามลำดับ จากการวิเคราะห์เชิงเศรษฐศาสตร์พบว่ามีความคุ้มค่าในการ ลงทุนโดยใช้ระยะเวลาคืนทุนที่ต่ำ

คำสำคัญ: น้ำส้มควันไม้, ไพโรไลซิส, เตาอบ, การออกแบบการทดลอง, การวิเคราะห์เชิงเศรษฐศาสตร์

Introduction

In Thailand, there are plenty of wood chips in many kinds of wood which are by-product from the furniture manufacturing. They could be sold as fuel, at low price. But if they are taken to be raw material in producing the wood vinegar it will make higher value added of them.

Pyrolysis

Pyrolysis is conducted at high temperature under limited amount of air (oxygen). Under this condition, wood is converted into various products including gaseous, liquid (tar and wood vinegar) and solid carbonized substances. Traditionally, wood pyrolysis has been used as carbonization and dry distillation processes for producing wood charcoal and some low molecular weight (MW) chemicals such as acetic acid and creosote (Kawamoto and Saka, 2006).

Wood vinegar

Pyroligneous acid, also called wood vinegar is a liquid generated from the gas and combustion of fresh wood burning in airless condition. When the gas is cooled, it condenses into liquid. Raw wood vinegar has more than 200 chemicals, such as acetic acid, formaldehyde, ethyl-valerate, methanol, tar, etc (Food and Fertilizer Technology Center, 2005).

Wood vinegar is a dark liquid produced by the destructive distillation of wood. Its principal components are acetic acid and methanol. It was once used as a commercial source for acetic acid (Kurlansky, 2002). Wood vinegar is widely used for pest repellent, bud opening for flowering plants, and soil improvement.

Application:

Blend with water in a ratio of 1:50 (1 liter wood vinegar and 50 liters water), or up to a ratio of 1:800 (1 liter wood vinegar and 800 liters water). Spray it over plant shoots. Wood vinegar, like hormones, will be absorbed into twigs, trunks, or leaves. Plants will be stronger, and leaves will be greener and resistant to pests and diseases.

Benefits:

1. Farmers can produce wood vinegar from branches trimmed from trees.

2. Wood vinegar is safe to human beings, animals, plants, and environment.

3. Wood vinegar helps plants to grow better and stronger, and be resistant to pests and diseases.

4. Crop produce is high quality and safe.

5. Low cost of production attributed to savings from cost of chemicals (Food and Fertilizer Technology Center, 2005).

Traditional wood vinegar production

The traditional method of wood vinegar production in Thailand is burning fresh wood, in airless condition, in a charcoal kiln with the chimney(s) and the bamboo pipes with the wet clothes wrap around to allow for wood vinegar collection from condensing.

Process of making wood vinegar:

1. Cure wood that has heartwood and bark for 5-15 days.

2. Pile wood in the kiln. Close the kiln and cover every hole with clay. Burn it at 120-430°C.

3. After 1 hour, put a tile at the top of the chimney. 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 the light and clear oil. Remove the tar and light oil, as well as the dark brown translucent oil and the remainder will be sour vinegar (Food and Fertilizer Technology Center, 2005). The raw wood vinegar from silting after leaving for 3 months separates into three layers, as shown in Fig. 1.
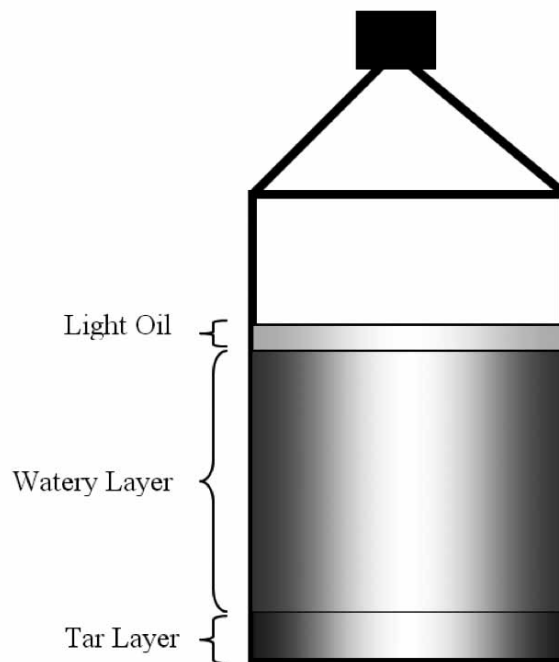
Fig. 1. Raw wood vinegar separates into three layers

