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Onion Drying Using Catalytic Infrared Dryer

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Summary

This research studied the drying and quality characteristics of onion and examined possible advantages of infrared drying. Drying rate, pungency retention, color change, and microbial load reductions were among the characteristics studied.

High-solids onions sliced to 2.5mm thick were dehydrated under three conditions: catalytic infrared (CIR) heating with and without air recirculation, and forced air convection (FAC) heating. The drying and quality characteristics of the onion slices were studied at three drying temperatures -- 60, 70 and 80°C -- for each drying condition. The drying temperatures were product temperature for CIR drying and air temperature for FAC drying. Loading rate was kept constant at 2.5 kg/m^2, and air velocity for the FAC and CIR-recirculation was set at 0.5 m/s. The drying and quality characteristics of CIR and FAC dried onions were compared.

It was found that CIR drying, both with and without air recirculation, had a higher maximum drying rate, shorter drying time to reach required moisture, and greater drying constants than FAC drying.

Air recirculation in CIR drying slightly reduced the drying rate, due to the cooling effect of the air recirculation. Drying curve plots showed nearly immediate entrance into the falling rate period for CIR samples, with the exception of the 80°C CIR test, which had a short constant rate period. The drying curve of FAC drying had both constant and falling rate periods. CIR drying had a higher drying rate than FAC drying before the moisture content reached 50% (dry basis). At drying temperatures of 60°C and 70°C the pungency degradations were similar for both the drying methods. But pyruvate content in 80°C CIR-dried onion was reduced rapidly near the end of drying. To have a product with white color using CIR drying it is recommended to dry the product at a mild temperature, such as 70°C, to take advantage of higher drying rate than 60°C drying and lower browning than 80°C drying. Microbial load tests showed little difference in aerobic plate counts (TSA agar) for any of the drying methods. Coliform counts, although insignificant, were slightly lower in CIR-dried samples, which also had significant reductions of mold and yeast compared to the FAC-dried samples. The laboratory CIR setup was too small to yield meaningful energy-efficiency figures, and this was not measured.

In general, catalytic infrared drying is more effective for onion drying than forced air convection drying. The recommended product temperature for CIR drying is 70°C and 80°C. 80°C should be used at the beginning of drying to achieve maximum drying rates while product degradation is minimal. If a combined IR/Convection drying system is used, it is recommended to use CIR drying in the early stage and FAC drying in the latter stage. For existing facilities, CIR drying could be added at the front of the current convection drying to take advantage of the high drying rate of IR and improve the overall rate.

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2.1. Objectives

Since catalytic infrared (CIR) heating technology has not yet been applied to onion dehydration in the food industry, the ultimate objective of this research is to explore the potential of its use in onion dehydration. The specific objectives of this research were:

1. Compare the drying characteristics of sliced onions dried by CIR and forced air convention (FAC) drying methods with various drying conditions.
2. Determine the pungency and color changes in dried onions produced by the two drying methods.
3. Determine the reductions in microbial loads of dried onion samples produced by the two drying methods.

2.2. Materials and Methods

2.2.1 Materials

Onions (Allium cepa var. Southport White Globe) produced in central California were used for this study. All onions were supplied by Gilroy Foods Inc. (Gilroy, CA) and were representative of onions used in their commercial operation for the 2003-2004 seasons. Onion diameter at the equator ranged between 40-70 mm. Solids content ranged from 24.3% to 29.3%.

2.2.2 Sample preparation

To achieve consistent composition of onion slices, onion was cleaned by removing the top and bottom along with the outer dry layers and first fleshy layer which accounted for about 20% of the onion. Roots, stems and outer dry layers of the onions have a lower moisture content, more microbial contamination, and greater variation in flavor components than inner sections of the bulb (ADOGA, 1997; Bacon et al., 1999). Cleaned onions were sliced perpendicular to the axis into pieces 2.5±0.2 mm thick using a 1/3 HP Hobart industrial food slicer (Troy, OH). This slice thickness was chosen based on the thickness used by commercial dehydrators. Furthermore, the literature also showed that thick slices did not offer any benefits in onion drying (Elustondo et al., 1996; Akbari and Patel, 2003). The slices with the perpendicular cutting could have higher drying rate due to the greater area for moisture removal than the parallel cutting (Elustondo et al., 1996; Markowski, 1998). The slices were maintained intact in all drying experiments except for pungency and microbial reduction tests in which the slices were broken apart into individual rings. Intact rings facilitated arrangement of a single layer during the drying experiments while broken apart rings were needed to obtain a homogeneous sample which is important to accurately determine the pungency and microbial reduction.

2.2.3 CIR dryer setup

The catalytic infrared (CIR) dryer arrangement (Fig. 2.1 and Fig. B1) consisted of a drying chamber (95 x 65 x 65 cm) with an CIR emitter (Catalytic Drying Technologies LLC., Independence, KS) mounted from the top of the chamber. The sample was placed on a drying tray (84 x 53 cm) which consisted of a fine mesh aluminum screen stretched across a strip steel frame. An aluminum wave guide (48 x 30 cm, upper rim; 42 x 22 cm, base perimeter) rested on top of the drying tray and surrounded the product. A balance (Ohaus Adventurer Pro; 8kg capacity, 0.1g accuracy) was placed beneath the drying tray and measured product weight over drying time. The balance was connected to a PC via a RS232 connection and a tarred weight was recorded using Window's Hyper Terminal. An insulating cover was made to protect the balance and cables as well as to minimize any drifting caused by high temperatures. A 1/100 HP exhaust fan (Dayton Electric Mnfg., Niles, IL) located on the top of the drying chamber was used to remove air from the drying chamber. Two 1/10 HP air recirculation fans (Dayton Electric Mnfg., Niles, IL) mounted on each lateral side of the dryer were used for the warm air recirculation. They pulled air from the top of the drying chamber and fed it back into the chamber through slits running the entire length of the drying chamber.

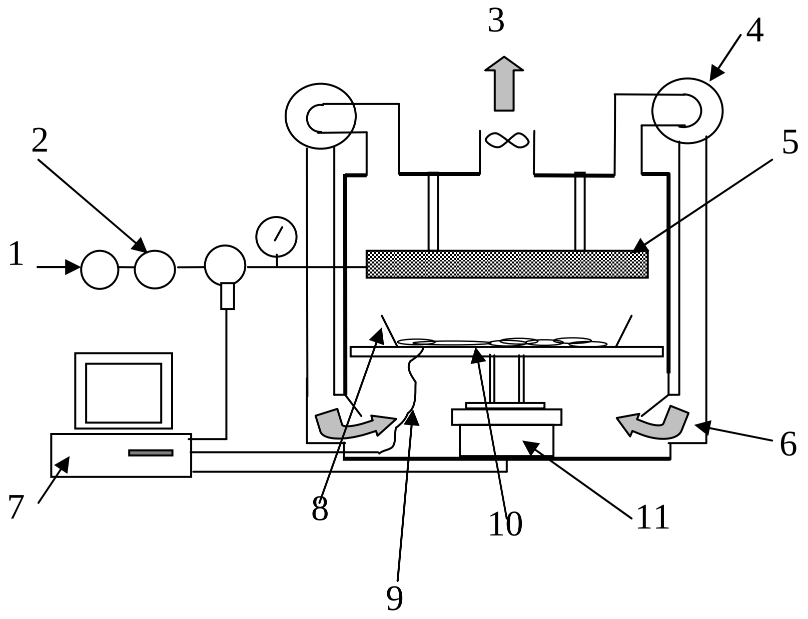


Fig. 2.1. CIR Dryer: 1- Natural Gas; 2-Gas Flow Control; 3-Exhaust; 4-Blower; 5-CIR Emitter; 6-Recirculation Air; 7-Computer Controller; 8-Wave Guide; 9-Thermocouple, 10-Onion Sample; 11-Balance.

The CIR emitter was preheated by an electric element located inside the emitter. The natural gas intake was regulated by a gas control valve controlled by the computer system. The thermocouples and balance inputs were processed by using a data acquisition system consisting of a personal computer with Test Point software (Capitol Equipment, Bedford, NH). All of the dryer inputs and outputs were connected to the data acquisition system with a multichannel board (PD-STP-9616, United Electric Industries, Boston, MS) and an A/D converter which interfaced to the computer via a PCI card. Two type T thermocouples were used to measure the product temperature. These thermocouples were placed randomly inside the innermost 10 cm^2 of the onion bed. The average temperature was used as input to control the product temperature by turning the emitter on and off which was achieved by opening and closing the gas supply valve of the emitter. For the off cycles the electric element was turned on to ensure that the emitter temperature remained high enough for catalytic reaction. The exhaust fan and the recirculation fans were also controlled via the computer. The graphic user interface for the control system can be seen in Fig. B2 in Appendix B.

2.2.4 FAC dryer setup

The forced air convection (FAC) dryer used in the tests was an electrically heated column dryer with diameter of 33 cm. A fan powered by a ¾ HP permanent magnet DC motor (Dayton Electric Mnfg., Niles, IL) blown air through an electric coil heater and then through the column. The on and off cycles of the electric heating coils were controlled automatically by the computer to maintain the set temperature. The fan speed could be adjusted manually to achieve desired air velocity. The air velocity for all of the tests was set at 0.5 m/s.

Product was placed in a circular mesh tray near the bottom of the column and suspended by wires to the Ohaus balance to record product weight change. The temperature of heated air was controlled by the same computer setup as the IR dryer using a type T thermocouple to measure the temperature of the air before it reached the product.

2.2.5 Moisture content determination

Fresh and dried onion samples of 10 – 15 g were placed in pre-weighted aluminum weighing dishes and dried according to ADOGA Official Standards and Methods (1997) (70°C for 6 h at 26.1 Hg vacuum) in a Thelco 29 vacuum oven (Precision Scientific, Chicago, IL). Dishes were removed and placed immediately in a desicattor to allow temperature to equilibrate before weighing. The balance used for the scale was with accuracy of 0.01 g. All moisture measurements for each trial were duplicated and reported as dry basis unless specified otherwise.

2.2.6 CIR drying temperature control trials

Experiments were performed to determine which heating regimen, continuous, fixed intermittent or variable cycle heating would work best for our experiments. From the data collected it was possible to determine which heating method could attain the set temperature the quickest and which would give the greatest drying advantage. Additionally, these trials tested the performance of variable cycle heating based on product temperature, a practice which is not commonly used. Although no quality tests were performed on samples dried in these trials notes were taken on appearance (brown or burned) of the final product.

For CIR drying trials, a 50 g sample of prepared onion slices was uniformly placed in the center of the mesh drying rack. The distance from the emitter to drying tray was set at 15 cm. Two thermocouples were randomly inserted into the sample from the underside of the slice. The head of the thermocouple was just beneath the opposite or top surface. The drying tray was placed into the preheated CIR dryer and an average temperature of the two thermocouples was recorded over the drying time period. The trials were conducted for continuous heating, fixed intermittent heating of 30 sec on and 30 sec off, and variable heating cycle with fixed product temperature.

