Drying Garcinia Atroviridis using waste heat from condenser of a split room air conditioner

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ABSTRACT

Garcinia Atroviridis which grows wildly in peninsular Malaysia are popular fruits in Southeast Asia and Northern states due to its economical and medical value. To preserve and increase economic value of the fruit, it usually dried or freeze. The paper discusses the experiment study of drying Garcinia Atroviridis using waste heat from condenser of a typical split air conditioner as a dryer. Test was conducted in a drying chamber housing the condensing unit, where the heat rejected by the condenser was used for drying the Garcinia Atroviridis. The experimental setup has been developed as an integrated air conditioner for drying purpose using waste heat from condenser. The study found that using waste heat from room air conditioner condenser for drying purpose is very reliable during raining day and efficient without additional electricity cost.

Keywords: Drying, Air conditioner, Waste heat, Garcinia Atroviridis, Moisture removal.

Nomenclatures

A Room area, m²
COPth Coefficient of performance of heating
C_par Constant pressure specific heat, kJ/kg.K
DR Drying rate, kg/h
DT drying time, h
E Voltage
I Amps
m air mass of the air, kg/s
P power input to the compressor, kW
PF power factor
Qcool cooling capacity of a room air conditioner, kJ
RACD room air-conditioner dryer
RH relative humidity, %
SEC ratio of the energy consumed per kg of moisture removed, kWh/kg
SMER the moisture removed per unit of energy consumption, kg/kWh
T_in air temperature entering the evaporator, °C
T_out air temperature leaving the evaporator, °C
v air flow velocity, m/s
Wp power consumption, kWh
X/g moisture removed, kg
ρ air density, kg/m³

1. INTRODUCTION

Food preservation by drying or freezing are recognized as one of the methods to increase the economic value of the food stock. The drying technique permits early harvest, save space, allows to store in a long time without deterioration and lighter weight for transportation. Some of similar previous work on food preservation is given by refs. (Borompichaichartkul et al., 2009; Chua et al., 2001; Ceylan et al., 2007; Nathakaranakule et al., 2007; Chou et al., 2000; Prasertsan and Saen-saby, 1998; Panchariya et al., 2002). Several researchers have been conducted research related to waste heat recovery in many applications and sources (PG&E, 2003; Talom and Beyene, 2009) such as industrial drying (Majumdar, 2000), drying of paper and textile (VanDeventer, 1997).

A study found that, the room air-conditioner dryer designed to dry clothes able to save time, cost and as well as energy (Braun et al., 2002). It is found that room air-conditioner dryer is not only can be used for drying clothes purpose, it’s also can be used for commercial purpose such as drying food or herbs (Teeboonma et al., 2001; Fatouh et al., 2006). The sample that taken is to conduct the experiment is Garcinia Atroviridis; in Malaysia known as “Asam Gelugur”.

Figure 1 Garcinia Atroviridis (Salleh, 2008).

Garcinia Atroviridis which is wildly grows in peninsular area, part of Malaysia and also widely cultivated especially in Northern States usually used as spices and medical ingredients. This fruit is very popular in peninsular Malaysia use as content of local dishes such as “Asam Laksa” or in curries. The tree physically has a long trunk, smooth grey bark, drooping branch with a dark green, shiny and long leaves and can grows more than 20 meters. The round fruits are borne singly on twig.
ends about 7 - 10 cm in diameter. The ripe fruits usually characterized by bright orange yellow fruit peel (Fruitipedia, no year). Some researches on *Garcinia Atroviridis* are discussed by Refs. (Elfita et al., 2009; Muensritharam et al., 2008; Mackeen et al., 2000).

There are many usages of *Garcinia Atroviridis*:

(i) Chemical composition
The fruit comprises natural acids such as tartaric acid, citric acid, ascorbic acid and malic acid.

(ii) Cosmetic use
The fruit are reported to have antioxidant activity. The extract of leaf, trunk, root and steam bark shows strong antioxidant activity exceeding *alpha*-tocopherol that known as standard antioxidant (Mackeen et al., 2002).

(iii) Food uses
The ripe fruits are widely used as cooking ingredients or eaten with a plenty of sugar whereas the unripe fruit is sliced and dried to give sourness to cooked dishes in place of tamarind.