In the common practice of charcoal burning using internal heating of the charged wood by burning a part of it, all the by-product vapors and

gas escapes into the atmosphere as smoke. The by-products can be recovered by passing the off-gases through a series of water cooled condensers to yield pyroligneous acid. The non-condensable wood gas passes on through the condensers and may be burned to provide heat. The wood gas is only useable as fuel and consists typically of 17% methane; 2% hydrogen; 23% carbon monoxide; 38% carbon dioxide; 2% oxygen and 18% nitrogen. It has a gross calorific value of about 10.8 MJoules per m^3 (290 BTU/cu.ft.) i.e. about one third the value of natural gas (Mechanical Wood Products Branch, 1985).

Methodology

Design Concepts

The pyrolysis oven is designed to contain 60-80 kg of pyrolyzing wood chips, provides tight airflow. The oven uses charcoal residual as fuel. The required temperature to heat the wood chips is about 270-450°C to give the good quality of wood vinegar, under limited amount of air (oxygen).

The off-gases known as the pyrolysis gases that are a mixture of volatile organic compounds pass through an air cooled condenser to be condensed into pyroligneous acid. The non-condensable wood gases which are a by-product are recovered by passing through the burning chamber to be burned to provide heat.

Operation and structure design

The oven consists of three main components; burning chamber and pyrolyzing chamber, and air cooled condensing unit. The oven with 98 cm diameter, 85 cm tall and 10 cm thickness, is designed

by having a pyrolyzing chamber inside in order to obtain the heat evenly distributed throughout the oven. The oven is covered with a lid. The oven is made of refractory brick living, rendered by refractory concrete. The chamber is made from sheet metal. The hollow space between the inner oven wall and the chamber wall is used for containing fuel, and the hollow space of the chamber, 54 cm diameter and 85 cm tall, with a lid, is used for containing the pyrolyzing wood chips. The pyrolyzing chamber's capacity is 0.2 m^3 for pyrolyzing wood chips. One chimney with a 10 cm diameter, attached to the chamber for more smooth ventilation. The air cooled condensing system is used in the extraction process, allows for raw wood vinegar collection. The oven is designed for a concept; by the thermal decomposition of organic substances (pyrolysis) harmful gases will pass on through the condenser, the non-condensable wood gas may be burned to provide heat. These gases then pass to a burning chamber where they are combusted in a high oxygen content environment. It is to help increase the performance and to help decrease the greenhouse effect.
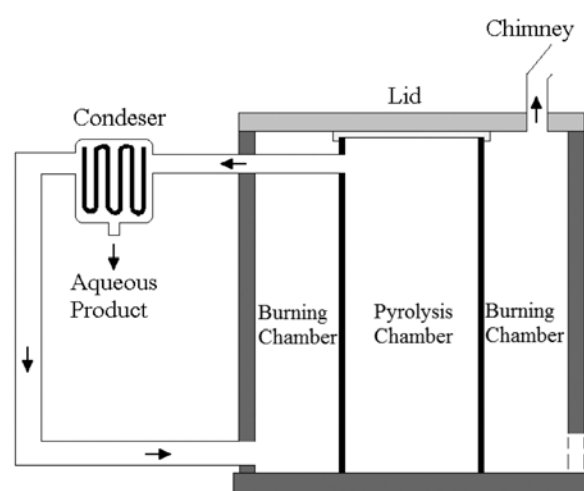

Fig. 2. Pyrolysis oven profile

Fig. 3. The air cooled condenser

Fig. 4. Inside of the oven

Pyrolysis oven operation test procedure

1. Leave the fresh Acacia wood chips for about 3-4 days before conducting an experiment.

2. Put 60 kg of the Acacia wood chips in the pyrolyzing chamber, and put 20 kg of charcoal residuals in the burning chamber. Close the pyrolyzing chamber with a lid and then close the oven with a lid.