Continuous heating was performed until product was burned and rendered unusable as a food product. The intermittent heating with 30 sec on/off cycle was controlled using the PC control system. The heating with variable cycle was also controlled by using the PC control system based on the product temperature. The trials were conducted for set product temperatures of 60, 70 and 80°C. The constant product temperatures were achieved by opening and closing the gas supply valve to control the gas supply to the emitter.

2.2.7 Drying trials

2.2.7.1 CIR drying

A 250 g onion sample of intact slices was arranged in a single layer on the drying tray within the confines of the waveguide at a loading rate of 2.5 kg/m^2. The drying tray was placed in the preheated CIR drying cabinet and the thermocouples were positioned. Distance between the emitter and drying tray was 15 cm. Emitter cycle was programmed for the set product temperature. The drying tests were conducted with and without air recirculation at three temperatures as follows:
CIR 60°C-Recirculation
CIR 60°C
CIR 70°C-Recirculation
CIR 70°C
CIR 80°C-Recirculation
CIR 80°C

Test with air recirculation had both the lateral recirculation fans on during the entire test. Average air velocity, measured using a hot-wire anemometer, was 0.5 m/s. Fans were manually switched off for 30 seconds at random intervals during the drying process to record the actual weight of the product to avoid the lift effect incurred by the recirculation air. Weight data was later corrected for the lift and noise. Onion weight and temperature were recorded every 6 seconds with the aforementioned data acquisition and control system.

Targeted final MC of the dried onion was set at about 10% (db) in this study. The final weight of dried onion sample was determined based on the initial and final MC and initial sample weight. Upon reaching the targeted product weight the product was removed and two 4-5 g samples were collected and used to determine the final MC of the product. The remaining product was sealed in zip-top bags and used for color tests.

The MC was calculated using equation (1)

$$MC_{(\%db)} = \left(\frac{x_i - x_s}{x_s} \right) \times 100 \qquad (1)$$

where x_i is the weight of the onion at any given time (i) and x_s is the weight of the solids of the onion sample. To minimize the effect of non-uniformity effect of onion sample on the MC results, the MC at any giving drying time was calculated as an average of results from two different calculation methods. One was based on the initial MC of fresh onion and the other one was based on the final moisture content of dried onion. The average MC was reported and used for other related calculation in this study. The Experiments were conducted at least duplicates.

2.2.7.2 FAC drying

For FAC drying tests, a 150 g onion sample of intact slices was used and arranged on the circular drying basket at a loading rate of 2.5 kg/m^2. The basket was lowered into the preheated FAC dryer's column to begin the test with air velocity maintained at 0.5 m/s. The weigh changes of the sample were recorded every 60 sec. Similar to the CIR drying, the blower was switched off occasionally for a short time to obtained the true sample weight by avoiding the effect of air lifting. The experiments were conducted in duplicates with 60, 70 and 80°C of product temperatures. The same average MC calculation method used in the CIR drying was also used in these tests.

2.2.8 Drying kinetics

2.2.8.1 Drying rate

Drying rate was calculated in gram of moisture loss per kg of initial weight of onion sample per minute (g/$\text{kg}_{\text{initial weight}}$ *min). Only MC data at every minute increment was used for the calculation of drying rate. Difference in weight (g) over difference in time (min) was calculated and then multiplied by a factor of 4 for CIR and 6.66 for FAC to obtain the initial weight basis as 1 kg since CIR test used 250g and FAC tests used 150g.

2.2.8.2 Drying Models

Modeling the drying process is important for characterizing the processes with different drying methods and conditions. Two models, the exponential and Page models, were chosen to describe the drying process since they have been widely used in drying modeling. Model curves were fitted to the experimental data and the performance of the model was determined by the correlation coefficient (R^2). A greater correlation coefficient means a better fitting of the model.

<u>Exponential model</u>

One of the most basic models used to describe moisture loss during the drying process is a simple exponential model:

$$\frac{dM}{dt} = \alpha\left(M - M_e\right) \tag{2}$$

This can further be integrated to the following equation:

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp\left[-kt\right] \tag{3}$$

where MR is the moisture ratio; M is the moisture content (% db) at any given time during drying; M_0 is the initial moisture content; Me is the equilibrium moisture content; *k* is the drying constant (hr^{-1}); and *t* is time in hours. This model assumes negligible internal resistance and considers only the resistance concentrated at the surface of the material (Afzal and Abe, 1997). The exponential model, equation (3), is a simple lumped model often used to describe mass transfer in thin layer drying (Wang, 2002). This model was used because of its simplicity, high correlation to most drying data, and common use in literature. Drying constant, k (h^{-1}), can be calculated by using the model.

Moisture ratio (MR) was determined using the moisture content data collected in the drying experiments. Since none of the tests were dried to equilibrium moisture content, the equilibrium moisture was estimated from findings in literature. A fixed EMC of 4% (db) was used which was in the range of 2.1-4.4% EMC reported by Wang (2002). MR was plotted on semi-logarithmic axis versus the time (hr) and the slope of the fitting line was the constant k. Correlation coefficients, means, and standard deviations were also calculated for all 9 drying conditions.

<u>Page equation</u>

Page (1949) modified the exponential model to include and additional exponent:

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp\left[-Kt^N\right] \tag{4}$$

where K is an empirical drying constant (hr^{-1}); and N is an empirical drying exponent. It has been used extensively in thin layer drying of paddy rice and other grains and can be used in many thin-layer drying applications (Afzal and Abe, 1997). The model was used in the study because of its simplicity and frequent use in literature.

The Page equation can be adapted from equation (4) as follows:

$$\ln\left[\frac{M - M_e}{M_0 - M_e}\right] = -Kt^N = y(t) \tag{5}$$

This may then be rearranged to read:

$$\ln[-y(t)] = \ln(K) + N\ln(t) \tag{6}$$

The slope of linear curve of a plot of ln[-y(t)] versus ln(t) was the value N and the exponential of the y intercept as the value of K (Singh and Erdogdu, 2004). Again, the EMC was assumed as 4% MC (db). Correlation coefficients, means, and standard deviations were also calculated for all 9 drying conditions.

2.2.9 Quality tests

2.2.9.1 Pungency degradation tests

To measure the pungency of dried products, four sliced onion samples, 40 g in each tray were dried in batches. Trays were removed at different times during drying. The times were 10, 20, 30, and 40 minutes for 80°C experiments; 10, 20, 40, and 60 minutes for 70°C experiments; and 30, 60, 120, and 180 minutes for 60°C experiments. After removal the sample weight was measured and corresponding moisture content was calculated. Deionized water was added to the dried products until the total weight of water plus product was 90±1 g. Samples were allowed to rehydrate for 5 min and then homogenized for 30 sec at 7,000 RPMs followed by another 30 sec at 10,000 RPMs using a hand-held Bahmix Bio-Mixer Homogenizer (Bartlesville, OK). Slurries were allowed to sit for 30 min for enzymatic formation of pyruvate.

Pungency was measured using a chemical pyruvic acid assay outlined by Anthon and Barrett (2003). Onion slurries were filtered thru two layers of cheese cloth and 25 µl of the filtrate was added to a 13 mm x 100 mm test tube using an Eppendorf pipette (Westbury, NY). Then 1.0 ml of deionized water and 1.0 ml of 0.25 g l^{-1} DNPH in 1M HCL were added to the solution. The sample solution was placed in a 37°C water bath for 10 min. After removal from the water bath 1.0 ml of 1.5M NaOH was added and the test tube was vortexed for 10 sec. Absorbance of the liquid at 515 nm was measured on a Beckman DU 7500 spectrophotometer. To measure the inherent, non-enzymatically formed pyruvate a fresh 40g sample was heated in an 800 W microwave oven (Sharp R-209HK) for 1 min and then analyzed using the above assay. The standard was prepared by adding 25 µl of sodium pyruvate solutions in concentrations of 0, 2, 4 and 8 mM instead of the onion filtrate.

The enzymatically formed pyruvate was the difference of the amount of total pyruvate and the non-enzymatically formed pyruvate. The results are reported as percentage loss in pungency from a fresh onion sample at various moisture contents. Duplicate tests were performed at each drying temperature

2.2.9.2 Color change tests

Dried onion samples from the drying rate trials were milled for 3 min in a ¼ HP Stein Mill (Hoffman Mnfg., Albany, OR). L.a.b. color measurements were performed using a Minolta CM-508 spectrophotometer. Saran plastic wrap covered the lens of the spectrophotometer and a 1.5 cm thick onion powder sample was placed directly on the warp surface completely covering the lens. The color values were average values of 5 readings of each sample measured.

2.2.9.3 Microbial load reduction tests

Experiments were performed to quantify the effect of the drying method and drying temperature on reducing specific microbial population during the drying process. Three media were used to examine the impact of drying on different groups of microorganisms. Tryptic Soy Agar was used to determine the aerobic plate counts, also known as standard plate count or total plate count. Aerobic plate counts enumerate mesophillic bacteria which grow aerobically and are used as a general indicator of bacteria growth (Morton, 2001). Dicholroan Rose Bengal Chloramphenicaol agar (DRBC) was used to enumerate yeast and mold populations. Yeast and mold counts are not accounted for in the aerobic plate counts because they grow too slowly. The last media was Coliform Petrifilms used to enumerate coliforms. Coliforms are index organisms which can indicate the increased chances of pathogenic contamination (Kornacki and Johnson, 2001). Coliform measurements are important for onions since they are grown in contact with potentially contaminated soil.

To measure the effect of drying on microbial load reduction, fresh onion sample was well mixed and then divided into seven 50 g experimental samples. The six of the samples were randomly chosen and dried with both CIR and FAC at three different temperatures, 60, 70 and 80°C. Each the sample was placed on a 70% EtOH sterilized aluminum mesh drying tray (12 x 10 cm) for drying. The samples along with the tray were removed periodically and weighed until they reached a calculated 10% MC. Sterilized tweezers were used to place 10 g of the dried onion sample into a stomacher bag. The bags were sealed and samples were stored for 5 days before performing the plate count test. The fresh sample was stored in the same way.

