# CONCENTRATED SOLAR THERMAL INTEGRATION INTO SPICE ROASTING INDUSTRY: AN ENERGY ANALYSIS OF AN INDIAN MASALA MANUFACTURING FACILITY

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**Abstract**: Roasted spices are an important ingredient in masala spice blends, a staple in many Indian dishes. Due to the high volume of masala consumed in India, the energy used for spice roasting—in the forms of liquefied petroleum gas (LPG) and electricity—is a notable contributor to greenhouse gas emissions from the Indian spice processing sector. The masala manufacturing industry has the potential to integrate various forms of concentrated solar thermal technologies into roasting and boiling processes in order to reduce its carbon footprint. This study analyzes the energy used at a masala manufacturing facility in the state of Maharashtra, India, for three heating processes: (1) open flame LPG roasting (2) roasting in an electric thermal oil vessel, and (3) boiling in an electric thermal oil vessel. The LPG roasting processes operate at approximately 300°C with thermal efficiencies between 21% and 39%. The thermal oil vessels operate at approximately 140°C and require 4.81kW (roasting) and 34.1 kW (boiling) of electrical power. Approximate sizing and integration strategies are discussed for concentrated solar thermal technologies including the parabolic trough concentrator and Scheffler dish.

**Keywords**: Spice roasting, masala, solar, thermal

## 2. INTRODUCTION

Masala spice blends are a staple of Indian cooking. India consumes 6.22 million metric tons of spices annually [1], often in the form of masalas. The key component in each variety of masala is a mixture of roasted spices. Common roasted spices include coriander, cumin, bay leaf, and coconut; additional components of masalas include turmeric, chili powder, salt, garlic, and boiled onion. Due to the volume of masala consumed in India, the energy used to roast and process spices is a significant contributor to the greenhouse gas emissions of the Indian spice processing sector. The primary energy sources for roasting are liquefied petroleum gas (LPG) and electricity.

Power subsidies and the import of petroleum-based fuels create a burden on the Indian economy. In many parts of India, the government subsidizes electricity and LPG for domestic customers [2]. Over half of the 21.55 million tons of LPG consumed in India during the 2016-17 fiscal year was imported [3]. Introducing renewable energy into the masala production industry can both reduce the greenhouse gas emissions and reduce the energy spending of the Indian Government.

The masala production process includes five major steps (Figure 1). After cleaning, ingredients are roasted or boiled as necessary. Roasting can be done in small batches over an LPG flame or in larger batches in a thermal oil vessel, where oil is heated in a closed loop using electric heaters. Boiling is conducted in a similar electric thermal oil vessel (see Section 2). The cleaning, grinding, mixing, and packaging steps all require electric power, mainly for electric drives.

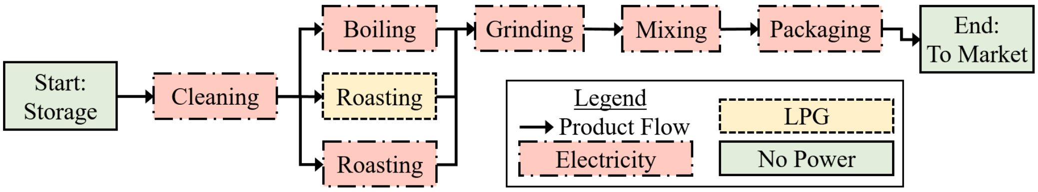

Figure 1. Masala production process flow diagram

Solar collectors are increasingly being used around the world to capture the sun's energy for purposes of power generation, industrial process heat, and cooking [4]. India is a particularly promising country for solar collectors, as most areas of India receive over 4 kWh/(m$^2$-day) of solar radiation [5] and have at least 300 days of sunshine per year [6]. Solar thermal collectors vary widely in size and scope, from non-concentrating flat plate collectors that can heat water up to 80°C [7] to concentrating collectors such as the parabolic trough concentrator (PTC) and Scheffler dish that can heat a working fluid to above 300°C (Figure 2) [4]. Unlike other high-temperature solar collectors designed for power generation, the Scheffler dish is designed specifically for cooking [8].

