Chapter 8

New Product Report

Quality Tea Processing for Small Growers and Instrumentation

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Key words: Small tea growers, Environmentally Controlled Manufacturing, Sensors, Instrumentation

Abstract

Small tea growers have a specific requirement of processing of low volumes of green leaf and yet achieving reasonable quality of the end-product while remaining competitive in the global market. Due to small tea growing areas, it becomes economically unviable for small tea growers to go with conventional tea processing machineries to perform withering, rolling, fermentation and drying operations. This usually forces them to go for selling of leaf to larger tea gardens often depriving them of fetching a good price. The bought leaf factories too find problem in achieving consistency in the quality of made tea due to heterogeneous leaf coming from various small tea growers. One, therefore, loses at both the ends when viewed from a macroscopic angle.

The present paper highlights the innovative design of environmentally controlled manufacturing machine having integrated processing units for withering, rolling/CTC, fermentation and drying operations. Due to its modular design, one can scale it up or down as per specific leaf processing requirements. The paper also described advanced sensing techniques and instrumentation based thereupon for monitoring of key parameters of green leaf/made tea which are applicable to both small and large tea growers. Such gadgets are quite handy in assessing the quality aspects at various stages of tea manufacturing.

1. Introduction

India has been the leader in tea cultivation and production of black tea of both CTC and orthodox types. Although several design modifications of processing machines have been carried out and various versions are being used in the industry, the control features have mostly been manual in nature. Another problem arises due to small processing volumes of green leaf which does not meet the criterion of cost-effectiveness. This is the reason that even the quality green leaf produced from the bushes do not contribute to the quality tea production due to inadequate processing methodologies followed by the small growers. This ultimately lead to the selling out of leaf to the bought-leaf factories which also face manufacturing problems due to heterogeneous nature of green leaf received from the cluster of small tea growers. Non uniform plucking standards, transportation delays and inadequate mechanical handling become key factor for loss of quality ultimately leading to economic non-viability.

One of the feasible solutions is to develop a scalable environmentally controlled manufacturing machine equipped with the monitoring and control instrumentation for processing lesser quantities of green-leaf suitable to small tea growers to achieve

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consistency in the quality of the end-product. There is also a dire need for indicating gadgets for quick-assessment of process parameters for monitoring as well as control of different unit operations. Several transduction principles have emerged in the recent past, which offer great potential for developing compact and smart instrumentation for estimation of various physio-chemical properties. This paper highlights some of the innovative gadgets and instrumentation systems of specific relevance to small tea growers.

2. Need of Instrumentation for Small Growers

Instrumentation can be broadly classified in two paradigms: i.e. technology driven and market driven. The former deals with the search of new sensors and devices so that cost-effective ways of measurement and subsequent regulation can be exercised while the latter deals with extending the existing knowledge to some un-explored areas of process monitoring and control. The requirements of small tea growers can be mostly met by hand held portable indicating devices for spot measurement of essential parameters such as temperature, moisture, pH, colour, size etc. This helps in quick assessment of key parameters of relevance to the manufacturing section.

Small growers by large have been either selling their leaf to the bigger houses or processing them by primitive methods which are neither energy-efficient nor cost-effective and hence are not conducive to their growth. One therefore needs to develop a dedicated miniaturised tea processing machine with built-in process attachments to perform withering, rolling/CTC, fermentation and drying operations with programmable features to suit their specific requirements. The machine may be used by single grower or a scaled-up version can be used on a co-operative basis by multi-farmers. The subsequent section describes the novel concept of Environmentally Controlled Manufacturing (ECM) system.

3.Environmentally Controlled Manufacturing

Quality of the end-product in any process industry depends mainly on the quality of raw material and tea is no exception. Soil condition, micro-nutrients, irrigation profile and most important the clonal varieties of bushes define the nature of green leaf and its potential of producing the characteristic features in the cup of tea. Plucking standard, age of bush, stage from previous pruning, plucking round etc. are some of the others factors that also contribute to the quality of the tea shoot. Besides, in the same shoot, the chemical composition of 1st leaf, 2nd leaf, other leaves, stem etc. also vary widely. Quality of tea further depends to a large extent on the methods of processing and the specific machines adopted for this purpose. The manufacture mostly deals with heterogeneous raw materials coming from different growers having different levels of chemical constituents and physical characteristics. When such materials are subjected to subsequent steps of processing each category responds differently resulting in ether over-processed or under-processed product. One therefore needs to segregate leafs as per two and a bud, three and a bud or banjhi so that processing of leaf can be done as per the specific leaf structure so as to apply the desired processing strategy.