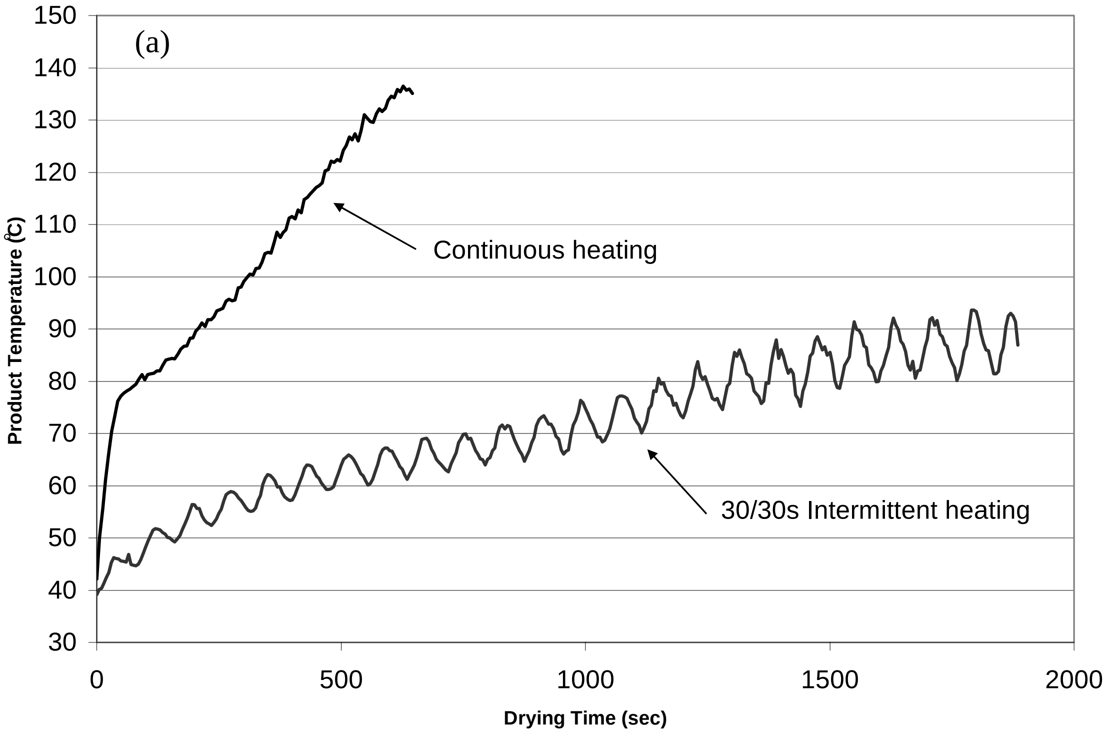
A 90 ml Butterfields buffer dilution blank was added to the stomacher bag and mixed to contact the entire onion sample. The bags were placed in a refrigerator (4°C) for 10 min to allow for rehydration and then stomached for 1 min before serial dilutions were made from the contents in sterile 9 ml peptone water dilution blanks. The dilutions were vortexed for 10 sec and then 0.1 ml were spread plated on Tryptic Soy Agar (TSA) and DRBC agar plates. Additionally, 1 ml of each dilution was added to 3M Coliform Petrifilms (St. Paul, MN). Duplicates of each dilution were made. TSA and Coliform Petrifilms were incubated at 35°C for 24± 2 h. DRBC were left at room temperature for 5 days. The plates were enumerated after incubation and results are recorded as Colony Forming Unit (CFU)/ sample. The microbial load test was performed in duplicate.

2.3. Results and Discussions

2.3.1.1 Product temperature changes with different heating modes

Three drying schematics were tested, namely continuous heating, intermittent heating, and variable heating based on product temperature. Continuous heating allowed for rapid achievement of high temperatures but caused significant undesirable quality changes in the product. The intermittent heating resulted in low heating rate of the product at the beginning of drying, but the product temperature continued to increase throughout drying. Variable heating used the product temperature as heating control input showed rapid temperature increases at the beginning of heating but maintained the set temperature once it was achieved.

Continuous heating of the infrared caused a rapid increase in temperature of onion sample until approximately 75°C when the increase became more gradual (Fig. 2.2a). The change in the rate of temperature increase could be caused by achievement of the critical moisture content or a change in the thermal properties of the sample due to moisture loss. The product reached a temperature of 136.5°C after 627 sec of heating. At this point the product was completely burnt and temperatures might have continued to increase if heating continued. Continuous heating provides the greatest amount of heat flux to the product. It could be used in the initial stages of drying to bring the product to a desired temperature to achieve high drying rates. But the maximum temperature must be carefully controlled to avoid excessive quality deterioration caused by high temperature.



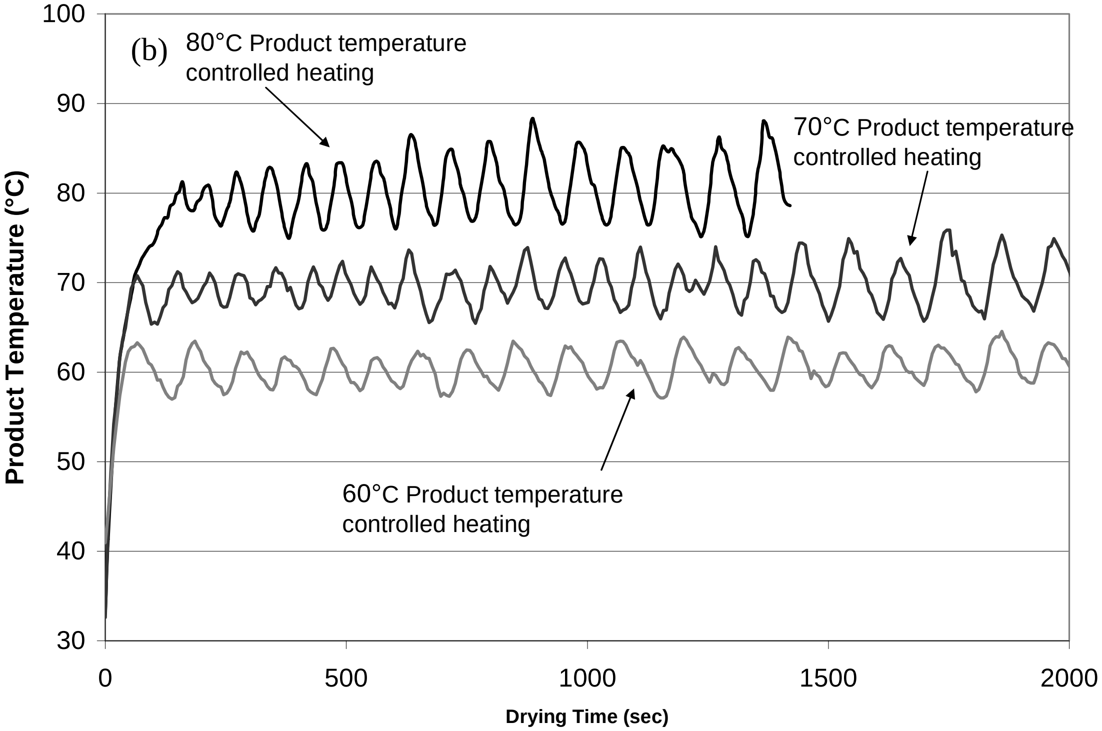


Fig. 2.2. (a) Product temperatures during continuous heating and 30 sec on / 30 sec off intermittent heating, (b) Variable heating based on product temperature for 60, 70 and 80°C.

In convection drying, stage heating is typically used to achieve high drying rate and quality product by using high drying temperature in the initial drying stage and low drying temperature in latter stage. Similar approach can also be adopted in infrared drying by using high energy intensity in the early drying stages. If only continuous heating is desirable to be used, low energy flux heating should be used in the latter drying stage. The low energy flux can be achieved by increasing the distance between the emitter and product, decreasing fuel supplied to the emitter, or using low capacity emitters. In general, continuous infrared heating may not be desirable especially for high intensity drying, because the product temperature could reach beyond the desired value causing quality deterioration.

The 30 sec on/off cycle test showed a gradual increase in temperature as the test progressed. Obviously, the intermittent heating significantly reduced the heating rate compared to the continuous heating. Normally this is not desirable because it took much longer time to bring the product to required temperature in the early drying stage. Also, the temperature continued to rise at the latter stages of drying in this test, which could lead to product degeneration. If the off cycle time is increased, the temperature in the latter drying stage may increase less compared with the current setting, but the total drying time could be increased.

Fig. 2.2b shows the product temperature profiles obtained with variable heating cycles, which were achieved based on preset product temperatures. The magnitude of the variation of the product temperature increased as drying progressed. This can be attributed to decreased specific heat caused by reduced moisture content in the product. Lower specific heat in the product meant that product temperature was more sensitive to the emitter on and off. The product temperature increased more at low moisture than at high moisture when the similar amount of residual heat from the emitter was released to the product after the emitter was turned off. Even though the fixed or set intermittent heating has more advantages than continuous heating, it is difficult to determine appropriate on and off cycle time. If variable heating cycles are used based on desired product temperature, high drying rate and better product quality could be achieved.

The product temperature increased rapidly during the first minute of heating like that obtained with continuous heating. The was no significant slow down in temperature increase for the 60°C and 70°C heating tests before the products reached the set temperature and heating started to cycle on and off. The 80°C heating test exhibited the similar temperature profiles like that from the continuous heating before reaching the set temperature. The increase rate of product temperature decreased at approximately 72°C.

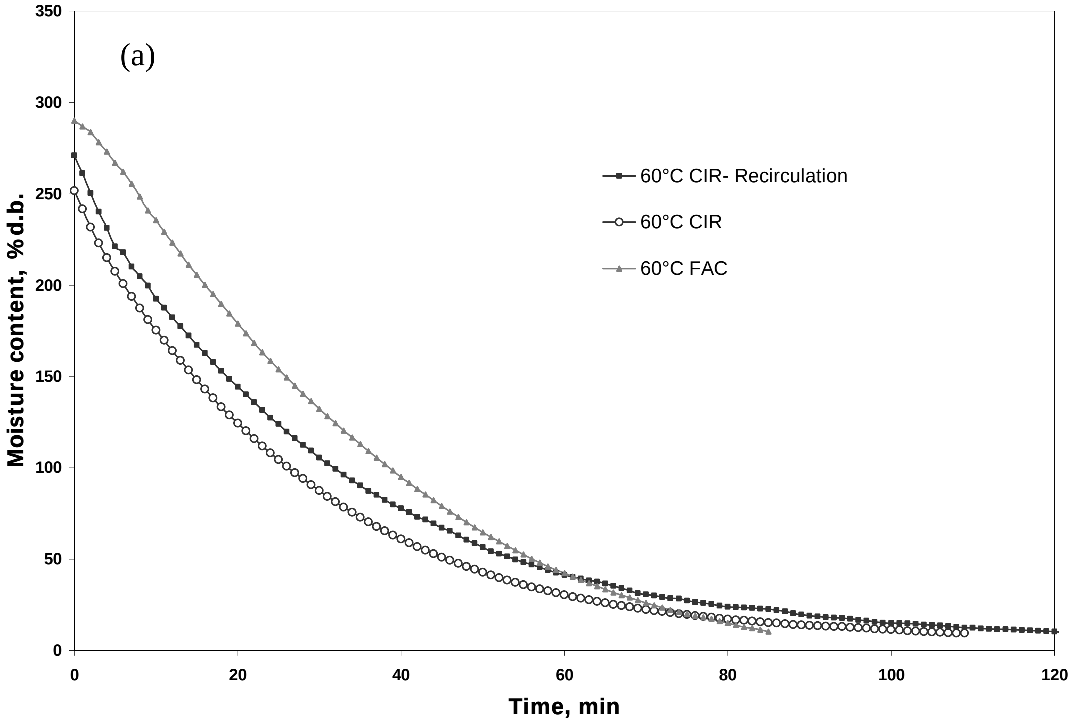
The use of product temperature controlled heating had high heating rate at the beginning of drying and stable maximum product temperature at the later drying state which could reduce the deterioration caused by the high temperature of continuous heating. This is in accordance to the conclusions made by Sandu (1986) that energy input should be greater at the beginning of drying and then have alternating periods of radiation and pauses. As a result of these findings the product temperature controlled heating or variable heating was used in the onion quality tests with the CIR dryer.