(iv) Medicinal uses
Although there has been no clinical results regarding the benefits of *Garcinia Atroviridis*, the fruits for generations has been used to treat earache, treat throat irritation, coughs, dandruff and gastralgia associated with pregnancy (Tisdale et al., 2003). *Garcinia Atroviridis* is also rumoured to have attributed such as anti-inflammatory and anti-acne.

(v) Reducing blood pressure and cholesterol levels
This plant contains hydroxycitric acid that can be transformed into *Potassium Hydroxycitrate* which is useful for reducing blood pressure and cholesterol levels. Some experiment has been conducted to verify the effect of potassium hydroxycitrate derived from *Garcinia Atroviridis* fruit juice. The results in rats body shows that potassium hydroxycitrate can reduces the body weight reduction and lowering the cholesterol as discussed in Ref. (Achmadi, 2001).

The important of introduce the room air-conditioner dryer (*RACD*) for commercial to dry *Garcinia Atroviridis* in Malaysia is supported by following reasons:

(i) Limited sunlight (cloudy day) and restricted air flow for certain areas
(ii) Natural drying process of *Garcinia Atroviridis* takes a long time
(iii) Conventional electric dryers are inefficient and expensive

Furthermore, solar radiation in the humid tropics mostly diffuses type which makes drying process less effective. On the other hand, the use of electrical dryer considered as unwise solution for *Garcinia Atroviridis* drying, as it is consumes high energy for intensive process. Therefore, low cost drying solutions for *Garcinia Atroviridis* are needed to reduce energy consumption resulting in energy conservation and the environment pollution reduction.

Moreover, this study is to investigate the possibility of using waste heat from air conditioner condenser that rejected to the environment for *Garcinia Atroviridis* drying process. It is considered as relevant feasibility study knowing that many people using air conditioner nowadays. Some similar works, but they are using heat pump instead of air conditioners are given in Refs. (Minea, 2010; Fatouh et al., 2006; Qi-Long et al., 2008a; Aktas et al., 2009; Best et al., 1996; Best et al., 1994; Rahman et al., 1997; Artnaseaw et al., 2009; Tee boonma et al., 2003; Qi-Long et al., 2008b; Hawlader et al., 2006; Perera and Rahman, 1997; Artnaseaw et al., 2010). However, this is the first kind of work attempt to use waste heat from condenser of room air conditioner for food preservation. The scope of the study is to utilize waste heat from typical split type air conditioner condenser to construct a drying chamber. The performance of the dryer has been evaluated and compared with the natural outdoor drying.

2. METHODOLOGY

Room air conditioner is designed to remove heat from an interior space and reject it to the ambient air. The *RACD* system consists of a split room air-conditioner unit and a drying chamber that is attached separately to a condenser. This combination allows the additional process of drying by using the room air conditioner heat rejection without increasing the energy consumption as compared to using a separate dryer. For instances, this *RACD* system was designed and used for the waste heat recovery at the exhaust of condenser air stream and then utilizes this hot air steam for drying purposes.

2.1 Theoretical Background

The system referred as a room air conditioner dryer (*RACD*) using a vapor compression refrigeration cycle. The waste heat from condenser was used for drying purpose in this experiment. The diagram of the *RACD* is presented in Fig. 2.

![Figure 2](image)

Figure 2 Modular configuration of the simple *RACD* for drying (Ameen and Bari, 2004).

The figure describes the diagram of space cooling (B→C→D), the diagram for drying process (d→e→f) and the diagram for refrigeration system (1→2→3→4). Fig. 3 shows p→h diagram for refrigerant circuit (1→2→3→4) that describes the energy available for heating or drying.
process is \((h_1-h_3)\), for space cooling is \((h_4-h_1)\) and the input energy to compressor is \((h_2-h_1)\). Based on this diagram, it can be defined that the total energy can be tapped for space cooling and drying process as a function of compressor power input \((P_c\text{ in kW})\) and the coefficient of performance of cooling \((COP_c)\) (Cengel and Boles, 2007; Ameen and Bari, 2004).