The basic process steps are invariably the same as

- Withering physical and chemical
- CTC/Rolling-cell maceration
- Oxidation/fermentation
- Drying
- Sorting ,grading and packaging

For small tea growers, the complete tea manufacturing process has been mostly artisan-dependent which leads to the non-consistency in the quality of the end-product. However, such problems can be tackled by adopting user friendly small manufacturing devices such as Environmentally Controlled Machine (under development at CSIO). The machine is a complete vertical continuous scalable processing unit which will perform the required tea manufacturing operations from withering to the drying. Built-in smart sensors backed up with intelligent control algorithms will perform various control actions under varying agro-climatic conditions of green leaf so that desired results are obtained at each stage.

Figure 1 shows the block diagram of the proposed machine. The plucked green leaf is fed into the hopper which allows it to move into the withering unit of the machine where the humidity and temperature are controlled to achieve desired rate of loss of moisture which provides the proper percentage of wither. After withering, the leaves are moved into the rotor vane block (CTC) or rolling table (orthodox) unit where temperature gradients and applied pressures are monitored to get optimum maceration. Subsequently, the leaves are pushed into fermentation unit to allow series of enzymatic reactions to proceed. The process variable such as colour, temperature, relative humidity and water -content in the leaf is monitored and humidified air is controlled to achieve the desired set of parameters for proper degree of fermentation. The leaf is finally fed to the dryer unit where precise temperature profile is maintained to obtain the desired rate of loss of moisture. Figure 2 shows the 3D layout of the ECM machine which is specifically designed for the small tea manufacturers.

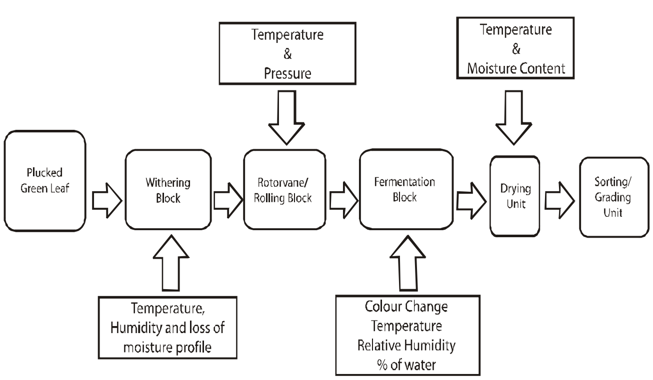

Figure 1: Block diagram of ECM machine

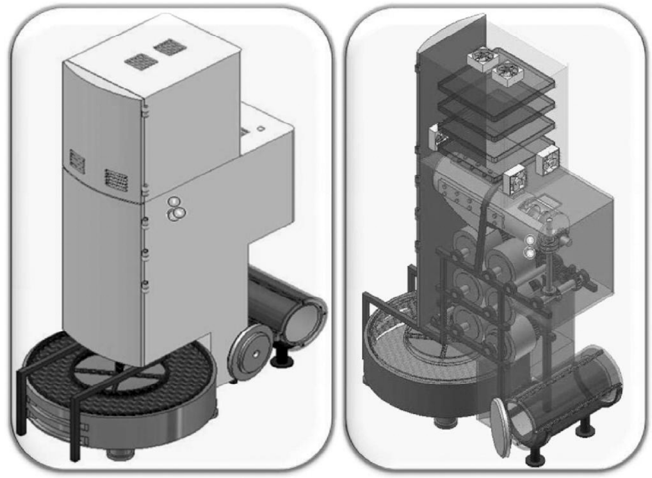

Figure 2: 3D layout of ECM machine for tea

4. Assistive Gadgets for Parameter Monitoring

One of the reasons for inconsistency in quality of tea produced is the lack of indicating gadgets for quick measurement of critical parameters during different stages of manufacture. Some of the gadgets, which may be useful for tea manufacturing right from pre-harvesting to final packaging of tea, are

