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Design and Development of an Experimental Setup to Study Tea Withering Process with Special Emphasis to RH and Temperature

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Abstract—*In this paper, development of an instrumentation setup is reported for the study of tea withering process online. The parameters considered in this study are relative humidity (RH) and temperature at two different positions of the withering trough. Two sensor modules are installed to measure the temperature and relative humidity at the inlet and outlet of the airflow path. A load cell based weighing arrangement is also incorporated in the system for measuring the moisture loss in withering process by gravimetric method. A microcontroller based 10-bit resolution data acquisition system is incorporated to collect data in the process. Five sets of experiments are conducted and results are reported along with the correlation with the standard method of moisture loss i.e. gravimetric method or weight loss method. The observation shows a considerable change in the difference in variation of temperature and relative humidity at the inlet and outlet of airflow path in the withering trough during the process of withering. The design considerations of a scaled down prototype of a withering trough and the associated signal conditioning of the sensors are reported in the paper.*

1. INTRODUCTION

Tea is one of the most popular t beverages. Moisture measurement plays an important role in the manufacturing process of tea. The quality and durability of produced tea is highly dependent upon the proper level of moisture in the processing steps involved in the manufacturing of tea. The quality of intermediate processing depends not only on the moisture level of the current process, but also on the moisture levels of previous. Hence, it is very important to measure and maintain proper level of moisture content in tea manufacturing process.

Withering is the foundation for achieving quality in tea manufacture and the first processing step (in the factory) in which freshly plucked leaf is conditioned physically, as well as, chemically for subsequent processing stages. The chemical withering (starts immediately after plucking) contributes to the quality attributes of tea like the 'body' and 'flavour' [1]. The impact of withering in the quality of the final product is always an important aspect. Tombs K. I. & Mashingaidze A. reported the influence of withering, including leaf handling, on the manufacturing and quality of black teas [2]. Soheili-Fard Farshad et al. studied the impact of time in withering for some biochemical properties and sensory quality attribute in final product [3]. Baruah D. et al. reported that chemical wither for a longer period produces liquor with better flavor quality and fuller cup characters [4].Various biochemical processes that occurs during withering of black tea production is reported by Omiadze N. T. et al. [5].

The physical withering reduces the moisture content of the fresh leaf which ranges between 74% – 83% and correct withering is essential for quality, although, it has always been a difficult task to determine the end-point of withers. The physical withering also makes the leaf `flaccid' or `rubbery' which is essential for the subsequent steps of processing. The same reduction in moisture percentage and increase of flaccidity of leaf to the desired level can be achieved in a shorter period but a longer period is (normally takes about 12 – 16 hours) necessary for chemical wither. Therefore, physical wither is regulated at a slower rate, so as to reach the desired physical withering in the same interval as required for the chemical wither. The objectives are achieved by passing air through the leaves [1].

Due to various advantages, trough withering is the most popular system currently being used all over the world. The troughs are of two types – (a) Open trough and (b) Enclosed trough [6]. However, attempts are going on for improvement of trough such as one reported by Singh Divya et al. [7].

In withering process, the drying is accomplished by vaporizing the water (moisture) contained in the tea leaves; and to do this the latent heat of vaporization must be supplied. There are two important process-controlling factors that enter into the unit operation of drying:

a) Transfer of heat to provide the necessary latent heat of vaporization,

b) Movement of water or water vapours through the tea leaves and then away from it to effect separation of water from tea leaves.

The necessary latent heat of evaporation is achieved from the inlet temperature in the airflow path. The moving air carries the evaporated water towards the outlet of withering trough which comprises a higher level of RH compared to that of the inlet.