The explanation above shows clearly that the energy available for drying process in vapor compression cycle is always greater compared to for cooling process. However, as it is only theoretical values, the verification is needed. The actual values will be restricted by the pressure losses in the circuits, the heat exchanger coils efficiency and heat losses to the environment.

![Diagram for refrigerant circuit](image)

Refrigerating effect available for space cooling (kW) is calculated by the following equation:

\[
R_e = (COP_c)
\]  

(1)

Heating effect available for drying (kW) is calculated by the following equation:

\[
H_e = (COP_c + 1)
\]  

(2)

The performance of a room air conditioner is by the ratio of cooling capacity and power consumption and is referred to as coefficient of performance \((COP_c)\) which can be calculated by the following equation:

\[
COP_c = \frac{\text{Cooling Capacity}}{\text{Power Consumption}} = \frac{Q_{\text{out}}}{W_{\text{in}}}
\]  

(3)

The cooling capacity of a room air conditioner can be calculated by the following equation:

\[
\dot{Q}_{\text{out}} = \dot{m} \cdot C_p \cdot (T_{\text{out}} - T_{\text{in}})
\]  

(4)

And the mass flow rate of air is calculated by following formula:

\[
\dot{m}_{\text{air}} = A \cdot \rho \cdot v
\]  

(5)

The electricity consumption is measured using a power meter and calculated by the following formula:

\[
W_{\text{in}} = EI PF
\]  

(6)

SEC and SMER are the most important criteria for a room air conditioner dryer with respect to the performance. SEC defined as a ratio of the energy consumed (kWh) per kg of moisture removed and can be written as the following equation:

\[
SEC = \frac{\dot{m}_{\text{mo}} \cdot C_p \cdot (T_{\text{out}} - T_{\text{in}}) + W_{\text{in}}}{X}
\]  

(7)

MERM defined as the moisture removed per unit kWh of energy consumption and calculated by the following equation:

\[
SMER = \frac{X}{\dot{m}_{\text{mo}} \cdot C_p \cdot (T_{\text{out}} - T_{\text{in}}) + W_{\text{in}}}
\]  

(8)

It should be noted that SMER is the inverse of SEC, and the drying efficiency is highest when SMER is maximum. In this study, the waste heat was used, and therefore it’s considered as free energy (Ameen and Nathan, 1996). The drying rate for each drying case is calculated by the following equation:

\[
DR = \frac{X}{DF}
\]  

(9)

2.2 Experimental Set-up

Systems that consist of a drying chamber and a moveable unit of split type air-conditioner have been constructed. The split unit is attached to a frame that was specifically designed for this experiment. The condenser is connected to the drying chamber with an air duct made from zinc and tube steel. The schematic diagrams for RACD and experiment set-up are presented in Fig. 4 and 5, respectively.

![Diagram for room air conditioner dryer](image)

The equipment and instrument used in this experiment are as follows:

- Load measurement instrument-load spring
- Drying chamber and moveable partition
- Thermocouples
- Room air conditioners
- Data acquisition system
- Digital power meter
- Anemometer
- Relative Humidity sensor
The specifications of the split air conditioner used in this study are shown in Table 1.

Table 1 Characteristic of split-type room air conditioner.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Technical Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Split unit</td>
</tr>
<tr>
<td>Volt/Ph/Hz</td>
<td>220-240/1/50</td>
</tr>
<tr>
<td>Cooling Capacity</td>
<td>10000 Btu/hr</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>R-22</td>
</tr>
<tr>
<td>Fan power Input</td>
<td>25 W</td>
</tr>
<tr>
<td>Rated Capacity</td>
<td>2.931 kW</td>
</tr>
<tr>
<td>Nominal Ampere</td>
<td>6.0 A</td>
</tr>
<tr>
<td>Power input (Watt)</td>
<td>881 W</td>
</tr>
</tbody>
</table>

Figure 5 Experimental set-up.

The airflow is as a function of air velocity and measured using an anemometer. The area of air flow is measured using a micrometer and a measurement tape. Meanwhile the density of the air depends on temperature and was taken from the thermodynamics Table (Cengel and Boles, 2007). Based on these data the mass air flow rate over the evaporator can be calculated using Eq. (5). A power meter was used to measure the electricity consumption during the drying process.

