Concentrated Solar Thermal Integration into Spice Roasting Industry: An Energy Analysis of an Indian Masala Manufacturing Facility

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Introduction

• Tavish Fenbert: Mechanical Engineering student at Northeastern University in Boston, USA
• Prof. Vishal Sardeshpande, Indian Institute of Technology Bombay
• Centre for Technology Alternatives for Rural Areas
Research Goals

• Analyze the thermal steps in the masala production process
• Determine power consumption of these processes
• Develop strategies for integrating solar thermal technology
Indian Masalas

• Masala = spice mixture
  • Coriander
  • Cumin
  • Black pepper
  • Cinnamon
  • Chili powder
  • Onion
  • Ginger
  • Garlic
  • Turmeric
  • Salt
  • And others...

• Used daily by families around the country
• 6.22M metric tons of spices consumed every year
Purpose of Roasting Spices

• Changes in:
  • Aroma
  • Texture
  • Appearance
  • Reduce moisture

• Labor-intensive process
• Skilled labor required
Indian Power Subsidies

• Main forms of heat for masala industry are LPG and electricity
• Indian Gov. subsidizes electricity and LPG in many parts of the country
• 21.55M tons of LPG consumed in India during 2016-2017
  • Over half was imported
• Solar thermal can:
  • Reduce greenhouse gas emissions
  • Reduce energy spending of Indian Gov.
Indian Solar Availability
Masala Production Process

Legend:
- Product Flow
- Electricity
- LPG
- No Power

Start: Storage → Cleaning → Boiling → Roasting → Grinding → Mixing → Packaging → End: To Market
Solar Concentrators Overview

Solar thermal technologies for process heat

Non concentrating technologies
- Flat plate collector
- Evacuated tube collector
- Compound parabolic concentrator (CPC)

Concentrating technologies
- Liner Fresnel reflector (LFR)
- Parabolic trough concentrator (PTC)
- Paraboloid concentrator (dish)
Method: Thermal processes

Boiling/Roasting in thermal oil vessel (elec.)

Roasting in pan (LPG)

Roasting in rotating vessel (LPG)
Method: Boiling/Roasting in electric thermal oil vessel
Method: LPG roasting
Energy Analysis Framework

Mass Balance: \[ m_{in} = m_{out} \]

Energy Balance: \[ E_{in} = E_{out} \]

\[ Q_{elec} = m_{onion} c_{onion} \Delta T_{onion} + m_{oil} c_{oil} \Delta T_{oil} + m_{steam} \Delta H_{vap} + Q_{loss} \]

Efficiency: \[ \eta_{LPG} = \frac{E_{required}}{E_{consumed}} \]
Energy Analysis: Boiling in electric thermal oil vessel

<table>
<thead>
<tr>
<th>Particular</th>
<th>Unit</th>
<th>Thermal Oil Boiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch mass</td>
<td>kg</td>
<td>700</td>
</tr>
<tr>
<td>Batch time</td>
<td>min</td>
<td>390</td>
</tr>
<tr>
<td>Vessel temperature</td>
<td>°C</td>
<td>130 to 150</td>
</tr>
<tr>
<td>Power required</td>
<td>kW</td>
<td>34.9</td>
</tr>
</tbody>
</table>

Temperature vs. Time for Onion Boiling

Ingredients added to inner chamber
Energy Analysis: Roasting in electric thermal oil vessel

Temperature vs. Time for Coriander Roasting

<table>
<thead>
<tr>
<th>Particular</th>
<th>Unit</th>
<th>Thermal Oil Roasting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch mass</td>
<td>kg</td>
<td>100</td>
</tr>
<tr>
<td>Batch time</td>
<td>min</td>
<td>80</td>
</tr>
<tr>
<td>Vessel temperature</td>
<td>°C</td>
<td>130 to 140</td>
</tr>
<tr>
<td>Power required</td>
<td>kW</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Diagram showing temperature vs. time for coriander roasting.
## Energy Use: LPG Roasting

<table>
<thead>
<tr>
<th>Particular</th>
<th>Unit</th>
<th>Pan</th>
<th>Rotating Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch mass</td>
<td>kg</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Batch time</td>
<td>min</td>
<td>28</td>
<td>7.4</td>
</tr>
<tr>
<td>LPG consumption rate</td>
<td>kg_LPG/hr</td>
<td>1.07</td>
<td>2.71</td>
</tr>
<tr>
<td>Power consumed</td>
<td>kW</td>
<td>13.7</td>
<td>34.7</td>
</tr>
<tr>
<td>Power required</td>
<td>kW</td>
<td>5.31</td>
<td>7.24</td>
</tr>
<tr>
<td>LPG heating efficiency, $\eta_{\text{LPG}}$</td>
<td>%</td>
<td>38.8</td>
<td>20.9</td>
</tr>
</tbody>
</table>
Solar Thermal Integration: Factors for consideration

- Temperature/power requirements
  - Time of day
- Solar space availability
- Backup power
- Plant layout
- Energy storage
- Cost
Solar Thermal Integration: Temp and power requirements

<table>
<thead>
<tr>
<th>Process</th>
<th>Solar Technology Suggestions</th>
<th>Area Required (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal oil boiling</td>
<td>PTC</td>
<td>117</td>
</tr>
<tr>
<td>Thermal oil roasting</td>
<td>PTC</td>
<td>16</td>
</tr>
<tr>
<td>LPG roasting in pan</td>
<td>Scheffler</td>
<td>~50</td>
</tr>
<tr>
<td>LPG roasting in rotating vessel</td>
<td>Scheffler</td>
<td>~50</td>
</tr>
</tbody>
</table>
Solar Thermal Integration: Potential Implementation Strategy

• Integrate a system of PTCs to heat the thermal oil for electric boiling/roasting processes

• Install Scheffler dishes to replace LPG for the pan and rotating vessel processes

• Some plant layout rearranging required

• PTCs are likely more practical than Scheffler
Conclusions

• Masala production industry is candidate for solar thermal integration
• Temperature range of processes is 140°C to 320°C

• Next steps:
  • Continue to gather data on energy use in masala production industry
  • Detailed economic analysis of solar thermal integration
Thank You!

Questions?