Drying starts from surface moisture and later on governed by diffusion or capillary movement explained by Geankplis [8]. Various attempts have been made to measure the percentage of wither and different techniques are reported. Bhuyan Manabendra developed a Computer-Based system for Monitoring and Control of the Withering Process in the Tea Industry using weight loss method. A representative section of the withering trough was used for the measurement [9]. Okamura Seichi et al. described a method for the measurement of moisture content (MC) in tea leaves using microwave transmission technique, where the ratio of change in amplitude and phase shift was used to determine the MC [10]. Hazarika D. et al. also developed a PC-based instrumentation system for the detection of MC of tea leaves at its final stage using capacitive fringe-field method [11]. Drying rate is an important factor in estimation of the withering of tea leaves. Ghodke et al. experimented and reported the drying curves of withering thin layer [12]. But in his experiment Relative Humidity (RH) was not mentioned. W. S. Botheju et al. showed that RH has a major impact on withering of tea leaves [13]. Chen Andrew et al. described a method to use Temperature and Humidity sensor for determining MC of Oolong Tea by Equilibrium Relative Humidity and Equilibrium Moisture Content [14].

To study the difference in variation of temperature and RH at inlet and outlet of airflow path in withering process a scaled down prototype of enclosed type trough is designed and developed. In the developed prototype, two sensor modules (each pair consists of a temperature and a relative humidity sensor) are incorporated to measure the temperature and RH (Relative Humidity). Two modules are placed at inlet and outlet of air flow path of the trough. Additionally, a load cell with proper signal conditioning and mechanical arrangement is also incorporated to obtain the weight loss of the tea leaves during withering. Using the developed instrumentation the variation and patterns of the effecting parameters are recorded for five sets of experiments. The experiments are conducted with constant airflow rate at ambient temperature and RH. The patterns of variation from obtained data from experiments are presented in comparison with the results obtained from gravimetric (weight loss) methods are reported.

2. SCALED DOWN PROTOTYPE OF THE TROUGH

The developed prototype with necessary arrangements is shown in Fig. 1. The prototype is equipped with the provision for measuring weight of loaded tea leaves along with the measurement facility for temperature and RH. The body of the prototype of enclosed type withering trough is designed using Perspex sheet, PVC (Polyvinyl Chloride) board, plastic and aluminum sheet. The bed (where tea leaves are loaded) of the trough is made of plastic net of grid size (5mm) attached to a small container of PVC so that the loaded leaves do not come into contact with the side walls of the trough which avoids the errors in the measurement of weight. The small container is placed on top of a load cell arrangement to measure the weight loss of loaded leaves during withering. Also the container is surrounded by an aluminum sheet to maximize the passage of the air though the loaded leaves. A fan is attached to blow air to carry out the withering process. Air flow occurs through circular holes (3cm diameter) at the inlet and outlet.

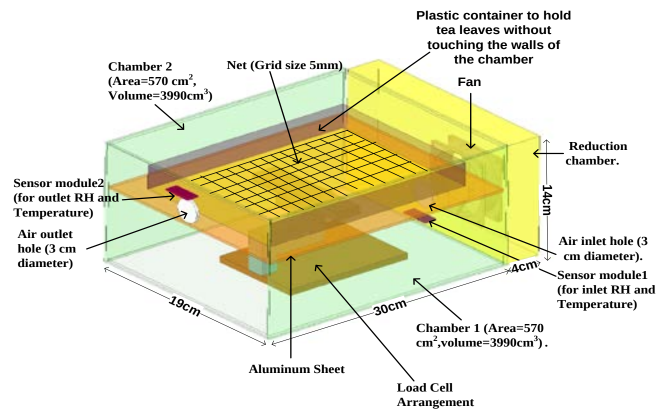

Fig. 1: Prototype of enclosed withering trough showing different parts

3. INSTRUMENTATION SYSTEM

The system is composed of two sensor modules and one load cell with signal conditioning circuits in association with microcontroller based data acquisition system. The system is connected to PC by RS485 communication to provide the facility for data logging. The block diagram of the system is shown in Fig. 2.