For this experiment, the drying chamber is mounted on a moveable partition and left opens at the back to allow hot air to flow through. The thermocouples are placed in four positions, which are two at the condenser (measure \(T_{in}\) and \(T_{out}\)) and, one for room temperature and another one was placed inside the drying chamber. All the data was read and recorded by Benchlink Data Logger III software.

The experiment was started by setting the room air-conditioner at 20°C and leaving it for 15 minutes to reach steady state condition. Then the power measurement test for the room air conditioner is conducted for 1 hour. Simultaneously the data logger recording the following data:

(i) Air temperature entering the condenser, \(T_{in}\)
(ii) Air temperature leaving the condenser, \(T_{out}\)
(iii) Room temperature

(iv) Room relative humidity
(v) Air temperature of drying chamber

The *Garcinia Atroviridis* are sliced into small pieces. Before drying, the sample is weighted. This weight was used as a reference to determine the drying time. Soon after the weight of the drying sample no longer show any weight loss, the experiment was stopped. The experiment was intended to investigate *Garcinia Atroviridis* drying process effectiveness by using waste heat from air conditioner condenser compared to conventional modes of drying.

3. RESULTS AND DISCUSSION

The data from the experiment has shown that the mass of *Garcinia Atroviridis* was reducing rapidly with respect to time until it reached a constant mass. The experiment was repeated for 3 times and the result is tabulated in Tables 2.

Table 2 Experiment results.

<table>
<thead>
<tr>
<th>Time (hour)</th>
<th>1st Experiment</th>
<th>2nd Experiment</th>
<th>3rd Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass</td>
<td>Moisture Removal</td>
<td>Mass</td>
</tr>
<tr>
<td>0</td>
<td>1170</td>
<td>1070</td>
<td>1200</td>
</tr>
<tr>
<td>1</td>
<td>920</td>
<td>820</td>
<td>920</td>
</tr>
<tr>
<td>2</td>
<td>700</td>
<td>600</td>
<td>680</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
<td>400</td>
<td>520</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>300</td>
<td>380</td>
</tr>
<tr>
<td>5</td>
<td>310</td>
<td>210</td>
<td>290</td>
</tr>
<tr>
<td>6</td>
<td>240</td>
<td>140</td>
<td>210</td>
</tr>
<tr>
<td>7</td>
<td>210</td>
<td>110</td>
<td>195</td>
</tr>
<tr>
<td>8</td>
<td>180</td>
<td>80</td>
<td>180</td>
</tr>
<tr>
<td>9</td>
<td>160</td>
<td>60</td>
<td>155</td>
</tr>
<tr>
<td>10</td>
<td>150</td>
<td>50</td>
<td>135</td>
</tr>
<tr>
<td>11</td>
<td>140</td>
<td>40</td>
<td>120</td>
</tr>
<tr>
<td>12</td>
<td>120</td>
<td>20</td>
<td>120</td>
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<tr>
<td>13</td>
<td>110</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>100</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>100</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

* Initial mass: 1st experiment 1170 gram, 2nd experiment 1200 gram and 3rd experiment 1200 gram.
** Mass and moisture removal in gram

The data and the sample calculation for first experiment is presented below:

Power consumption, \(W_{in} = 0.8575\)kW
Average air temperature leaving the condenser, \(T_{out} = 38.8\) °C.
Average air temperature entering condenser, \(T_{in} = 26.0\) °C
Average air temperature at drying chamber, \(T_{chamber} = 34.1\) °C
When \(T = 25.968\)°C, the air specific heat \(C_{air} = 1.005\) kJ/kg.K
And the air density, \(\rho = 1.1816\) kg/m3
Air flow velocity, \(v = 1.3\) m/s
Room area, \(A = 0.495\) m²
i) Moisture removal, \(X = 1070\) g
ii) Drying time, \(DT = 14\) hour
iii) Drying rate, 
\[DR=\frac{1.07}{14} = 0.0764\] kg/h
iv) Air conditioner power consumption with dryer, \(W_{in} = 857.5\)W
v) Mass flow rate = \( A \rho \nu = (0.495)(1.1816)(1.3) = 0.590 \) kg/s  
vi) Cooling capacity, \( Q_{\text{out}} = m \cdot C_p \cdot (T_{\text{out}} - T_{\text{in}}) \)
\( = (0.590)(1.005)(38.8-34.1) = 2.786 \) kW/s  
vii) Moisture removed per unit of energy consumption, 
\[ \text{SMER} = \frac{X}{[m \cdot C_p \cdot (T_{\text{out}} - T_{\text{in}}) + W_m]} \]  
\[ \text{SMER} = 0.1070/(2.786+0.8575) = 0.2937 \text{ kg/kWh} \]  