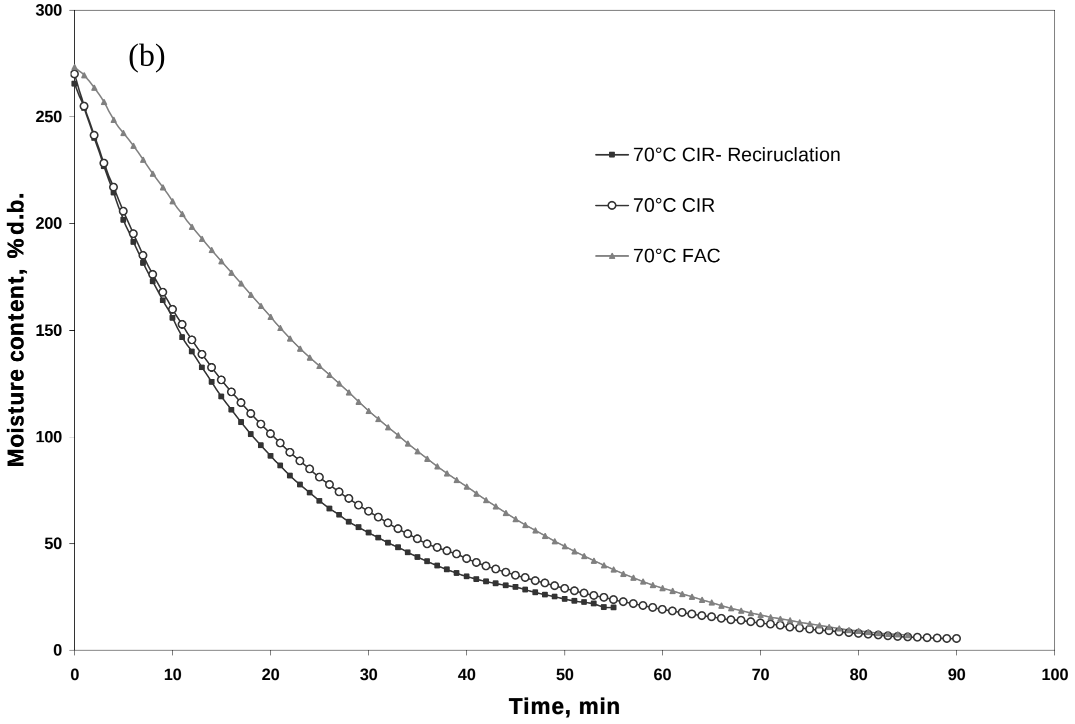
2.3.2 Drying rates and kinetics

2.3.2.1 Drying rates

The relationships between the moisture content and time at various drying conditions are shown in Fig. 2.3 and Table B1. The moisture content decreased rapidly in the early drying stage when the CIR drying was used compared with FAC drying. For the FAC drying the plots appeared to be more linear representing a consistent removal of moisture during the drying process. It is apparent that the greater drying rate was obtained with FAC than CIR at the latter stage of drying, especially for 80°C. The drying times in these trials represented the thin-layer drying. Commercial FAC drying normally has greater loading rates and thicker drying beds than that obtained in this study. It is apparent that air recirculation in the CIR drying caused longer drying times, especially for the 60°C and 80°C trials. Recirculation air had an evaporative cooling effect which decreased the drying rate and increased drying time, which has been reported by Sandu (1986) and Paakkonen et al. (1999).

When the drying rates were calculated and plotted against moisture content, it can be seen that for each of the three drying temperatures the CIR tests showed much higher drying rates than the FAC drying before the MC reaching 50% (Fig. 2.4). Increasing the drying temperature in the CIR drying trials increased the drying rate. However, the effect or air temperature in FAC drying on drying rate was less significant than the effect of temperature of product in CIR drying. This is more apparent in comparing the maximum drying rates of all the trials.


(a)
60°C CIR- Recirculation
60°C CIR
60°C FAC
Moisture content, %d.b.
Time, min
0
50
100
150
200
250
300
350
0
20
40
60
80
100
120


(b)
70°C CIR- Reciruclation
70°C CIR
70°C FAC
Moisture content, %d.b.
Time, min
0
50
100
150
200
250
300
0
10
20
30
40
50
60
70
80
90
100

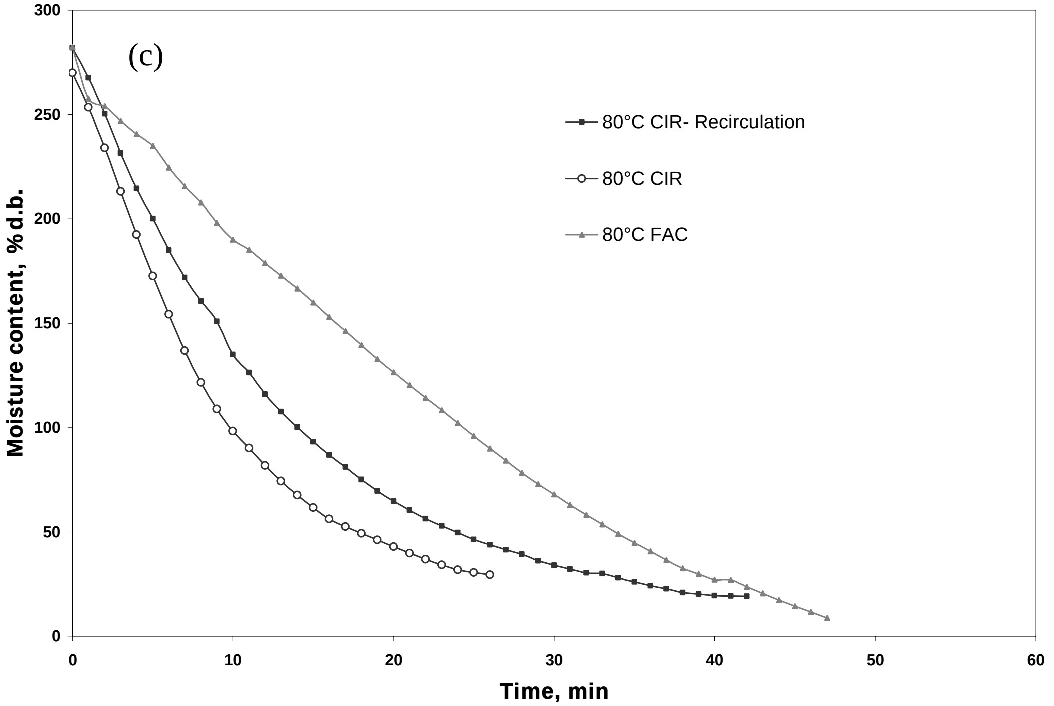
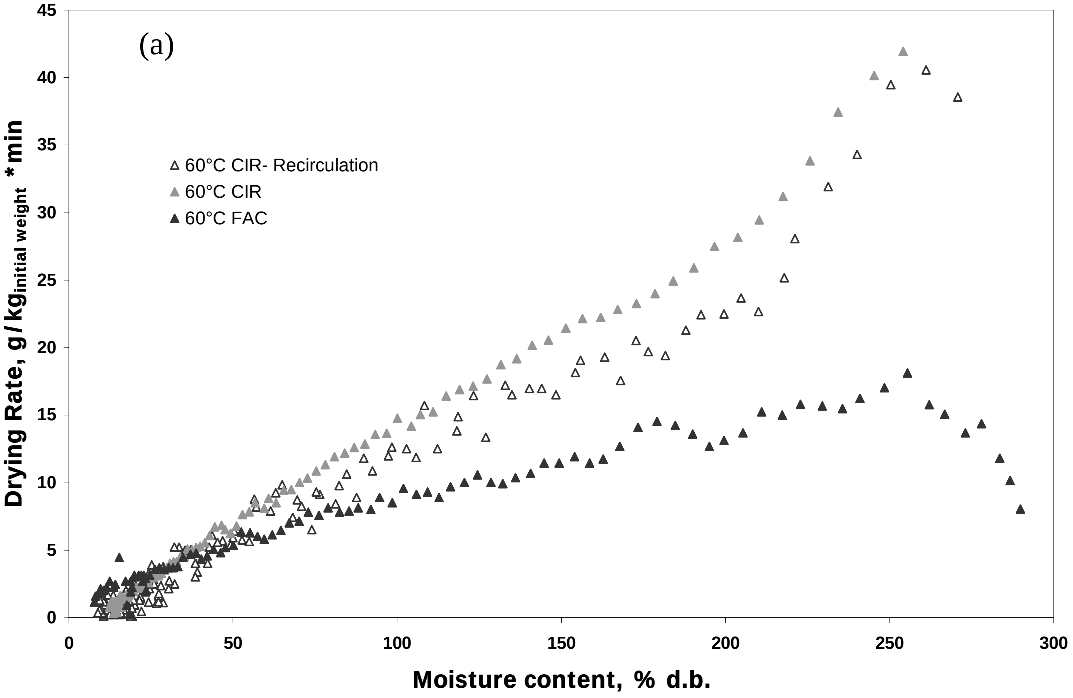


Fig. 2.3. Onion moisture changes during drying with different methods and conditions at drying different temperatures, (a) 60°C, (b) 70°C, and (c) 80°C.