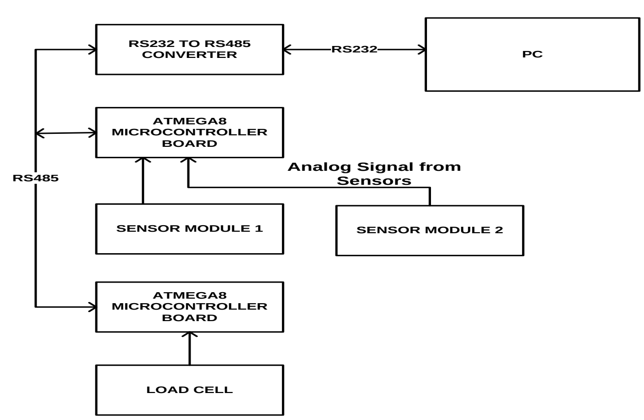

Fig. 2: Block diagram of Withering Trough Instrumentation

3.1 Sensor modules

The sensor modules are designed incorporating LM35C [15] temperature sensor and HIH5030 [16] humidity sensor. Since the output of HIH5030 depends on the supply voltage, precession reference voltage from MCP1541 [17] through buffer made of TLC272 [18] operational amplifier is used to provide the required supply voltage to the sensors. Precision Voltage Ref MCP1541 has output voltage of 4.096V with accuracy ±1% and ±50 ppm/°C temperature drift. The circuit schematic of a sensor module is shown in Fig. 3.

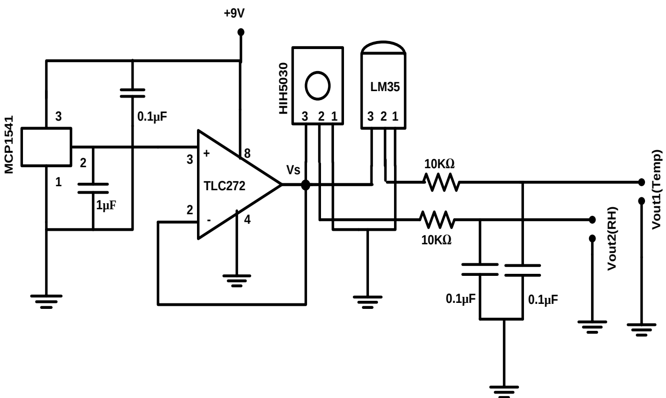

Fig. 3: Circuit schematic of sensor module.

The output voltage V_{out2} (RH) (Fig. 3) and RH is related by the following equation at 25ºC.

$$RH = \left[\frac{\frac{V_{out2}(RH)}{V_s} - 0.1515}{0.00636} \right] \% \tag{1}$$

The true *RH* requires temperature correction and is given by the following equation

$$True\ RH = \frac{RH}{(1.0546 - 0.00216\ T)} \% \tag{2}$$

Where, T is the measured temperature in ˚C.

The scale factor of temperature sensor is 10mV/ºC with an accuracy of 0.5ºC.

The Humidity sensor and temperature sensor are assembled close to each other to minimize the temperature gradient between them.

3.2 Load Cell Signal Conditioning and weighing arrangement

The signal conditioning circuit for the load cell (full bridge) is shown in Fig. 4. The circuit composed of LM336-2.5 [19] precision shunt diode, TLC272 operational amplifier and AD620 [20] instrumentation amplifier.

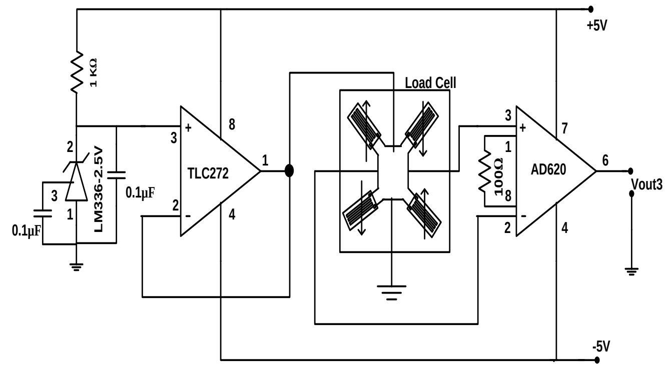

Fig. 4: Signal conditioning circuit for load cell

The precision 2.5V shunt regulator diode, LM336-2.5, gives 2.5V output with low temperature-coefficient and 0.2Ω dynamic impedance. TLC272, precision dual operational amplifier is configured as unity gain amplifier to drive the load cell. The bridge output is amplified by a high accuracy instrumentation amplifier, AD620 [20], where the voltage gain is set as 495 using a 100Ω precession resistor of 0.1% tolerance.