- pH and Salinity meter for soil
- Thermometer for biologically active compost
- Dissolved Oxygen Meter
- Leaf temperature meter
- Humidity transmeter
- Moisture analyzers for green leaf, made tea etc
- Size and shape meter
- Colorimeter
- Oxygen/carbon dioxide concentration meter
- Concentration of specific bio-chemicals

Central Scientific Instruments Organisations(CSIO), a constituent unit of CSIR has expertise in the field of instrumentation and is fully backed-up by strong R&D support from Optics, Mechanical design & fabrication, Electronics & computers, etc. Some of the current R&D programmes are already going on towards the development of these indicating gadgets and are briefly described in the following sub-sections of this paper.

5. Advanced Transduction Techniques and Associated Instruments for Quality Tea Processing

This section describes some of the state-of-art techniques which can be used for the development of gadgets for on-site measurement of critical parameters during field operations, tea processing and quality assessment. These are ideally suited for tea factories of the future.

5.1 NIR reflectance technique

Near Infrared Reflectance (NIR) technique is quite effective in assessing the concentration of specific molecules such as protein, water, oil, starch, amino acids, etc. and can be utilised for the development of instrument for such measurements. Figure 3 shows a block Schematic of NIR Transmission/Reflectance Meter, which can be applied for rapid assessment of these parameters.

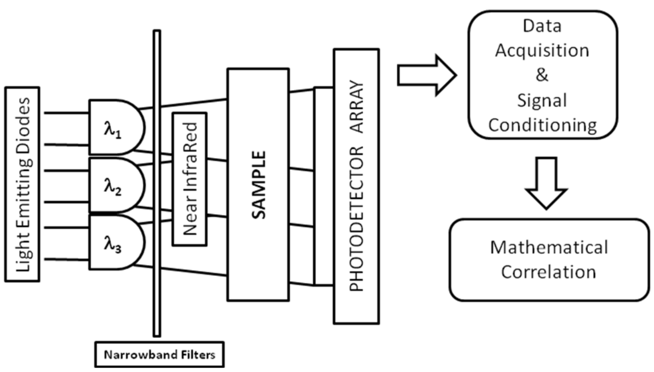

Figure 3: Conceptual Schematic of rapid NIR analyzer

Samples are taken in a sample-cup placed in a protected enclosure to avoid any interference from ambient light, and is irradiated by an array of Light Emitting Diodes producing different wavelengths in the near Infrared region selected through appropriate narrow band filters. Wavelength-dependent signals transmitted through the sample are detected by the matching photodetector array and fed to the Data Acquisition System (DAS) interfaced with the computer. Feature extraction algorithms operate on the data to derive a quantitative assessment of chosen bio-chemical parameters. One can therefore make an on-site measurement of parameters such as moisture, amino acids, poly phenols and proteins etc. Such gadgets are quite handy to assess the fermenting floor parameters.

5.2 Surface Plasmon Resonance

Total internal reflection occurs when a light beam from a denser medium (higher refractive index) meets an interface at a medium of lower refractive index at an angle of incidence above a critical value. The incident light is totally reflected while the electromagnetic field component penetrates a short distance (tens of nanometers) into the medium and generates an exponentially detenuating evanescent wave. If the interface between the media is coated with a thin layer of metal (gold), and light is monochromatic and p-polarized, the intensity of the reflected light is attenuated significantly at a specific incident angle producing a sharp shadow. This condition is referred as Surface Plasmon Resonance (SPR) which occurs due to the resonance energy transfer between evanescent wave and surface plasmons. The resonance condition is influenced by the material under study which is adsorbed onto the thin metal film. Satisfactory linear relationship has been reported between the resonance energy and mass concentration of biochemically relevant molecules such as proteins, sugars, etc. The SPR signal which is expressed in resonance units, is therefore a measure of mass concentration of the biochemical sample under study. Figure 4 shows the working principle of SPR based measurement.

This technique can be applied to tea liquor quality analysis, for assessing flavanols and colored compounds, theaflavins and thearubigins. The sensitivity and the specificity can be enhanced by developing antibodies of specific compounds to be detected and coating them on the gold surface, enabling development of rapid disposable analysis kits for tea quality.

