DESIGN AND DEVELOPMENT OF A FURNACE PROTOTYPE FOR RUBBERWOOD VINEGAR PROCESSING

Somchai Chuchom, Thanate Ratanawilai, Sarut Suppathammarat, and Supattaradit Yamniyom
Department of Industrial Engineering
Faculty of Engineering
Prince of Songkla University
Hatyai, Songkhla, Thailand 90112
Corresponding author’s e-mail: somchai.c@psu.ac.th

Abstract: Wood vinegar is conventionally obtained as a by-product from charcoal production process. Though the process is a low-cost production process and easy to operate, it requires more spaces and time consuming. Moreover, it is difficult to control the wood vinegar quality, and can generate air pollution problems. Therefore, this research focuses on designing and making the furnace prototype for possibly and efficiently processing wood vinegar from the left-over of rubberwood. The information concerning wood vinegar, furnace design and production is applied for this research. Finally, the furnace prototype was designed and fabricated successfully. It consists of 4 main parts: the main body (with insulation), the left-over material container, the heater and controller, and the condenser system. The prototype was tested satisfactorily. It can produce rubberwood vinegar at operating temperature of 300-400 °C with the yield of 28%. The physical quality of the wood vinegar is acceptable, however, its chemical compositions and other properties need further detail investigations.

Keyword: wood vinegar, furnace prototype, design and development

1. INTRODUCTION

In Southern areas of Thailand, each year biomass from rubberwood in the form of torn stripes and dust particles is generated approximately 5 tons. Most of them are abundant or exploited as low cost energy for hot-water boiler, and raw material for charcoal industry. However, the cost of rubberwood for furniture in this recent years is raising high, making all concerned parties search for alternatives and new forms of uses. Wood vinegar, brown liquid, which is obtained by pyrolysis or carbonization of wood, have demonstrated high potential [4]. Since the activities of wood vinegar are ranging from plant growth acceleration, weed control, repellent action against small animals (cat, mite, centipede, etc.), deodorization, and control of microorganisms, its applications are, therefore, involved chemical industry, food industry, house uses, agricultural treatments, and livestock production [1].

Wood vinegar, conventionally obtained as a by-product from charcoal processing process, is less-expensive and easy to operate. However, it takes 3 to 4 days to collect 280-320 kg. of wood vinegar for each batch of 1 ton of raw material (dried wood). In addition to the process itself, the quality of the wood vinegar cannot be controlled. It is necessary to refine raw pyroligneous liquor. In conventional process, the standing method is applied for refining the wood vinegar and this will take up to 3 months before distribution to the users. During the collection of the wood vinegar, a high proportion of hot smoke is released into open air resulting in an environmental problem. Therefore, this research was set with the aim to investigate for a new design and construct the furnace prototype in order to produce wood vinegar from small wood-parts or the rubberwood particles. Some works in this area were proposed, ie; patent no. JP9078071 “Apparatus for producing wood vinegar from rice hulls”, patent no. TW499406 “A method for making wood vinegar from rice husk and the apparatus thereof”, and patent no. JP2002053868 “Method for producing wood vinegar and charcoal and apparatus therefor”. However, their main focuses are different. [2]

2. METHODOLOGY

This research started by searching for the information concerning wood vinegar, including properties, applications and usages, production processes, furnace and apparatuses concerned and etc. Since the purpose of the study was focused on producing wood vinegar from the left-over parts of rubberwood, the furnace prototype design process was then ignored charcoal and concentrated only on the possibility to speed up the rate of producing wood vinegar. Next, the main components of the furnace system were investigated and subsequently carried out by setting up their functions, the configurations,
material selections, and then calculation for their sizes. The next step was the construction of the designed model. And finally testing the prototype and correction were made to confirm for the obtained results.

In order to speed up the rate of producing wood vinegar, the electric coil was applied to heat and burn up the rubberwood particles. The hot smoke was generated inside the container and released via the outlet on the top part of the main body. After the temperature of hot smoke in the container was raised up to 300-400°C, the water was flowed through the outer tube to condense it into crude wood vinegar.

From the constraints and the requirements mentioned above, the furnace prototype design was proposed as shown in Figure 1. It was composed of 3 main systems; the main body, the heater and control system, and the condenser.

![Diagram of furnace prototype](image)

**Figure 1.** The proposed system design of the furnace for rubberwood vinegar

2.1 The main body system

This system consists of 4 components. The detail specifications were shown in Table 1.

<table>
<thead>
<tr>
<th>Part List</th>
<th>Number of piece</th>
<th>Dimension (mm.)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer container</td>
<td>1</td>
<td>Ø496x551x3</td>
<td>Steel</td>
</tr>
<tr>
<td>Lid</td>
<td>1</td>
<td>Ø496x201x3</td>
<td>Steel</td>
</tr>
<tr>
<td>Inner tank</td>
<td>1</td>
<td>Ø210x403x2</td>
<td>Stainless steel type 304</td>
</tr>
<tr>
<td>Insulator</td>
<td>-</td>
<td>-</td>
<td>Fire-resistance brick</td>
</tr>
</tbody>
</table>

2.2 The heater and control system

There were 3 main components of this system as listed in Table 2.