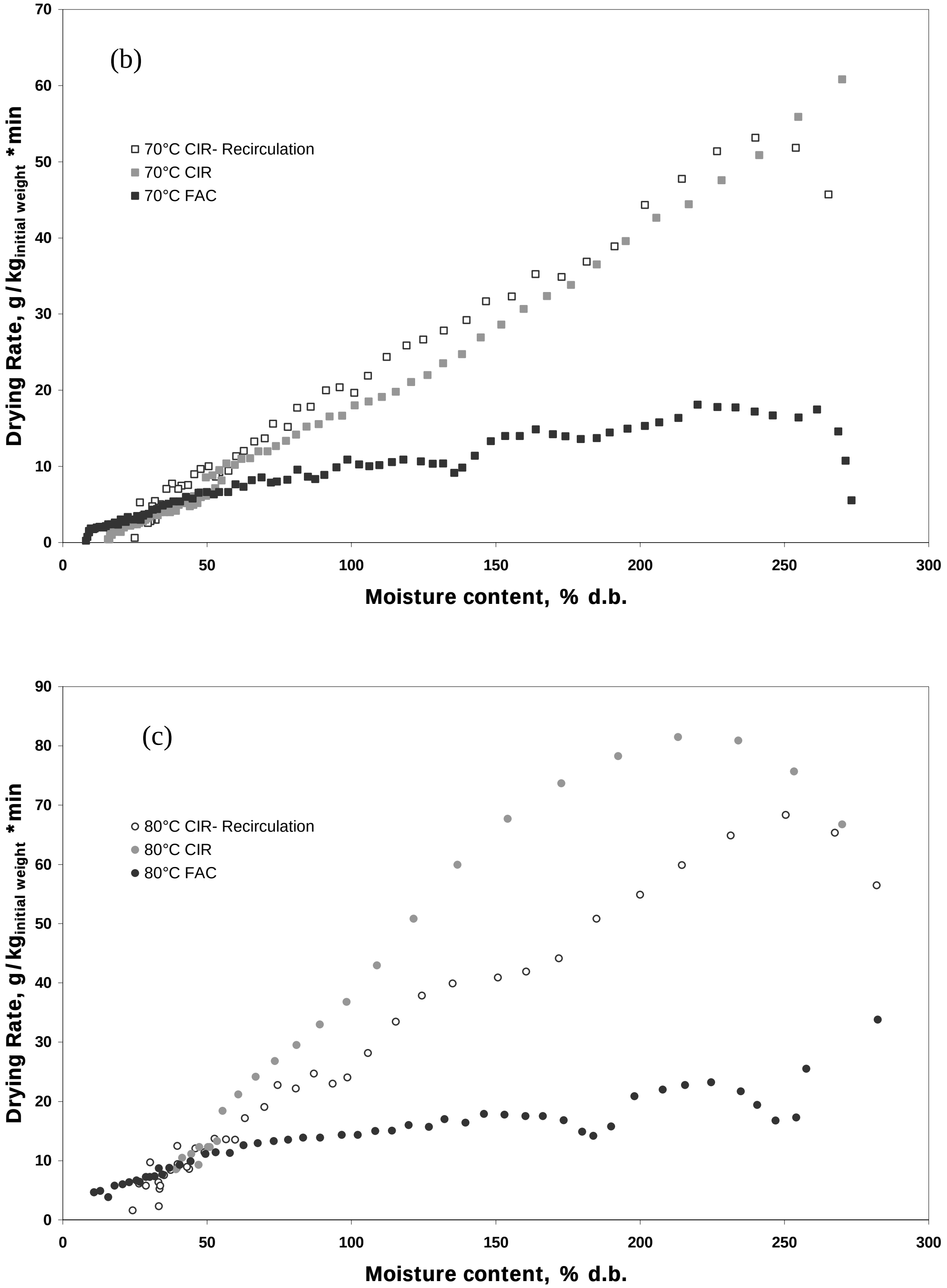


Fig. 2.4. Drying rates of different drying methods and conditions at various drying temperatures, (a) 60°C, (b) 70°C, and (c) 80°C.

For CIR drying, the air recirculation clearly reduced the drying rate at 80°C. The effect of air circulation on drying rate at 60°C and 70°C was not as significant as 80°C. This could be due to the increased cooling effect of evaporation and heat loss caused by the circulation of low temperature forced air. Since the infrared did not directly heat the recirculation air, the air temperature was sometimes as low as 15°C below the set temperature. The result was consistent with the reported research of Navarri et al. (1992).

Dying rate varied with the drying temperature (Fig. 2.4.) as expected. For each of the plots from the CIR drying tests, with the exception of the 80°C CIR test, there was an absence of or very brief appearance of a constant rate period. This could be caused by onions being a hygroscopic food which had immediate entrance into the falling rate period (Rahman and Perera, 1999). In general, many foods do not exhibit a constant rate drying period because of their colloidal and hydrophilic nature which binds water (Mazza and LeMaguer, 1980; Baker, 1997). Additionally, the onions used for the tests were high solid onions and had low free moisture which was accounted for during the constant rate period. However, the immediate entrance into the falling rate period was also seen in experiments performed with low solids onions which had greater free moisture (Gowda et al., 1986).

Another reason for the absence of the constant rate period in the CIR drying tests could be the achievement of the critical moisture content in the first few minutes of each test. When the critical moisture content is achieved, the drying enters the falling rate period. This theory did conflict with the plot of the 80°C CIR drying trial that showed, what appears to be, a constant rate period. The 80°C CIR drying test exhibited the highest drying rate among the tests and should have achieved the critical moisture content faster than any other tests. If this had been the case, all of the drying would have been in the falling rate period. This occurrence might be explained by the use of variable cycle heating used in the CIR dryer. This type of heating took nearly twice the time for the product to reach the 80°C set temperature compared to the 60 or 70°C set temperature. For the 60 and 70°C test the set temperatures were attained quickly and the emitter was switched off leading to lower drying rates over the course of the variable cycle drying. Whereas the 80°C drying took a longer time to achieve the set temperature resulting in constant heating of the product. During that time a constant and steady removal of water occurred exhibiting a constant drying rate period.

The FAC drying tests showed more of a distinct constant rate period at each of the 3 temperatures tested although the 80°C was not as profound as the other two trials. This may be caused by the lower heat flux resulting in a longer time to reach the critical moisture content.

The plots at all of the temperatures seem to converge at approximately 50% MC (db). The same effect was seen in convection drying of onions by Gowda et al. (1986) but at a MC of 100%. This difference may be a result of different initial moisture contents and characteristics of the onion samples and the drying methods used. They used an onion with an initial MC of 660% (db) compared to the about 300% (db) in the study. For MC below 50%, the CIR plots showed slightly lower drying rates than the FAC drying. This might be due to the differences in heating methods. In the latter stages of drying the product had a lower specific heat due to the loss of moisture. As a result the product retained a higher temperature for a longer time as was seen in the product temperature experiments. Therefore, the variable cycle heating of the CIR dryer turned the emitters on less often for maintaining the product temperatures in the latter stages of drying. The FAC used continuous heating which was independent of changes in the product's specific heat. Therefore, the FAC dryer maintained steady heat fluxes throughout drying. This higher rate in the FAC drying could also be explained by the constant air movement in the FAC drying, which assisted in moisture removal at the end of the drying process.

Based on the results, it is recommended to use IR drying in the early drying stage and then FAC drying in the latter stage if a combined IR/ Convection drying system is used for drying onion. For existing drying facilities, IR drying could be considered by addition at the front of the current convention drying to take advantage of high drying rate of IR for improving the overall drying rate.

The maximum drying rates under various conditions are shown in Fig. 2.5. They increased with the increased product or air temperatures. The maximum drying rates of IR were significantly higher ($p<0.05$) than that of FAC drying at corresponding temperatures. But no significant difference between the CIR drying with and without air recirculation at each corresponding temperature.

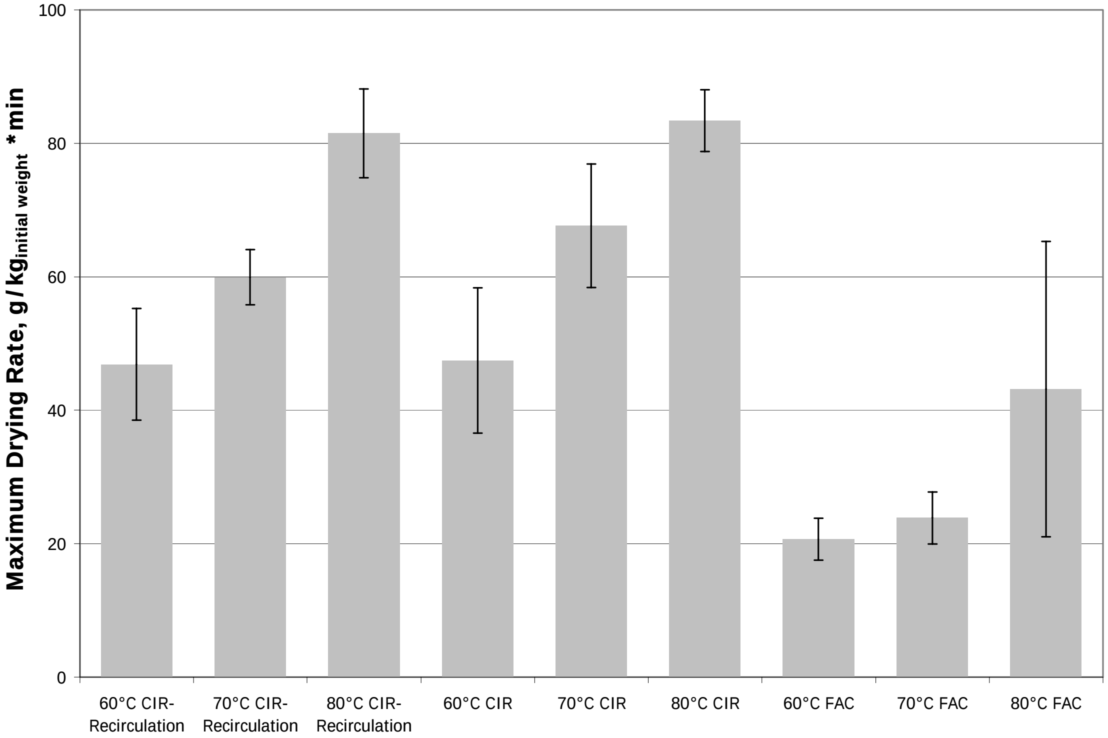


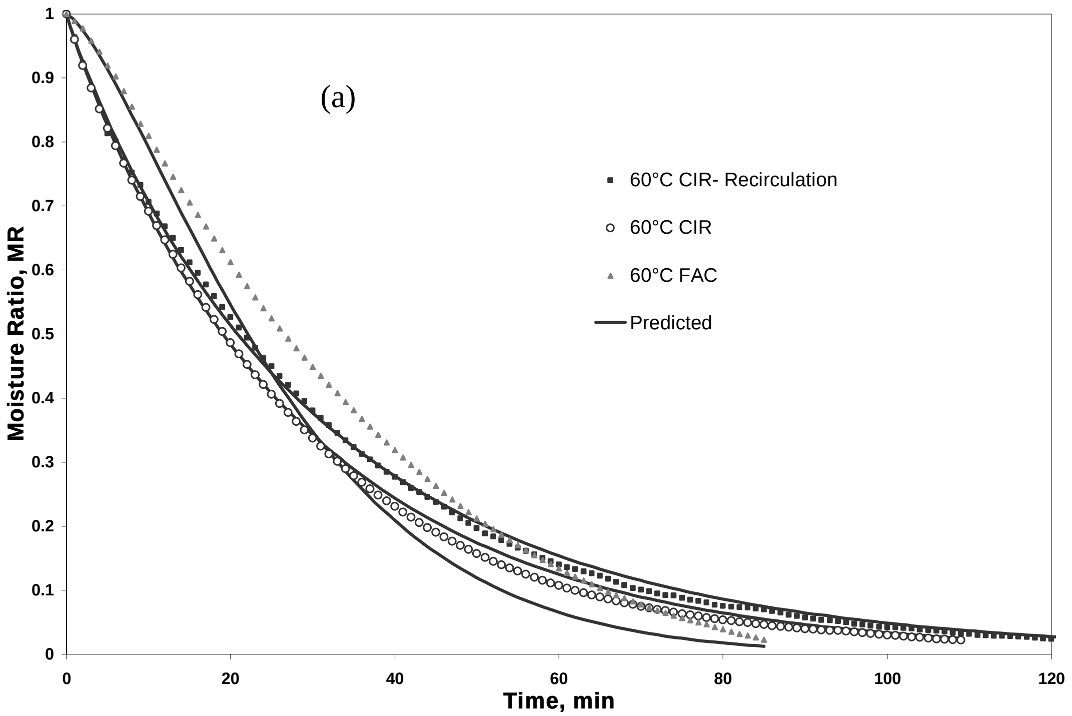
Fig. 2.5. Maximum drying rates of onions with different drying methods and temperatures.