The system is calibrated by loading the arrangement by some known loads. The mass of the loads are measured by a balance (model no: AB54, make: Metler Toledo) prior to use in calibration. The output (V_{out3}) for different loads are measured using Digital Multi –Meter (Agilent, Model no: 34401A) and recorded. Using the data obtained for various loads, a linear fit calibration curve is obtained and is shown in Fig. 5.

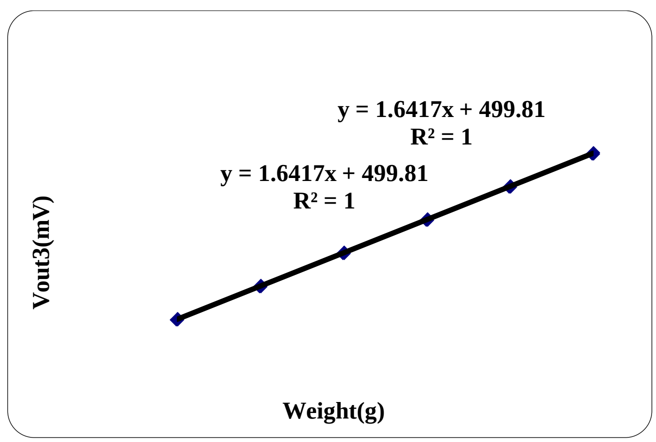

Fig. 5: Calibration of weighing system

The obtained linear fit equation is

$$y = 1.641x + 499.8 \tag{3}$$

Where, y is the output voltage of the weighing system in mV and x is the applied load in gram.

The sensitivity of the system is obtained as 1.641 mV/g.

The residual plot is shown in Fig. 6.

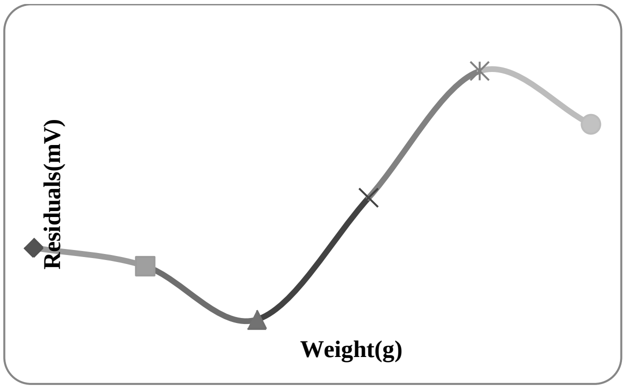

Fig. 6: Residual plot for weighing system calibration

3.3 Data Acquisition

The outputs of two pairs of sensors are connected to 4 channels of inbuilt ADC (Analog to digital converter) of an ATmega8 [21] microcontroller. The output voltage (Vout3) from the load cell signal conditioning circuit is connected to one ADC channel of another ATmega8 microcontroller. The two microcontrollers are connected to a PC (Personal Computer) by RS485 network. An algorithm is developed for reading the sensors, compensating the effect of temperature in RH measurement and finally sending the data to PC in proper format. The developed algorithm is implemented in ATmega8 microcontroller by writing suitable C-code in Atmel Studio4 IDE (Integrated Development Environment) [22]. The temperature compensation is done using the equation (1& 2). To log the received data in a PC, a program is developed in C language using Turbo C++ IDE. Data are stored in PC in .XLS format along with records of date and time. Fig. 7 & Fig. 8 show the flowchart of developed algorithms that are implemented in microcontroller and PC respectively.

The added network capability to the ATmega8 microcontroller boards enables the extensibility of the system to be used for more number of sensors in a bigger trough.

4. EXPERIMENTAL RESULTS

In the prototype of the trough, fresh tea leaves are loaded on the withering bed. The withering process was started by running the fan at a constant speed of air flow rate (AFR) of $0.25 m^3/s$. The process is continued at ambient temperature and RH. The data acquisition system is employed to record the data continuously at an interval of 7 seconds for all the sensors (including load cell) along with the records of date and time.