<table>
<thead>
<tr>
<th>Part List</th>
<th>Number of pieces</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil heater</td>
<td>1</td>
<td>Ni-Cr, 3000W</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>1</td>
<td>Type K</td>
</tr>
<tr>
<td>Control board set</td>
<td>1</td>
<td>40A/15A</td>
</tr>
</tbody>
</table>
2.3 The condenser system

There were also 3 main components of the condenser system as listed in Table 3. The condenser tube comprised the inner and outer tubes co-centered and connected to the 3-way connector to release the hot smoke and receive the condensed liquid into the wood vinegar collector.

<table>
<thead>
<tr>
<th>Part List</th>
<th>Number of pieces</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser tube</td>
<td>1</td>
<td>Glass, Ø35x600 mm</td>
</tr>
<tr>
<td>3-ways connector</td>
<td>1</td>
<td>Glass, Ø35x150 mm</td>
</tr>
<tr>
<td>Wood vinegar collector</td>
<td>1</td>
<td>Glass</td>
</tr>
</tbody>
</table>

3. RESULT AND DISCUSSION

After fabrication and testing the furnace prototype, some modifications have been made for better performances and ease of operating. The micro-fibre insulator was replaced for the fire-resistance brick for fabrication and availability reasons. The final result can be summarized below.

3.1 Furnace Prototype Components

The completed prototype was illustrated in Figure 2 to Figure 6. The main body and the lid were shown in Fig. 2 whereas Fig. 3 demonstrated the coil heater. The thermocouple was inserted into the furnace from the bottom as shown in Fig. 4. Figure 5 demonstrated the control board and its components. The condenser system was illustrated in Fig. 6

Figure 2. The main body and the lid
3.2 Operating Procedure

In order to efficiently operate the furnace prototype system, the operator was suggested to prepare raw materials with the moisture contents approximately 12-15%, and follow the steps as shown in Fig. 7.

- Fill the container with 500 g. rubberwood particles
- Insert the container into the furnace main-body
- Heat the container with electric coil
- Burn the rubberwood particles
- Release the hot smoke to the condensed tube
- Flow through water
- Collect the pyrolytic liquor

**Figure 7.** Flow chart for operating the furnace prototype
3.3 Tested Results

To provide high confidence level in the design and fabrication processes of the prototype, the pilot tests were conducted and the results were recorded as shown in Table 4. At 300°C of starting to collect the wood vinegar, the furnace produced 28% yield on average with the acceptable wood vinegar properties; i.e., pH of 3.033, SG. of 1.08, and %tar contents of 2.57. It took 2 hours and 15 minutes on average for processing time cycle.

Table 4. Tested results from operating the furnace prototype

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Order</th>
<th>Time Interval (Hrs.)</th>
<th>pH</th>
<th>S.G.</th>
<th>%Yield (ml/g)</th>
<th>Tar contents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1</td>
<td>2.15</td>
<td>3.014</td>
<td>1.08</td>
<td>26</td>
<td>2.40</td>
</tr>
<tr>
<td>300</td>
<td>2</td>
<td>2.30</td>
<td>3.051</td>
<td>1.07</td>
<td>30</td>
<td>2.74</td>
</tr>
<tr>
<td>300</td>
<td>Average</td>
<td>2.23</td>
<td>3.033</td>
<td>1.08</td>
<td>28</td>
<td>2.57</td>
</tr>
</tbody>
</table>

3.4 Discussion and recommendation

Though it has shown that wood vinegar can be produced from left-over rubberwood particles by electricity heating, it needs deep investigation in two aspects before turning into industrial practice. The obtained wood vinegar properties, and the economy of scale are those aspects.

The furnace prototype has not been tested for continuous and long processing cycles, the coil heater and the controller may not working properly under those conditions. During the heating process, parts of the hot smoke can be condensed into liquid and drops onto the heating coils causing damage to the system. Therefore, the furnace designer should provide the cover or the proper draining system as well. Furthermore, the position and distances of the condenser system should be carefully handled. Since the hot smoke may be released too fast if not enough distance provided, leading to low condensation rate. In the case of too long distance, it becomes liquid earlier and causes damages to the system components.

4. CONCLUSION

It has demonstrated that the furnace prototype which consists of metal main body, stainless steel inner tank, micro-fibre insulation, condenser system, heater and the controller was successfully produced quality wood vinegar. The general criteria for evaluation its efficiency were the acidity, specific gravity, yield of the wood vinegar and tar contents quantity. The furnace prototype was tested by operating at the condition of the temperature of 300 to 400 degree Celsius with the 500 gram of left-over rubberwood particles. The experimental results showed acidity, specific gravity and tar content quantity of 3.033, 1.08 and 2.57%, respectively. For higher efficiency of producing high quality wood vinegar, chemical properties and detail investigation techniques need to be further carried out.

5. REFERENCES