Specific application based measurements set-ups can be configured which will ultimately lead to cost reduction.

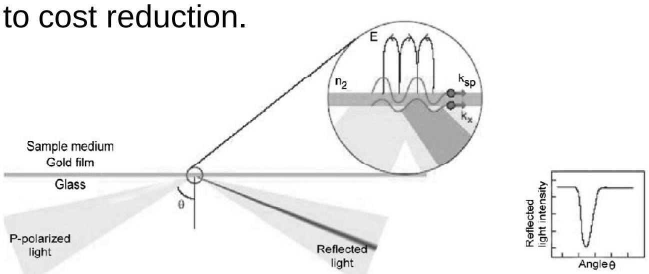

Figure 4: Surface Plasmon Resonance Principle

5.3 Quartz Crystal Microbalance

Quartz crystal resonates at a frequency depending upon its cut and size. Any addition of mass (occurring due to the temporary deposition of biomolecule on the quartz crystal) alters this resonance frequency. This change in the frequency is directly proportional to the mass of the molecule and can be related to the characteristic feature of the material under study. It is well established that the impedance spectrum for a Quartz Crystal Microbalance (QCM) contains vital information about the nature of the molecule which makes it a powerful tool for sensor development. The quartz crystals are generally AT cut and are available in standard resonance frequency ranges. The change in the total resonance frequency is directly proportional to the corresponding mass changes being deposited. This approach can be applied for bio-sensing of parameter responsible for tea quality. A rapid disposable biosensor kit can be developed by producing compound specific antibodies and coating them on the gold coated QCM surface. Figure 5 shows a schematic of QCM based tea quality analysis instrument. A suitable chamber inhales the flavanols which sit on matching antibodies causing a spectrogram indicating its concentration. Usually array of sensors are used which give a series of measurements over a range of bio-chemicals. Such systems are quite powerful to assess the quality parameters under actual manufacturing environment so that corrective action could be applied on-line.

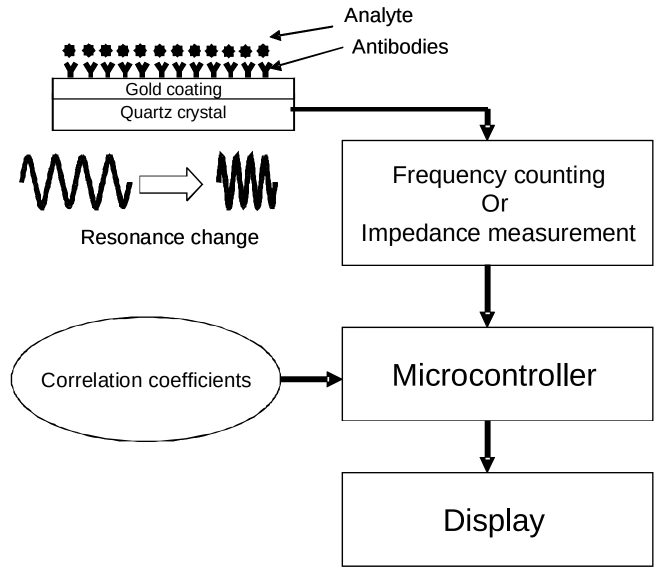

Figure 5: Schematic of QCM based tea quality analysis instrument

5.4 Dielectric spectroscopy

Agri-produce such as tea, spices, herbal medicines etc. are mainly enzymatic reactions based generating a series of bio-chemicals which ultimately decides its quality. One needs to protect them during the course of processing so that these are retained in the finished product to a greater extent. In case of tea processing, withering and rolling/CTC set a pace for the growth of variety of bio-chemicals which ultimately get matured during the course of fermentation. The enzymes primarily responsible for tea quality are Polyphenol Oxidase, Pectinase, Lipase, -glucosidase and Polyphenol Peroxidase. Since direct measurement of the enzymatic activity through detailed wet chemistry methods is time consuming these could be correlated with changes in the physico-chemical properties of the leaf which undergoes a significant change. This transformation can be utilized to relate with the engineering parameters such as temperature, humidity, rate of loss of moisture profile, etc. to optimize the process behaviour. Due to the remarkable dielectric behaviour of biological materials, the Dielectric spectroscopy provides a promising method to monitor the enzymatic activity. One observes high dielectric permittivity at low frequencies which decays steadily as frequency increases. The frequency dependence of dielectric permits to identify and investigate a number of biochemical mechanisms which can be characterized by three major dispersions phenomena observed at different frequency, namely at low frequency (), radio frequency (), and microwave frequency () respectively.