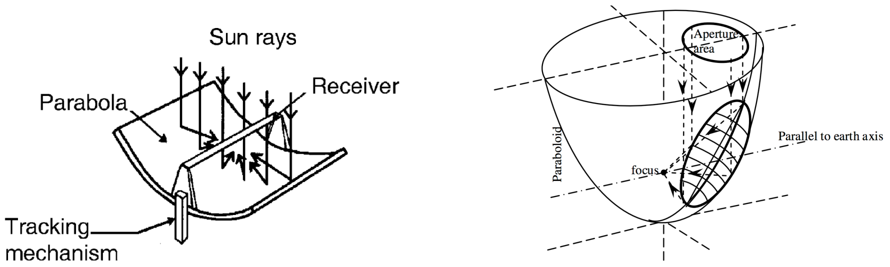

Figure 2. Diagram of PTC (left) [4] and Scheffler dish (right) [9]

The authors are interested in integrating solar thermal technology into the Indian spice roasting industry. This requires careful study of the effects of roasting a spice, current spice roasting processes, and the energy these roasting processes consume. Much information is available about how roasting a spice releases volatile oils [10] and can change the spice's appearance, aroma, texture, and nutritional value [11], but there are few studies concerning spice roasting practices and the energy consumed in the spice roasting process. To gather such information, the authors undertook a field study of a spice roasting factory located in central India. This paper discusses the results of the field study and potential options for integration of solar thermal technology into a spice roasting plant. There is potential for solar photovoltaic integration into the masala production process to offset electricity consumption, but this is outside the scope of this study.

## 2. METHOD

The measurements of the roasting and boiling processes were conducted during multiple visits to the spice roasting plant. The processes and measurement protocols are described in this section. Temperature measurements of the spices were taken with an infrared thermometer. Temperature measurements of the thermal oil were taken via a probe installed in the vessel's oil chamber.

### 2.1. Thermal oil vessel roasting and boiling

Boiled onion is one of the major ingredients for a spice mixture called 'Chatpat Masala;' roasted coriander is a main ingredient in both 'Garam Masala' and 'Chatpat Masala' spice mixtures. The boiling of onion and roasting of coriander in large batches take place in separate thermal oil based heated vessels (Figure 3). The two vessels are of a similar construction, with the onion boiling vessel being larger. Each vessel has an inner chamber with a helical stirring mechanism (not pictured) where ingredients are heated. Surrounding this inner chamber is a closed thermal oil bath with electric heating elements. The electric heating elements are programmable (of/off) based on the temperature requirements of the process. A thermocouple with continuous digital output monitors the temperature of the thermal oil bath and controls the on/off operation of the electric elements. A door on the underside of the vessel can be opened to discharge material after the boiling or roasting process ends.

The experimental protocol for these vessels involved measurements of ingredient masses, operating temperatures of ingredients and thermal oil, and total batch times.

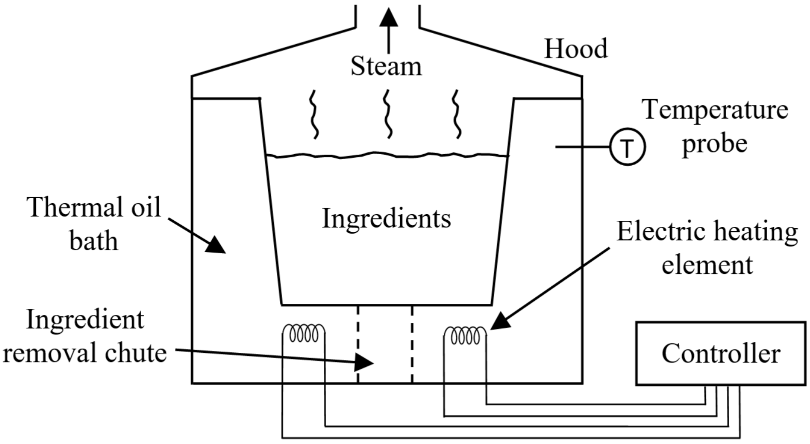

Figure 3. Thermal oil vessel.

## 2.2 Open flame LPG roasting

Most spices for masala spice mixtures are roasted over an open LPG flame. These spices are roasted in two distinct formats: shredded coconut is roasted in a rotating vessel positioned above an LPG flame, and other spices are roasted in a rounded pan stirred continuously by an operator (Figure 4). The set of spices required for one type of masala, such as ‘Chatpat Masala,’ are roasted in the pan individually, one after another. They are then mixed with other ingredients and ground together.

