Abstract

Tea industry is one of the traditional plantation based industries in India and holds a prime position in production, consumption and export. It employs more than 1.6 million people in India and contributes to the welfare and development of the region besides contribution to the national economy. Thus, growth and development of the tea industry require appropriate attention. Technical innovation and supply of sustainable energy to ensure economical and quality tea production is considered crucial aspects for sustainable growth of the tea industry. Understanding of the behaviour of the tea sample is pre-requisite for application of such innovation. Therefore, focus of the present study is to examine some basic properties of tea and also to investigate the prospect of a new tea drying technique ensuring quality production at optimum energy use.

Processed tea also called made tea is classified as white tea, green tea, oolong tea and black tea based on the processing technique. CTC tea is a typical black tea which is prepared through some specific processing steps viz., (i) withering (ii) CTC (iii) fermentation and (iv) drying.

The present research work is carried out with dry ready CTC tea samples of T3E3 cultivar obtained from a reputed tea research organization (Tea Research Association, Tocklai Experimental Station, Assam India) for (i) identifying best fit desorption isotherm model, (ii) investigation of drying kinetics using (a) hot air with varying temperature and (b) microwave radiation with varying microwave power level, (iii) optimizing the variable process parameter for best quality at least specific energy consumption for combine mode (microwave-hot air) of CTC tea drying. Standard experimental procedure and analysis are followed for all of the above as discussed in brief below.
Drying some food products like tea, which require careful hygienic attention, availability of water for growth of microorganisms, germination of spores, and participation in several types of chemical reaction becomes a critical issue. This water availability depends on water activity ($a_w$), which is the equilibrium relative humidity of the food material. Water activity ($a_w$) is one of the most critical factors that affect the shelf life, safety, texture, flavor, and smell of foods. Water activity of a food product can be determined from the sorption isotherms of the food product. The sorption isotherm is a graphical relationship between the equilibrium moisture content of a material and its equilibrium relative humidity at a specific temperature. Sorption isotherm of food product is useful for designing of the dryer and specifies optimum drying, storage and packaging conditions to assure long-term stability of dehydrated foods. Sorption isotherms are determined by the standard static gravimetric technique, which is based on the use of saturated salt solutions to maintain constant relative humidity. Nine salts (viz., KOH, MgCl$_2$, K$_2$CO$_3$, NaNO$_3$, KCl, BaCl$_2$, LiBr, LiCl and KI) have been used to achieve varying degree of ambient relative humidity (RH) around identical CTC tea samples kept in the temperature-controlled cabinet. Reduction of moisture contents corresponding to 30, 40, 50, 80 and 90 $^\circ$C ambient temperature for each of the above nine ambient RH conditions is recorded for investigating temperature dependent desorption behavior of CTC tea sample. Six available models, viz., BET, GAB, Halsey, Pleg, Oswin and Henderson have been used for fitting the experimental data. However, Oswin model has been found as the best-fit for predicting the desorption data of the CTC tea. The monolayer moisture content of CTC tea has been found as 0.0477, 0.0457, 0.0420, 0.0321 and 0.0311 kg kg$^{-1}$ (d.b.) at 30, 40, 50, 80 and 90 $^\circ$C, respectively. Correlation between net isosteric heat of desorption and equilibrium moisture content has also been derived from experimental data. Further, theoretical energy required for drying is assessed from net isosteric heat of desorption data.

Drying is a critical step amongst these CTC tea manufacturing processes - considering its impact on quality and energy requirement. In drying, moisture of the fermented tea-leaf particles is reduced from about 2.33 to 0.03 kg kg$^{-1}$ (d.b.). Hot air drying has been the most common method in tea drying, requiring maximum share
from thermal source of energy. Longer time required, particularly during the falling rate period of drying, has been the characteristic feature of traditional hot air tea drying. Attempt to shorten drying time, aiming to improve energy efficacy and quality of processed tea, is desirable for the tea industry. Ideally, such attempt requires comprehensive investigation of drying phenomena, taking into account of the physical and chemical changes of tea samples during drying and their relationships with energy consumption and quality. However, in the present investigation, reduction of moisture content with time and associated energy consumption could be assessed with experimental set-up.