3.25

Table 3 Overall results for RACD experiment.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th>Experiment 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Condition (°C)</td>
<td>27.9</td>
<td>27.9</td>
<td>27.9</td>
</tr>
<tr>
<td>Initial Weight (kg)</td>
<td>1.17</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>Final Weight (kg)</td>
<td>0.10</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>Moisture Removed (kg)</td>
<td>1.07</td>
<td>1.08</td>
<td>1.06</td>
</tr>
<tr>
<td>Drying time (hour)</td>
<td>14</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Drying Rate (kg/h)</td>
<td>0.0764</td>
<td>0.0982</td>
<td>0.0964</td>
</tr>
<tr>
<td>AC Power input (kJ/s)</td>
<td>0.8575</td>
<td>0.8575</td>
<td>0.8575</td>
</tr>
<tr>
<td>Mass of Air (kg/s)</td>
<td>0.590</td>
<td>0.590</td>
<td>0.590</td>
</tr>
<tr>
<td>Cooling Capacity (kJ/s)</td>
<td>2.786</td>
<td>2.786</td>
<td>2.786</td>
</tr>
<tr>
<td>SMER (kg/kWh)</td>
<td>0.294</td>
<td>0.296</td>
<td>0.291</td>
</tr>
</tbody>
</table>

*Average drying rate: 0.0903 kg/h; Average SMER: 0.294 kg/kWh

In this study, we found that RACD is very capable of drying *Garcinia Atroviridis*. Normally, drying it at outdoor will take approximately 4 days. In the RACD experiment, the average drying time just takes 11 to 14 hour which is approximately 12.50% of the outdoor drying time.

During the experiments, the air temperature at the condenser outlet was about 38.8°C at with average ambient air temperature and relative humidity about 27.9°C and 56.8%, respectively. The average SMER obtained from the experiment is about 0.294 kg/kWh with the average drying rate is 0.0903 kg/h.

From the graph of moisture removal versus drying time of *Garcinia Atroviridis* using RACD, it can observed that the moisture remove rapidly from the first to sixth hour. After the sixth hour, it starts to slow down. The experiment conducted until it obtains a constant weight for two hours. Then the experiment stopped when moisture of the *Garcinia Atroviridis* is totally removed.

The average energy consumption of the split air conditioner is about 0.8575 kW for 60 minutes running time at a temperature of 20°C. It consumes 8.575kWh per day for 10 hours operation. Therefore, 3,087 kWh of energy is consumed every year. The electricity rates in Malaysia is RM 0.286/kWh, so the cost of the electric usage of air conditioner is about RM 882.88/year. However, the energy used by RACD is a waste heat from air conditioner condenser that purposely use for cooling. Hence, drying *Garcinia Atroviridis* with waste heat can consider as free energy. With the same cost, it can be used to cooling inside a room and at the same time drying the *Garcinia Atroviridis* for commercial purpose. Therefore, it is effective way to save cost and cut down the energy consumptions. The savings relative to regular dryer can be calculated with the assumption that the energy consumption for standard dryers is 898 kWh per year and the price of electricity in Malaysia is RM 0.286/kWh, therefore the bill savings is about RM 257/year (US$ 1 = RM 3.492) per one RACD.

4. CONCLUSIONS

The advantages of using RACD in *Garcinia Atroviridis* drying process is free energy from heat recovery resulting in cost savings. For the *Garcinia Atroviridis* case, it shows that RACD usages are multipurpose. It can be used to dry other commercial raw material and for drying clothes. RACD needs only 12.50% of the outdoor drying time to dry the *Garcinia Atroviridis*. By using the waste heat for drying purpose, it is not only save the cost of electric but also save the time from long natural drying.

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