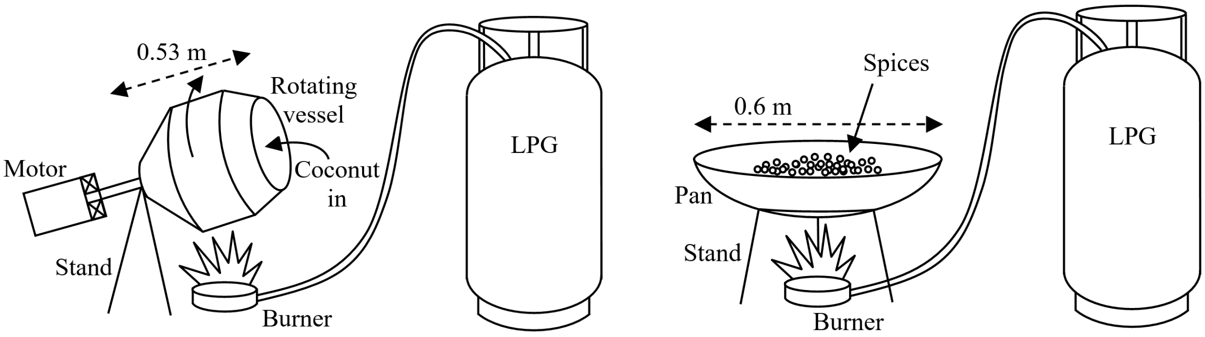

Figure 4. Open flame LPG roasting in rotating vessel (left) and pan (right).

Measurements were taken of the mass of cooking oil and spices roasted, the mass of LPG consumed, the time taken to roast each spice, and each spice’s final temperature after roasting. Spice temperature measurements were taken using the infrared thermometer at a distance of about one meter from the pan.

## 3. THERMAL ENERGY USE DURING SPICE ROASTING

This analysis focuses on the mass and energy balances of each thermal process described in the previous section. These calculations reveal the thermal energy transferred to the ingredients and the power requirement of each process. Operating temperatures of the ingredients and the vessels are also presented here.

### 3.1. Thermal oil vessel boiling and roasting

Figure 5 shows the temperature of the thermal oil and the ingredients during the boiling of 700kg of onion in the thermal oil vessel. The thermal oil was heated for one hour before ingredients were added to the inner chamber. The onion mixture reached its steady-state temperature of 88°C approximately two hours after the ingredients had been added. The mixture continued to boil at steady state for 3.5 hours, then the onion mixture was removed from the vessel.

Figure 6 shows the temperature of thermal oil and coriander during the roasting of a 100kg batch of coriander in the thermal oil vessel. Unlike the onion boiling process, during which the ingredients reach a steady state condition, the temperature of the coriander slowly rose from room temperature to 89°C. There are large gaps in the temperature data because the author was taking measurements of another process in the factory while the coriander was roasting.

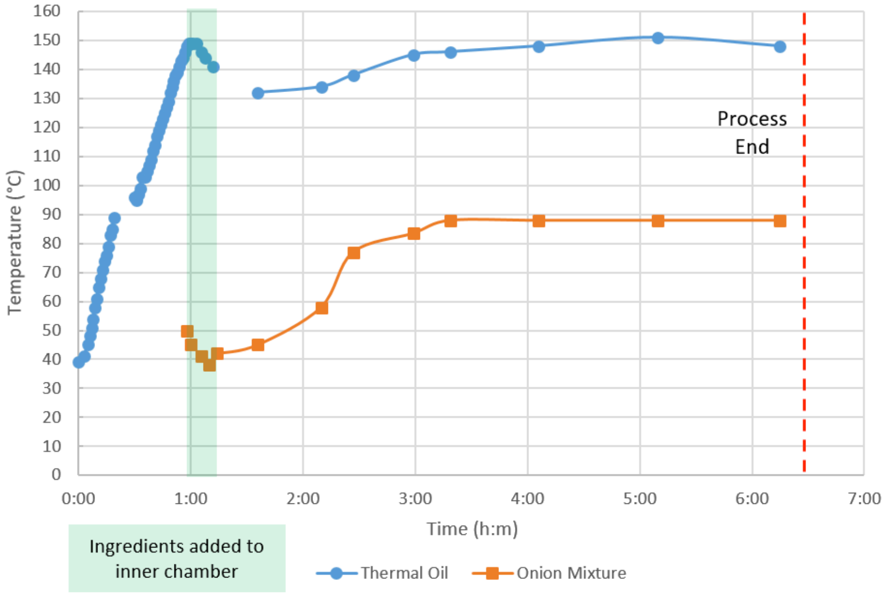

Figure 5. Plot of temperature versus time for onion boiling process.