The laboratory scale experimental set-up simulates thin layer hot air drying of tea. The set-up consisted of an electrical heater, a blower, a flow controller, a humidity controller and weighing device. Hot air streams with three levels of temperature (80, 90 and 95 °C) and 70% RH can be generated for drying CTC tea samples maintaining constant air flow rate (2.33 × 10⁻³ kg s⁻¹). Repeated experiments are conducted with identical tea samples (ready-to-dry) at varying temperature. The generated data are used to fit in six popular thin layer drying models, viz., Henderson and Pabis model, Lewis model, Page model, Logarithmic model, Two term model and Midilli et al. model. Drying curves and subsequently best-fit drying model for CTC tea is identified. Out of six available drying models, the Midilli et al. model has been found the best fitted for thin layer drying of CTC tea samples. The higher temperature of hot air stream resulted relatively quicker drying and consumed lesser specific energy.

Microwave drying has been reported as rapid and energy efficient drying technique compared to conventional hot air drying of food materials, such as apple, carrot, banana, garlic, potato etc. resulting more uniform end product quality. Microwave drying is suggested for the “falling rate period” to take care of the overall economy of the process. Prospect of application of microwave drying technique for CTC tea has been the central focus of the present investigation. A domestic microwave oven is used as a drying chamber for investigating microwave drying behaviour of CTC tea. Ready-to-dry CTC tea samples are kept in the tray of the
microwave oven. Losses of moisture with time are recorded while exposing samples to microwave in the chamber. The experiments are repeated varying microwave power level (175, 350, 525, 700 and 875 W). Observed data are also fitted in the available drying models. Among all drying models used in this study, the Page model is found the best fitted model to represent microwave drying of CTC tea. Higher the microwave power resulted quicker drying while reducing the moisture reduction from 2.33 to 0.03 kg kg\(^{-1}\) (d.b.). Further, irrespective of the microwave power level, “constant drying rate period” is observed during 2.33 to 0.26 kg kg\(^{-1}\) (d.b.) moisture reductions accounting about 88% of the total moisture removal.

Drying kinetics in microwave drying is different from hot air drying of CTC tea. A combination drying (hot air and microwave) is decided on the basis of the observation on two individual mode of drying. Microwave mode of drying is used for reduction of moisture beyond 0.2 kg kg\(^{-1}\) (d.b.). Partially dried samples at 0.2 kg kg\(^{-1}\) (d.b.) from the hot air drying set up are transferred to the microwave oven for the final phase of drying. The experiments are conducted using varying hot air temperature (first phase) and microwave power level (final phase). The observations pertaining total drying time and energy consumption are recorded for combined drying.

The made tea samples are further tested for quality as per the prevailing industrial procedure in a reputed tea research laboratory. The procedure consists of providing score values for each sample of made tea corresponding to all treatments. Ten point scoring scale for five quality parameters (viz., colour, strength, brightness, briskness and thickness) of the CTC samples corresponding to the treatment under consideration is used by professional tea tasters.

The specific energy consumption (MJ kg\(^{-1}\)) corresponding to all experimental treatments are also assessed from related observed data on energy consumption. An optimization procedure is used to identify the optimum process variable (hot air temperature and microwave power level) for best quality and least specific energy consumption in case of combine mode of drying. In general, increased in microwave
power and hot air temperature reduces specific energy consumption. However, while higher drying temperature favourably influenced quality, higher microwave power have a negative effect on tea quality. The optimisation exercise predicts a temperature of 95 °C (first phase hot air drying) and 225 W microwave power (final phase) for the best quality with minimum specific energy consumption of 3.23 MJ kg⁻¹.

Finally, the observation on specific energy consumption recorded from three local tea factories are compared with the results of the present investigation. The comparative assessment indicates the prospect of reducing energy consumption using microwave assisted hot air drying.

The outcomes of the present investigation are expected to be useful for development of new drying process vis-à-vis techniques for preparation of made tea.