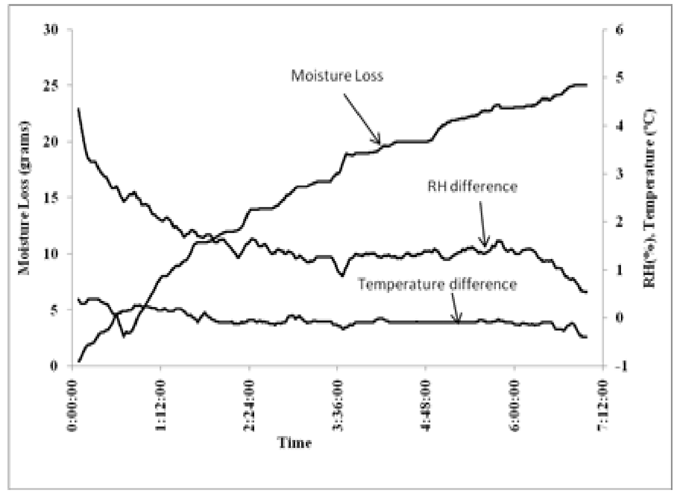

Fig. 7: Test 1 shows the moisture loss obtained from gravimetric method and difference of RH and Temperature at inlet and outlet of airflow path of the withering trough.

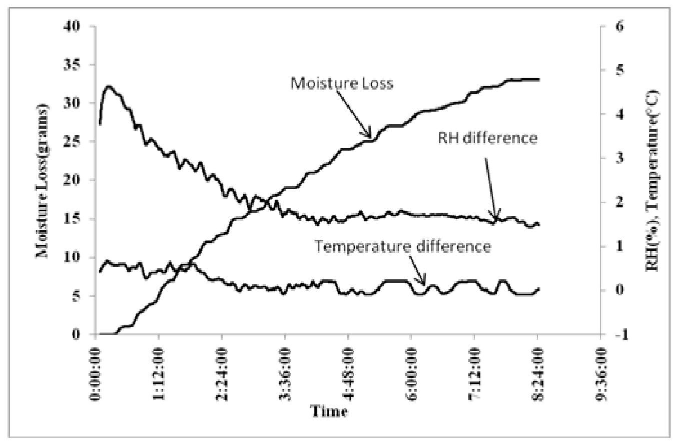

Fig. 8: Test 2 shows the moisture loss obtained from gravimetric method and difference of RH and Temperature at inlet and outlet of airflow path of the withering trough.

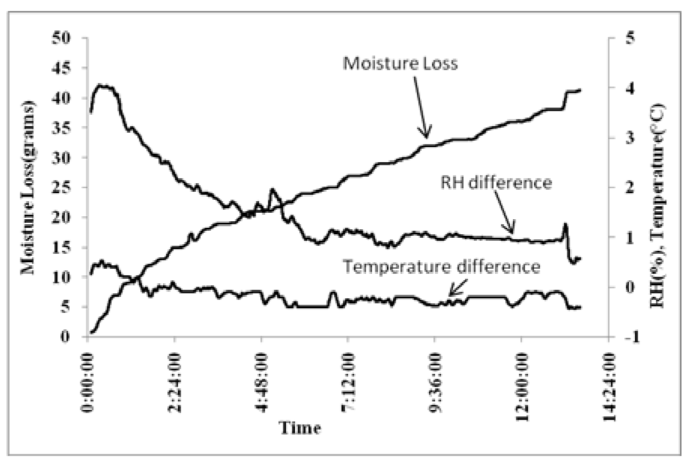

Fig. 9: Test 3 shows the Moisture loss obtained from weight loss method and difference of RH and Temperature at inlet and outlet of airflow path of the withering trough