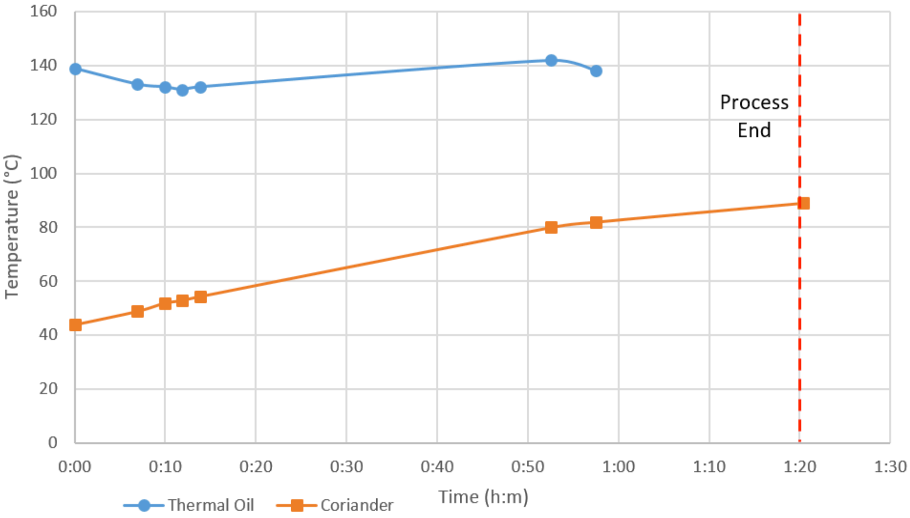

Figure 6. Plot of temperature versus time for coriander roasting process.

Figure 7 and Equation 1 show the mass balances for the thermal oil boiling and roasting processes.

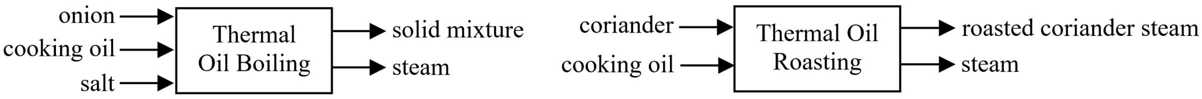

Figure 7. Mass balances for thermal oil boiling (left) and roasting (right) processes.

$$m_{in} = m_{out} \tag{1}$$

An energy balance for the onion boiling process (Figure 8, Equations 2 and 3), was used to calculate the total thermal energy delivered to the ingredients during the onion boiling process ($Q_{elec}$). The sensible heating of the ingredients was added to the energy required for evaporation of moisture. In these equations, $c$ represents specific heat, $\Delta T$ represents change in temperature, $\Delta H$ represents the latent heat of evaporation for water at atmospheric pressure, and $Q$ represents energy in the form of heat. For this analysis, the efficiency of conversion of electrical energy to heat was considered to be 100%, the energy lost to the environment ($Q_{loss}$) was considered negligible, and the sensible heating of salt was ignored. These estimates were appropriate for this analysis because overall trends in the data were being analyzed. Similar energy balance calculations were performed for the coriander thermal oil roasting process.

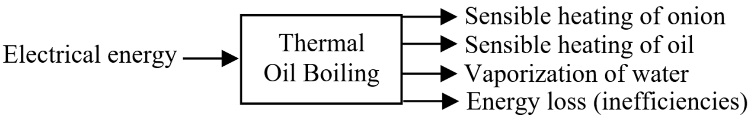

Figure 8. Energy balance for thermal oil boiling process.

$$E_{in} = E_{out} \tag{2}$$

$$Q_{elec} = m_{onion}{}^{*}\mathrm{c}_{\mathrm{onion}}{}^{*}\Delta T_{onion} + m_{oil}{}^{*}c_{oil}{}^{*}\Delta T_{oil} + m_{steam}{}^{*}\Delta H_{vap} + Q_{loss} \tag{3}$$

During the onion boiling process, the total thermal energy delivered to the ingredients was 670MJ over a period of 6.5 hours. During the initial heating of the thermal oil, 7.3kW of power was required. After the ingredients were added, 34.9kW of power was required.

During the coriander roasting process, the total energy delivered to the ingredients was 23.1MJ over a period of 80 minutes, or an average power of 4.8kW. The moisture evaporated was conservatively assumed to be 5% because the final mass of the coriander was not able to be measured.

### 3.3. Open flame LPG roasting

Mass (Figure 9) and energy balances were performed for the open flame LPG pan and rotating vessel roasting processes using Equations 1 and 2.

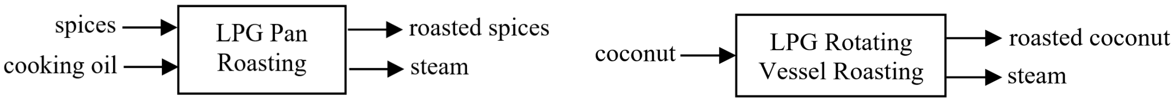

Figure 9. Mass balance for open flame LPG roasting processes.