3. Burn the charcoal residual. Start to time, measure the temperature every 10 minutes at pyrolyzing chamber.

4. When start to smell the acid smoke more strongly, notice the color of the aqueous product from the condenser. If the color turns to light brown, which means it is becoming raw wood vinegar. Place a plastic container to collect the vinegar drops from the condenser.

5. If there is no more aqueous product from the condenser, which means the liquid substance in wood are all evaporated, or the pyrolyzing wood chips become completely charcoals.

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

7. Weigh the charcoal obtained.

8. Repeat the item 1-7, with 2 more replicates.

9. Leave the raw wood vinegar for 3 months to become silted. Remove the tar and light oil, as well as the dark brown translucent oil and the remainder will be sour vinegar.

Fig. 5. Operation testing

Design of experiments

In this research, a factorial design of experiments with 3 replicates and 5% significant level, has also been developed in order to study the influence of kind and weight of pyrolyzing wood

chips on yield percent of wood vinegar collected, and to determine the optimal conditions for producing wood vinegar.

In this research, the pyrolysis oven is developed for the production of wood vinegar, by using charcoal residual as fuel. A by-product from wood vinegar production is charcoals which can be sold. Then the influence of kind and weight of pyrolyzing wood chips on yield percent of wood vinegar collected is studied. Three kinds of wood chips which are Eucalyptus, Rubber wood and Acacia chips are used in the experiment as the pyrolyzing wood chips to produce the wood vinegar, and using three levels of weight of pyrolyzing wood chips of 20, 40, and 60kg. Finally, the economical analysis of the production of wood vinegar is performed.

By varying two variables simultaneously and obtaining multiple measurements under the same experimental conditions, the experimental responds are randomized. The normality of the respond data is assumed. They are analyzed by using SPSS statistical software. The results of applying the analysis of variance are shown in Table III and IV.

Results

The oven is constructed, and tested about its operation.

Results from the operation test with 3 replicates, are following below,

Pyrolyzing wood (Acacia)	60	kg
Fuel needed	20	kg
Process time	7.2	hour
Net wood vinegar	7	kg
Net charcoal	14.5	kg
Wood vinegar yield	8.75	%
Charcoal yield	18.13	%

The average interval of the measured temperature at the pyrolyzing chamber while happening the pyrolysis process is about 300-450°C that meets the desired temperature.

Fig. 6. The obtained charcoal

Fig. 7. The obtained raw wood vinegar

Results from study the influence of kind and weight of pyrolyzing wood chips on the yield percent of wood vinegar collected, with 3 replicates. In each experiment uses 20 kg of charcoal residuals as fuel. The experiment results are shown in Table I.

Table I.

The weight average of wood vinegar obtained from the experiment

Kind of pyrolyzing wood	Weight average of pyrolyzing wood (kg)	Weight average of wood vinegar collected (kg)	Yield percent of wood vinegar
Eucalyptus	20	2.87	7.17
	40	4.29	7.15
	60	5.77	7.22
Rubber wood	20	3.13	7.84
	40	4.79	7.98
	60	6.37	7.96
Acacia	20	3.57	8.93
	40	5.44	9.07
	60	7.18	8.97

The analysis of variance is used to analyze the influence of kind and weight of wood chips on the yield percent of wood vinegar collected, as shown in Table II.

Table II.

ANOVA table

Test of between-subjects effect

Dependent variable: vinegar_ yield

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	15.025[a]	8	1.878	77.667	.000
Intercept	1741.787	1	1741.787	72029.805	.000
Wood_kind	14.946	2	7.473	309.042	.446
Wood_weight	.041	2	.020	.846	.413
Wood_kind*	.038	4	.009	.390	
Wood_weight	.435	18	.024		
Error	1757.247	27			
Total	15.460	26			

a R Squared = .972 (Adjusted R Squared = .959)

ANOVA table shows that the interaction between the kind and weight of pyrolyzing wood chips on the yield percent of wood vinegar collected is not significant, but the kind of wood chips is significant. Then Duncan's multiple range test is applied to the means of the kind of wood chips.