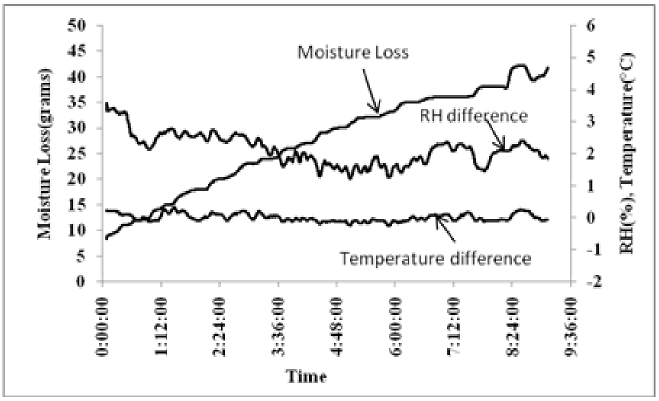

Fig. 10: Test 4 shows the Moisture loss obtained from weight loss method and difference of RH and Temperature at inlet and outlet of airflow path of the withering trough.

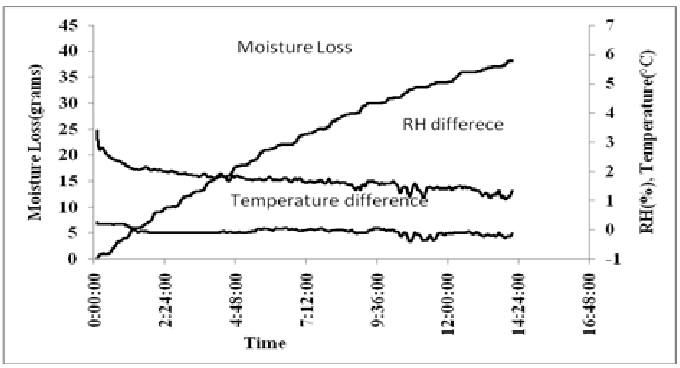

Fig. 11: Test 5 shows the Moisture loss obtained from weight loss method and difference of RH and Temperature at inlet and outlet of airflow path of the withering trough.

Experimental results are shown in table 1.

Table 1

Experiment No.	Loaded leaf weight (grams)	Withering time (hh.mm)	Maximum RH difference	Minimum RH difference	Moisture loss (grams)
1	76	7	5.1%	0.5 %	25
2	89	8.30	4.8%	1.2 %	33
3	89	13.30	4.2%	0.3 %	42
4	103	9.05	5.5%	1.7 %	42
5	113	14.10	6.3%	0.8 %	39

In all these experiments temperature at inlet is higher compared to outlet by 0.7˚C (±0.1˚C) and outlet temperature gradually increases and becomes higher than the inlet by 0.4˚C (±1˚C).

At the initial stage of withering process the difference of RH at outlet and inlet is less and even sometimes inlet RH is more compared to outlet RH. This is due to the random distribution of moisture in the surroundings of the bed and accumulation of moisture in the chamber of withering trough. After the removal of accumulated moisture from the trough chamber the actual withering starts. It takes around 10 munities to remove the accumulated moisture from the chamber.

5. CONCLUSION AND DISCUSSION

The developed instrumentation for the measurement of RH and temperature are designed as modular nodes. The network capalility of the nodes provide extensibility and applicability of the system in an actual trough. There is also possibility to conFig. the nodes as smart sensors.

Five experiments are carried out in a scaled down prototype of actual withering trough and in one directional airflow path i.e. one dimensional mass flow. The experimental results show that RH at the outlet is more compared to inlet in the air flow path. That means the moving air carries the moisture from tea leaves towards the outlet. Again the temperature at outlet is less compared to the inlet of airflow path in all the five experiments.

Since a considerable diference in RH and temperature is obtained at the inlet and outlet of the airflow path, from further investigation moisture loss can be measured from the measurement of RH and temperature at the inlet and outlet. Again proper investigation of theoretical approach or employment of soft computing tool can give better prediction of moisture loss in the witherng process. For implementing the system in factory, consideration of some new parameters may be necessary.

Since online monitoring of moisture loss in withering is always been a problem in withering process. The developd system can provide a solution for the problem, that usually faced by the tea factory, with out disturbing the current setup of withering troughs.

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