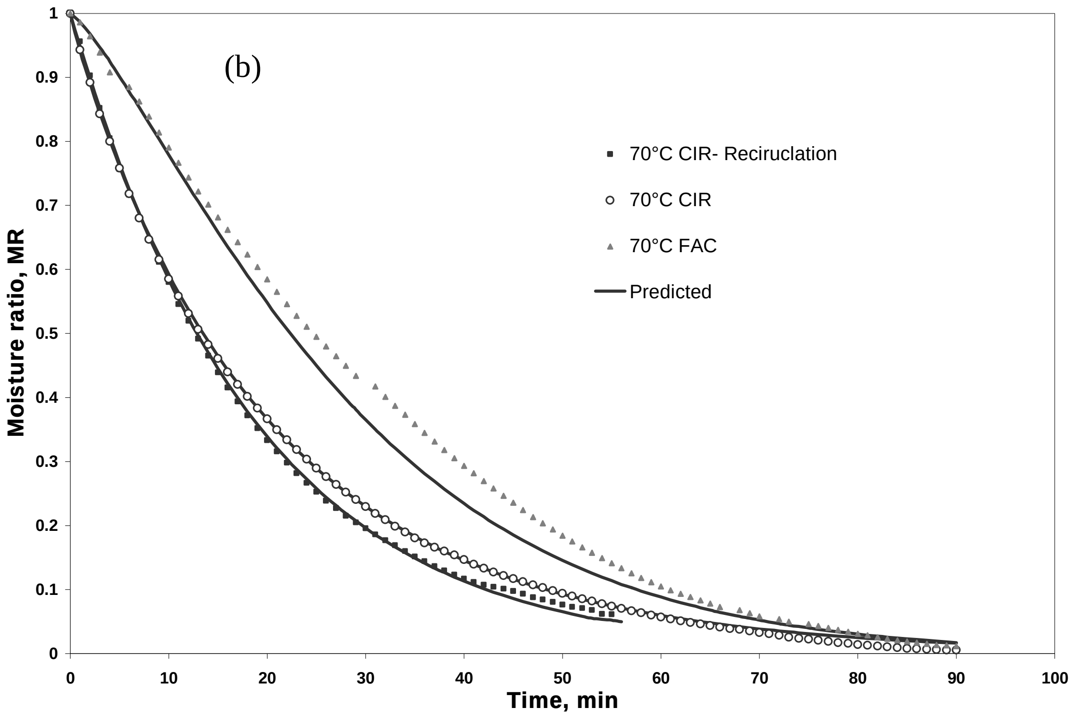
2.3.2.2 Drying modeling

Both exponential model and Page model fit well with the experimental data, which indicate that they can be used to predict the moisture change of onion under the tested conditions. Table 2.1 summarizes the drying constants and the Page model's drying exponent for the drying trials. The calculated drying constants using the exponential and Page models were very similar. However, the Page model performed better than exponential model as previously reported by Wang (2002). The greatest deviation in the calculated exponents was found in the FAC trials. Exponents for these trails were 1.37±0.22, 1.27±0.09, and 1.17±0.26 for the 60°C, 70°C and 80°C FAC trials, respectively. Because the exponents were much greater than 1, the predicted data from the Page model had better fitting with the experimental data than that from exponential model. This was shown by the lower correlation coefficient values (R^2), 0.927, 0.937, and 0.844 for exponential model than 0.993, 0.993, and 0.950 for the Page model at 60, 70 and 80°C, respectively, for FAC tests. When the predicted data from the Page model at various conditions were plotted and compared with the experimental data, it showed that Page model has better prediction for the CIR drying process than the FAC drying (Fig. 2.6). The predicted data did not fit well with the experimental data at the middle of the FAC drying process, which could be due to the long constant rate periods of drying process. This is most apparent for the 80°C FAC trial.

Table 2.1. Result summary of onion drying characteristics.

Drying Condition	Drying time to reach 50% MC (db)	Max drying rate	Drying constant, K (exponential model)	Drying constant, K (Page model	Drying exponent, N (Page model)	Correlation Coefficient (Exp./ Page)
	min	$g/kg_{initial\ weight}$ *min	h^{-1}	h^{-1}		R^2
60°C CIR-Recirculation	54.5±7.8	46.9±8.4	-1.88±0.42	1.93±0.3	0.94±0.04	0.988/ 0.997
70°C CIR-Recirculation	32.0±1.0	59.9±4.2	-3.23±0.39	3.32±0.5	1.01±0.08	0.995/ 0.998
80°C CIR-Recirculation	24.0±4.6	81.5±6.6	-4.47±0.67	4.96±1.3	1.07±0.12	0.997/ 0.998
60°C CIR	47.3±7.5	47.5±10.5	-2.04±.0.24	2.06±0.2	0.96±0.02	0.992/ 0.992
70°C CIR	36.5±7.8	67.7±9.2	-2.87±0.83	2.94±0.9	0.94±0.10	0.991/ 0.998
80°C CIR	18.0±2.8	83.4±4.6	-5.95±1.25	7.63±3.4	1.12±0.16	0.991/ 0.995
60°C FAC	56.0±8.5	20.7±3.1	-2.23±0.26	2.11±0.3	1.37±0.22	0.927/ 0.993
70°C FAC	51.0±1.4	23.9±3.9	-2.45±0.16	2.31±0.2	1.27±0.09	0.937/ 0.993
80°C FAC	33.0±5.7	43.2±22.1	-3.82±0.94	3.53±0.4	1.17±0.26	0.844/ 0.950


(a)
■ 60°C CIR- Recirculation
○ 60°C CIR
▲ 60°C FAC
— Predicted
Moisture Ratio, MR
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
Time, min


(b)
■ 70°C CIR- Recirculation
○ 70°C CIR
▲ 70°C FAC
— Predicted
Moisture ratio, MR
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Time, min

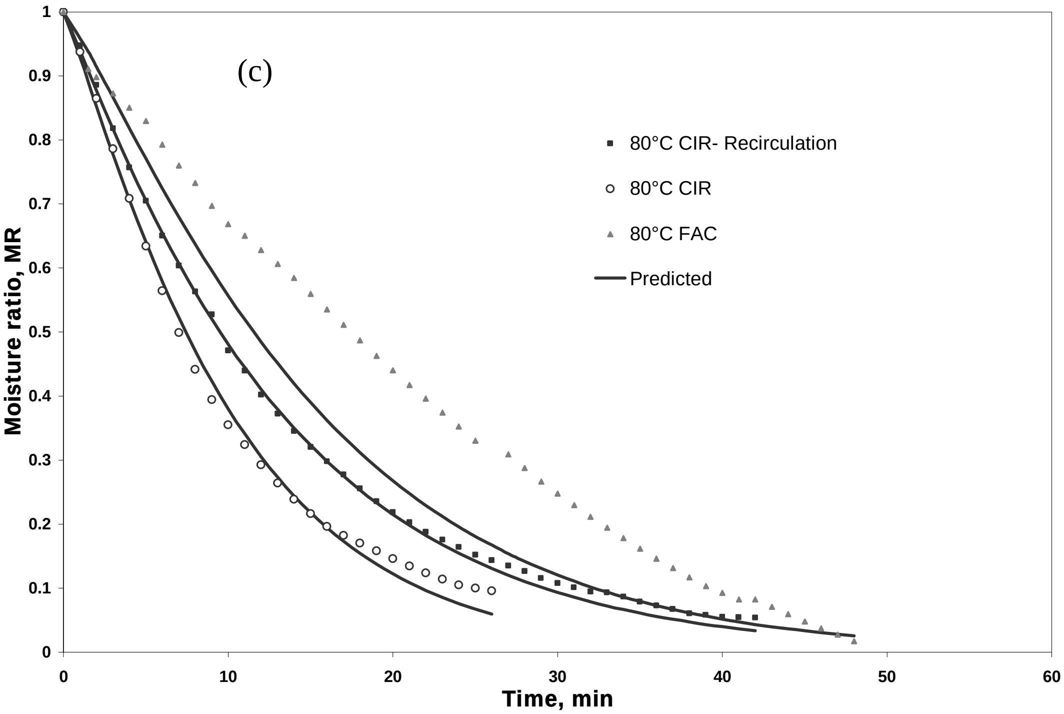


Fig 2.6. Predicted and measured moisture ration at different drying time and temperatures (a) 60°C, (b) 70°C, and (c) 80°C.

2.4.2.3 Summary of drying process

In general, the CIR had much faster drying rate than the FAC drying, especially at the early drying stage. When the air recirculation was used in CIR drying, it slowed down the drying rate. The Page model was appropriate model for describing the CIR drying process, but not for FAC drying process. To take the advantage of high drying rate of CIR drying, CIR drying may be used in early stage drying to quickly remove moisture from onions and then heat air can be followed to dry the onion product to desired final moisture.