Enzymes have been reported to undergo conformal changes under varying electric fields which produce harmonics under the effect of electric field. The equivalent circuit of the sample comprises resistive and reactive components R & C as depicted in figure 6 (a & b). Under a sweep ac field the R & C are plotted against frequency and the acquired data is analysed using statistical techniques such as ANN, FL, PCA, GA etc. The extracted information about the specific biochemical compound can be combined with the knowledge of supporting parameters like temperature, moisture content and colour change to form a powerful measuring setup.

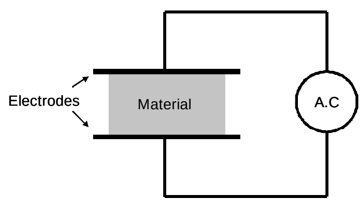

Figure 2 : Material placed between two electrodes excited by alternating electric filed

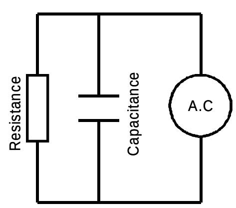

Figure 3 : Electrical equivalent circuit

Figure 7 shows a conceptual block diagram of the proposed setup to monitor and control the conditions most conducive to the growth of fermentation process. A frequency sweep is generated by the controller unit and the R&C measurement at each frequency is recorded and processed. On the basis of dielectric parameters measurement and other supporting variables measured through other sensors the figure of merit of the process can be estimated which gives an estimation of bio-molecular growth during the course of reaction process. The controller loop activates the humidification and aeration cycles for regulation of these reactions. A prototype model on the lines similar to ECM can be specifically designed for miniaturized tea processing units which can also be scaled-up for large tea processing houses.

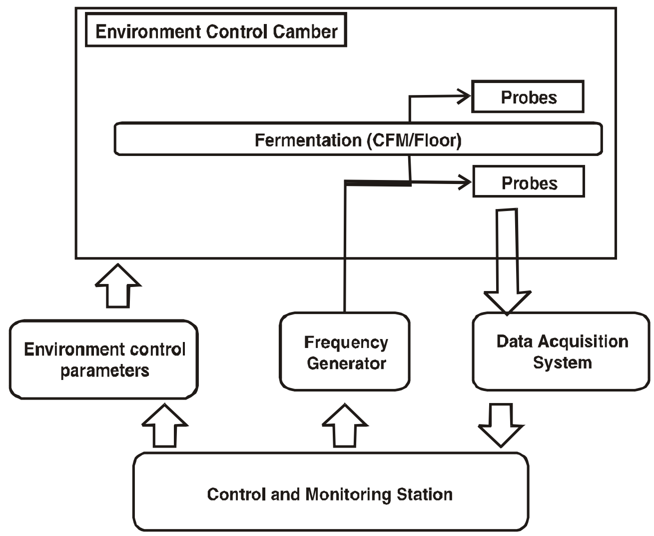

Figure 7 : Schematic of on-line tea fermentation monitoring and control

5.5 Fibre Optic Sensors

Fibre optic based sensors rely on the guided propagation of light energy through the core of fibre with its cladding made of suitable material having the refractive index conducive for total internal reflection to happen within the fibre. Suitable cladding material can be chosen or a portion can be cut and deposited with another material where immobilization of antibodies can be made. Antigen which forms a matching pair with the antibody alters the refractive index of the core thereby affecting the amplitude and phase of the detected signal of the output when excited by the source of light at the input end. Fibre Bragg Grating (FBG) is the graded refractive index pattern written on the core using phase mask or holographic techniques. Depending upon the pitch of grating, particular excitation wavelength and the difference in the refractive index between the core and cladding, resonance takes place and some specific wavelength called Bragg wavelength are absent from the output spectrum. Due to the presence of analyte the antibody and antigen combination takes place which causes a shift in the Bragg wavelength () which is a measure of the concentration of the desired biochemical/ physical parameter. In Long Period Grating (LPG) the pitch of the grating is of the order of 100 microns as compared to 1 micron in the case of FBG. Such sensors are very effective in measurements due to advantages such as immunity from EMI, distributed sensors configuration, higher signal to noise ratio, sensitivity and more over cost effectiveness. Figure 8 shows the underline principle and the typical response observed. CSIO has setup a complete infrastructure and has generated expertise in the design and fabrication of FBG and LPG based sensors which have been tried in various applications.