The heat energy delivered to the spices, $E_{required}$, was then compared to the energy value of the LPG consumed, $E_{consumed}$, to determine the thermal efficiency, $\eta_{LPG}$, of the heating process, (Equation 4). The power required and power consumed were then calculated from these energy calculations.

$$\eta_{LPG} = \frac{E_{required}}{E_{consumed}} \tag{4}$$

Table 1 shows the average energy data for batches of various spices roasted in a pan and coconut roasted in a rotating vessel over an LPG flame. The pan temperature during this roasting process was approximately 320°C and the rotating vessel temperature was approximately 280°C.

Table 1. Open flame LPG roasting data

| Particular | Unit | Pan | Rotating Vessel |
|---|---|---|---|
| Batch mass | kg | 35 | 5 |
| Batch time | min | 28 | 7.4 |
| LPG consumption rate | $kg_{LPG}$/hr | 1.07 | 2.71 |
| Power consumed | kW | 13.7 | 34.7 |
| **Power required** | **kW** | **5.31** | **7.24** |
| LPG heating efficiency, $\eta_{LPG}$ | % | 38.8 | 20.9 |

## 4. SOLAR THERMAL COMPATIBILITY WITH MASALA PRODUCTION INDUSTRY

This section outlines potential options for integration of solar thermal technology into the masala production process. Factors discussed include the temperature and power requirements of the roasting or boiling process, backup power, and the duration of the energy demand.

### 4.1. Temperature and power requirements

The heating method (direct or indirect), and the temperature requirement of a heating process are two requirements which guide the choice of solar thermal technology. Once these characteristics are appropriately matched, the chosen concentrator can often be scaled to deliver the necessary power.

The electric thermal oil boiling and roasting processes use an indirect heating method, so a solar concentrator that heats a working fluid would be the most practical to integrate with these processes. PTCs would be a good choice because they can heat thermal oil to the required operating temperature (approximately 140°C). To provide the 35kW of power necessary for steady state operation of the onion boiling vessel, PTCs with 117m$^2$ of collection area would be needed, assuming a normal beam radiation of 5kWh/m$^2$-day [5] and a 50% efficiency [12]. PTCs with a total collector area of 16m$^2$ could provide the required power input for the smaller coriander thermal oil roasting vessel.

The open flame LPG roasting processes use LPG as a direct heat source, so it would be most practical to integrate these processes with a solar concentrator that heats a cooking vessel, such as the Scheffler dish. The Scheffler dish also fits the operating temperature requirement (approximately 300°C). The collection area of the Scheffler dish needed to meet the power needs of the LPG roasting processes is approximately 50m$^2$, assuming a 20% efficiency [9]. Further analysis of the available solar space at the plant is needed to determine if these shadow-free areas are available.

### 4.2. Solar integration strategy

Integration of solar thermal collectors with existing processes requires consideration of duration and size of the energy demand, plant layout, backup power, and energy storage. The most crucial of these elements is ensuring that backup power or stored energy is available at all times in case of passing clouds or a non-sunny day. It is likely not practical to install a storage system for solar thermal energy at the roasting plant due to the high temperature requirements and the daytime energy demand of the plant. Therefore, present power systems must be kept in place

Integrating a system of PTCs with the electric thermal oil processes would be simple in this regard. The controller that determines when the electric heaters are turned on and off could continue to function as normal; the addition of heat to the system via the PTCs would allow the electric heaters to turn on less frequently. Retaining backup power for the LPG roasting processes with an integrated

Scheffler dish would be somewhat more difficult, as the Scheffler dish would concentrate solar radiation on the cooking vessel, the area where an LPG burner would generally be placed. Given the potential difficulty of switching quickly from Scheffler heating to LPG heating if clouds are present, it may be more practical to only use the Scheffler dish to roast spices on clear sunny days.

## 5. CONCLUSION

A field study of a masala production plant in central India was conducted to determine the temperature and energy requirements of their thermal processes in order to facilitate the integration of concentrated solar thermal technology. The roasting and boiling processes at the plant, using LPG or electricity as an energy source, operate at temperatures ranging from 140°C to 300°C and require between 4.8kW and 34.9kW of power. PTCs can be integrated into the roasting and boiling processes that use an electrically heated thermal oil vessel. A Scheffler dish can be integrated with roasting processes that use an open LPG flame. Further economic analysis of the masala production plant and available solar thermal systems are needed before integrating these technologies.

## 6. ACKNOWLEDGEMENTS

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