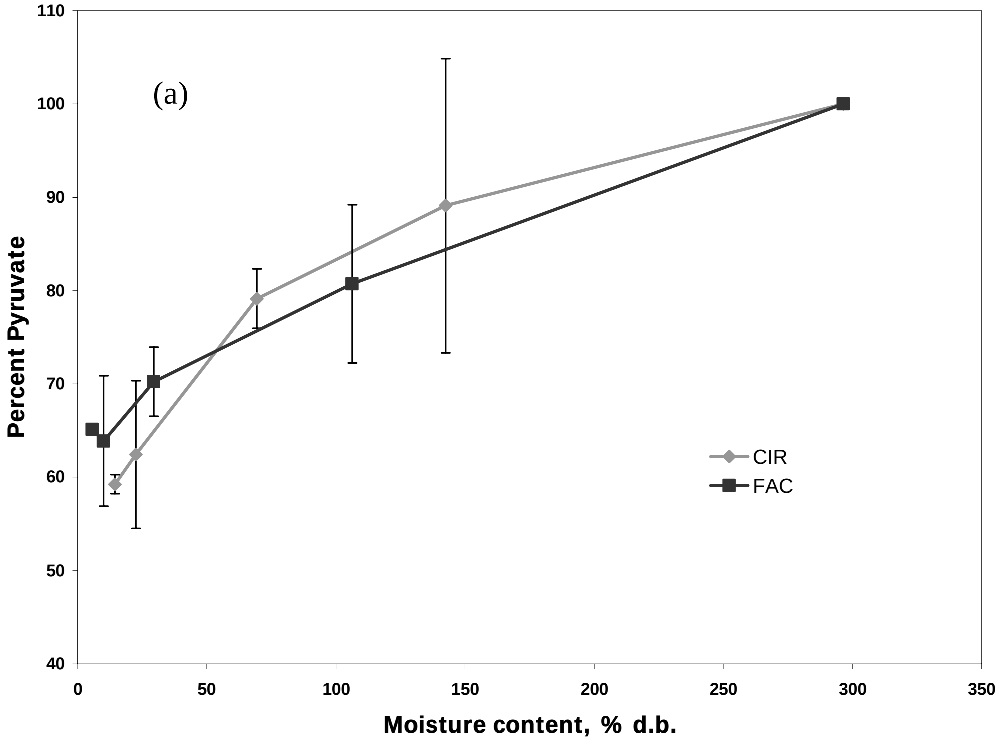
2.3.3 Quality of dried onions

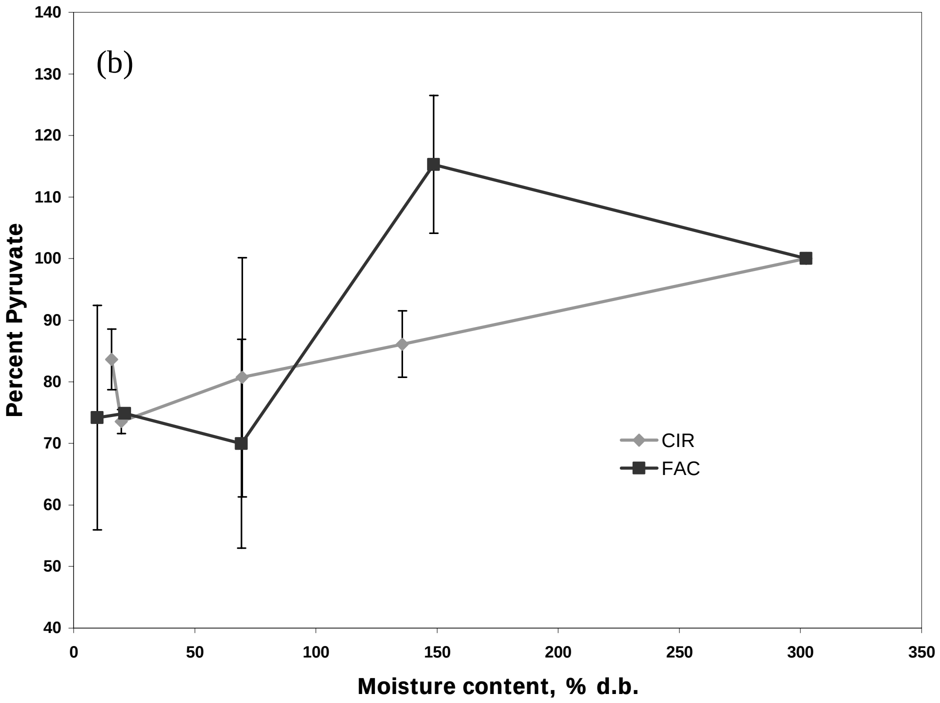
2.3.3.1 Pungency

Pungency changes caused by drying had similar trends for onion samples dried using both CIR and FAC drying methods (Fig. 2.7 and Table B2). Although the measured pungencies varied with drying conditions and moisture during drying, the pungencies in the final samples with similar moisture content were similar, except for the 80°C trial. The 80°C trial showed a greater loss in pungency in the samples dried in the CIR, especially near the end of drying. For all CIR dried samples, the pungency changes had a similar trend. For FAC drying, the final pungency values decreased as the drying temperature decreased. Presumably this was a result of the longer dying times from the lower drying temperatures. The large variability of measured pungency results could be caused by non-uniform drying among the samples, difficulties in achieving a homogenous sample, and human error during the assay.

There was no significant difference in the pungency loss between the CIR and the FAC dried products at 60°C (Fig. 2.7(a)). Furthermore samples dried at 70°C (Fig. 2.7(b)) for both drying methods had similar pyruvate levels at the end of drying. However there was variation in the pyruvate levels during the course of drying from the two drying methods. During the 70°C FAC drying the pyruvate level reached above 100% pyruvate after 10 min of drying. Theoretically, the fresh sample should have higher measured pyruvate content than dried samples. During the course of drying this value either decrease or remain the same. In this experiment the pyruvate level increased to above the level of the fresh sample. This could be caused by an incomplete conversion of precursors to pyruvate. To prevent this from happening in the future the measurement methods should require the blended sample to rest for longer periods of time before being analyzed. This would ensure a complete conversion of all precursors to pyruvate.

For the 80°C drying with both drying methods, the pungency did not change significantly until the moisture reached approximately 75%. After 75% MC the pungency of FAC dried samples did not change much, which could be due to fast drying compared to 60°C and 70°C FAC drying. However, the pungency of CIR dried samples dramatically decreased with the moisture reduction. This decrease may be caused by the large heat flux delivered to the product and resulted in alliinase inactivation and/or precursor degradation. Significant color changes were also noted during this time.





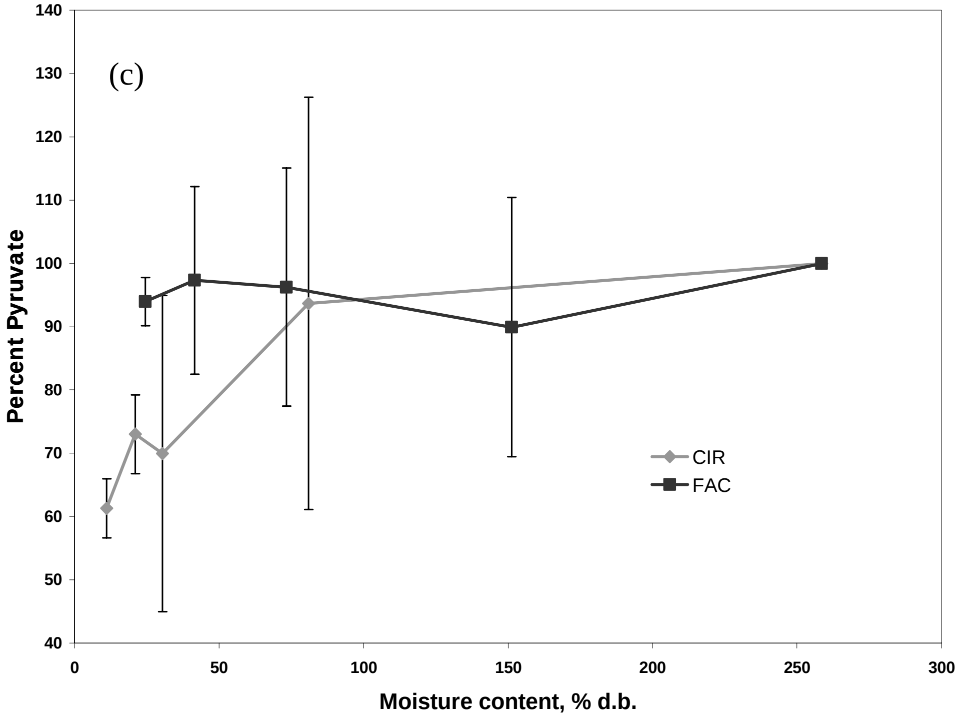


Figure 2.7. Pungency change at different moisture contents of onions dried at with (a) 60°C, (b) 70°C, and (c) 80°C.

Pungency of FAC dried samples at the latter drying stage showed a greater decrease at the lower temperatures (60°C and 70°C). The result could be due to longer drying times causing more degradation to the product. This is consistent with the findings of Lee et al. (1995). Additional studies (Mazza and Maguer, 1979; Brewster and Rabinowitch, 1990) have shown that accelerated drying in the initial stages would retain volatiles. This is because the volatiles become "locked" into the product when it reaches the critical moisture content.

Based on the above results, if 80°C drying temperature of CIR drying is used, it is recommended to use it in the early drying stage before the moisture reached to 75%. Then low temperature drying can be used in the latter drying stage to prevent severe browning and pungency degradation. This method of drying was also suggested by Bakr and Gawish (1999).

2.3.3.2 Color

The color measurement results of onion samples with 10% MC are shown in Fig. 2.8 and 2.9 and Table B3. The L color parameter indicates whiteness of the product. The b color parameter measures the yellowness of the product. The a parameter was not reported because it is not relevant to the color quality of dried onions. For the CIR drying, whiteness decreased while yellowness increased as the drying temperature increased. For FAC dried samples, whiteness increased while yellowness decreases as the temperature increased. The optimal drying conditions for maintaining color quality was 70°C for the CIR and 80°C for FAC.