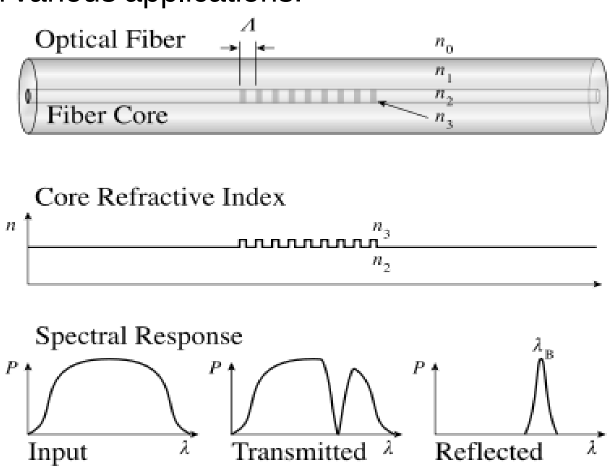

Figure 8: A Fiber Bragg Grating structure

Such a sensor can be quite effective in the measurement of parameters such as moisture content, temperature, colour change, oxygen uptake or carbon dioxide concentration, humidity, pressure etc. which are key variables in the tea industry.

6. Applications of advanced sensors in Tea Manufacturing

This section describes how the different transduction techniques and associated gadgets dealt in the previous section can be effectively utilised for the monitoring of different parameters during the course of withering to final drying and ultimately packaging. FBG and LPG based sensors offer promising solutions for withering and fermentation processes where each sensor module in a distributed pattern can form a combination for measurement of moisture and temperature , humidity and temperature , colour change and temperature, oxygen uptake and carbon dioxide release etc. Pressure sensor and temperature combination can be useful for CTC rotor vane / rolling table while moisture and temperature profiles can act as a basic sensing device for the dryer. Special sensor as descried above can be helpful in a specific biochemical parameters estimation such as polyphenols , TF , TR , caffeine etc. Conducting polymer offer a great potential for the development of bio-sensors to make series of measurements. ECM described above would be fitted with appropriate sensors for on line display of process-wise parameters to regulate the particular unit operation as per the desired specifications. SPR,QCM are at the present bit futuristic but NIR ,dielectric spectroscopy and fibre optic based devices are quite suitable for applications to small as well as large tea gardens.

7.Conclusion

The paper has highlighted the next generation instrumentation systems for use in tea manufacturing process. The requirements of small tea growers can be specifically met by environmentally controlled manufacturing machine proposed by the author which can be scaled as per the processing load. It can also serve the purpose of establishing optimal conditions even for large tea factories before being actually applied at commercial scale. The integrated processing feature of the machine provides greater flexibility to suit requirements for small as well as large tea estates.

The ultimate need for the optimal tea processing, however call for a variety of indicating instruments for measurement of conventional parameters (temperature, humidity, moisture etc.) as well as special measurements related to bio-chemical variables (caffiens, TF, TR, polyphenols etc) which describe the growth of the enzymatic reactions ultimately leading to healthy tea processing. Such gadgets have tremendous potential and will find wide acceptance for on-line assessment of different unit operations. Appropriate combination of sensors is also feasible to have assessment of flavour and taste. Electronic nose and electronic tongue are typical examples of convergence of technologies in the areas of sensor development, data acquisition modules, signal processing techniques and computer interfacing options. Efforts are being made to miniaturise the configuration for handy operation for quantification of quality. Computer vision backed up with bio-sensor array will lead towards purposeful electronic tea tasting devices. It is expected that such devices, although currently expensive, can be used at centralised testing labs where even small growers can take benefit for quality parameter measurements on a co-operative basis.

It is evident that scientific and engineering interventions can lead to a new concept of modern tea processing mechanisms applicable to both small and large tea manufacturing units.

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