Table III.

Duncan's multiple range test

Vinegar_yield

Duncan [a,b]

Wood_kind	N	Subset		
		1	2	3
Eucalyptus	9	7.1778		
Rubber wood	9		7.9267	
Acacia	9			8.9911
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square (Error) = .24.
  a. Uses Harmonic Mean Sample Size = 9.000.
  b. Alpha = .05.

The result shows that Acacia wood gives the highest yield percent of raw wood vinegar for the production of wood vinegar by using this oven.

When the Acacia is known that it gives the highest percent yield of wood vinegar, then the wood vinegar produced from the Acacia is tested for the important ingredient. The results are shown as below.

The important ingredient of the produced wood vinegar:

Water	83 %
Organic acid	4 %
Other organic substance	13 %

The quality of the produced wood vinegar: pH = 3.2 and specific gravity = 1.02

Economical analysis

Even though, the weight of pyrolyzing wood does not significantly effect on the yield percent of wood vinegar. But the weight of 60 kg is most appropriate, because it is a maximum capacity of the oven. The wood vinegar production can be finished by 1 day, just like the weight of 20 and 40 kg. So, the weight of 60 kg will be worth production.

Therefore, Acacia wood as the pyloryzing wood and the weight of 60 kg is considered in economical analysis.

In economic analysis for wood vinegar production by using the pyrolysis oven, and 1 labor, cost of the pyrolysis oven is approximately 17,000 Baht. it is assumed that the oven has a useful life expectancy of 5 years, the working days are 300 days a year, direct labor cost per day is 200 Baht/labor, weight of wood vinegar obtained is 7 kg/day, weight of charcoal obtained is 14.5 kg/day, selling price of wood vinegar and charcoal are 50 Baht/kg and 5 Baht/kg respectively, raw material (Acacia wood chips) cost and the charcoal residual cost are 1 Baht/kg and 3 Baht/kg respectively and maintenance cost per year is 10% of the oven's price. A result from the analysis show that, payback period for the production is approximately 7 months.

Discussion

The first distillate (condensation from the gases) is almost entirely water and it is not until about the 4th hour that the liquor slowly darkens and contains increasing amounts of acid. The crude condensate ingredient produced from the distillation of wood is called Pyroligneous Acid.

From the preliminary test by using Acacia wood chips found that yield of produced wood

vinegar and charcoal are 8.75% and 18.13% respectively, which are quite high capacity.

The measured temperature at the pyrolyzing chamber while happening the pyrolysis process is about 300-450°C that meets the desired temperature as prior design. When wood is heated above 270°C it begins a process of decomposition called carbonization and heat is evolved. If the temperature is below about 200°C, the wood vinegar will consist mainly of water. By if the temperature is above about 450°C, it will consist mainly of tar.

The product of the designed oven is wood vinegar, and the by-products are charcoals and the non-condensable wood gases. The wood vinegar is very valuable, high selling price. The charcoal can be re-used as fuel in the wood vinegar production, or can be sold as fuel. The wood gases can be recovered by passing through the burning chamber to be burned to provide heat.

The ANOVA table shows that only the kind of pyrolyzing wood significantly effect on the yield percent of wood vinegar, and from Duncan's multiple range test shows that Acacia wood gives the highest yield percent of wood vinegar.

The wood vinegar and the charcoals, produced by this oven will make income for the investors about 400 Baht/day. The first investment of the oven is 17,000 Baht. Payback period is approximately 7 months. It is a simple oven structure, low investment, low cost and high gains.

Conclusion

From this research, the following conclusion may be drawn. From the ANOVA results show that the interaction between the kind and weight of pyrolyzing wood chips on yield percent of wood

vinegar collected is not significant, but only the kind of pyrolyzing wood significantly effect on the yield percent of wood vinegar, and from Duncan's multiple range test shows that Acacia wood gives the highest yield percent of wood vinegar.

Finally, the economical analysis of the production of wood vinegar is performed. The results show that the oven is economically attractive and payback period is approximately 7 months.

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