The L values showed a decrease with increasing temperatures for the CIR drying and the opposite effect for the FAC drying (Fig. 2.8). The FAC results were opposite findings from those of Lee et al. (1995) where L values decreased with higher air temperatures for convection drying of onion. The low L values for 60°C FAC sample may be a result of extended drying time resulting from low drying temperatures. For the CIR drying, high drying temperature could increase browning and result in dark color

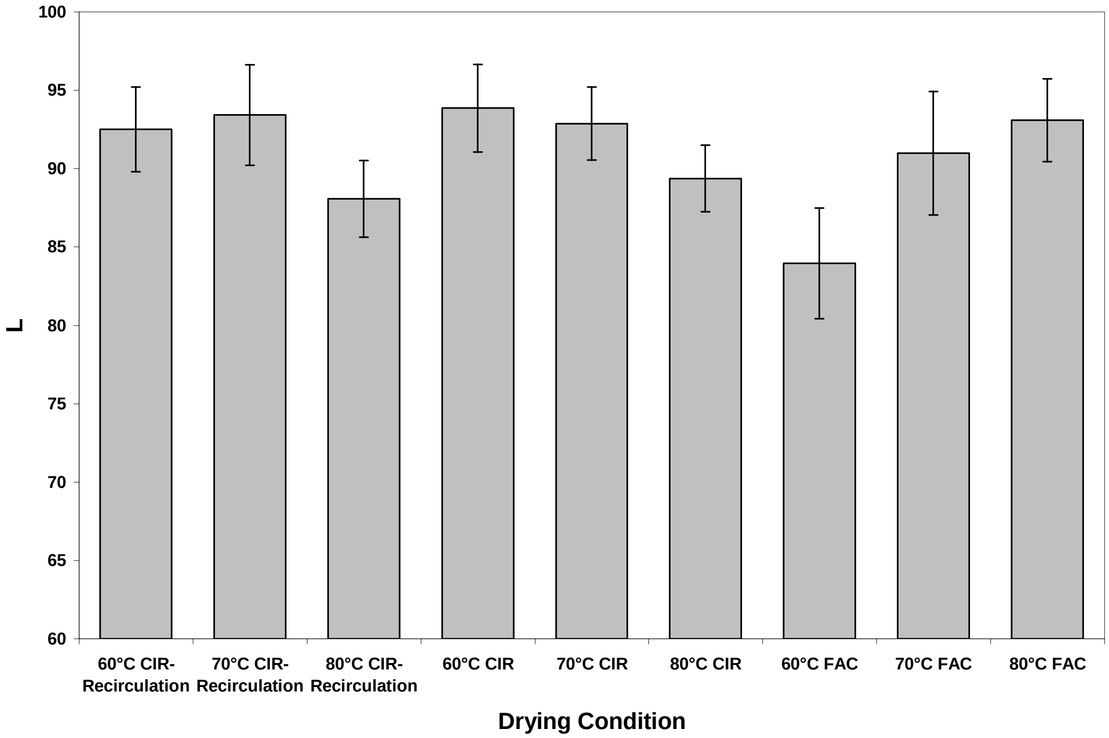


Fig. 2.8. L values of onion dried with different methods and temperatures

The 60°C FAC dried sample was significantly ($p<0.05$) less white than either of the CIR samples. Samples from the other drying temperatures are not significantly different from each other. The L color parameter alone does not describe well the color changes occurring during the drying process. It is necessary to compare the b parameter of the samples in order to evaluate the color data in its entirety.

A higher b value indicates a higher degree of browning and other color developments caused by enzymatic and non-enzymatic browning reactions. Thus there was more color development in the CIR dried samples at higher temperatures due to the aforementioned reasons (Fig. 2.9). Likewise, FAC drying has less browning at higher temperatures due to shorter drying time. The b value of the onion sample dried at 70°C with CIR and air recirculation did not follow the trend from CIR drying without air circulation, which could be due to experimental variations. The higher b values of samples dried at 60°C and 70°C with CIR plus air recirculation could be due to increased drying times compared to using CIR drying without air recirculation.

To have a product with white color using the CIR drying it is recommended to dry the product at a mild temperature, such as 70°C to take advantage of higher drying rate than 60°C drying and lower browning than 80°C drying.

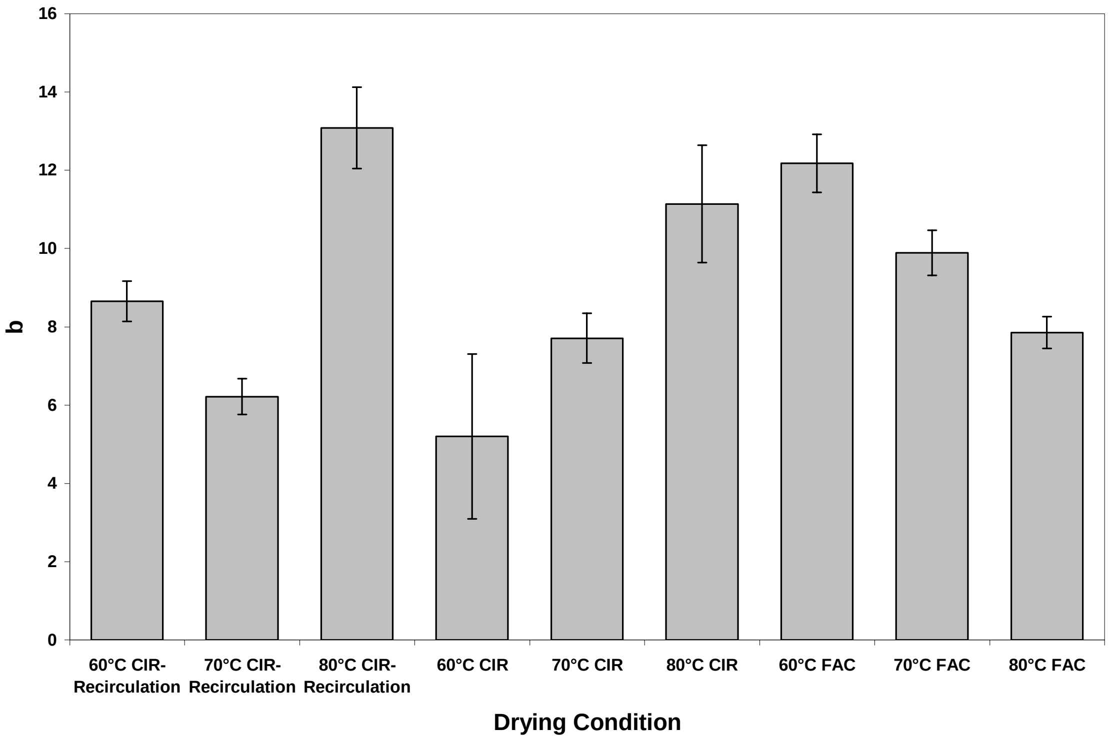


Fig. 2.9. b color parameter for the 9 drying tests.

2.3.3.3 Microbial load reduction tests

The results of microbial counts from individual experiments are summarized in Table 2.2. The average results with the standard error bars are presented in Fig. 1.20 and Table B4. The results of aerobic plate counts (APC) for all of the dried samples were relatively similar (Fig. 2.10(a)). There was no difference between the two drying methods nor was there a difference in

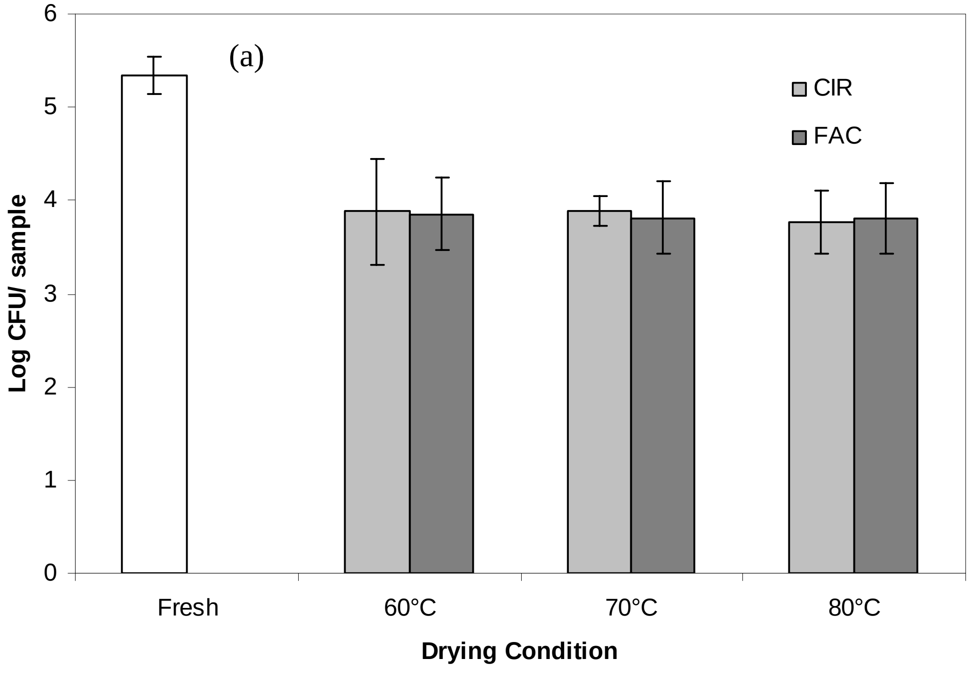
	Trial 1			Trial 2			Average		
Aerobic Plate Counts	**Fresh**	5.24		**Fresh**	5.54		**Fresh**	5.39±0.22	
		CIR	**FAC**		**CIR**	**FAC**		**CIR**	**FAC**
	60°C	4.21	4.08	60°C	3.23	3.41	60°C	3.72±0.70	3.75±0.47
	70°C	3.98	4.05	70°C	3.71	3.36	70°C	3.85±0.19	3.71±0.49
	80°C	3.97	4.03	80°C	3.37	3.39	80°C	3.67±0.42	3.71±0.45
Coliform Counts	**Fresh**	5.27		**Fresh**	5.51		**Fresh**	5.39±0.17	
		CIR	**FAC**		**CIR**	**FAC**		**CIR**	**FAC**
	60°C	3.04	3.95	60°C	2.40	2.40	60°C	2.72±0.45	3.18±1.10
	70°C	2.18	3.93	70°C	2.40	2.18	70°C	2.29±0.16	3.05±1.24
	80°C	1.70	3.00	80°C	1.00	1.00	80°C	1.35±0.49	2.00±1.41
Yeast and Mold Counts	**Fresh**	4.56		**Fresh**	4.84		**Fresh**	4.70±0.20	
		CIR	**FAC**		**CIR**	**FAC**		**CIR**	**FAC**
	60°C	4.16	4.72	60°C	4.12	4.81	60°C	4.14±0.03	4.77±0.07
	70°C	3.83	4.69	70°C	4.00	4.31	70°C	3.92±0.12	4.50±0.27
	80°C	3.44	4.10	80°C	3.44	4.00	80°C	3.44±0.00	4.05±0.07

Table 2.2. Microbial data for aerobic plate counts, coliform counts, and yeast and mold counts of CIR and FAC dried samples.

counts at different drying temperatures. It was assumed that the final counts were composed primarily of aerobic sporeformers. According to Gray and Pinkas (2001) these are the predominant microorganism in dehydrated spices. Sporeforming bacteria are likely to survive the drying process. The high survival of the aerobic sporeformers and inactivation of other population of microorganisms would account for the similar final counts. The population that were reduced were most likely vegetative cells, of which include coliforms.

Coliform in fresh samples had an average count of 5.39 log. This would account for a large percentage of the APC. The coliform counts were reduced in the drying process with a reduction of over 2 logs at 60°C for both drying methods to a 3 logs reduction for the 80°C samples (Fig. 2.10(b)). There is no significant difference between the FAC and CIR dried samples at corresponding drying temperatures although all the dried samples are significantly different from the fresh sample.

The measured coliform populations were assumed to be accounted for on the APC counts. This was not apparent because no variations between temperatures and drying methods were shown on the APC. Whereas there was variation due to temperature on the coliform counts. On the APC media, this variation may be difficult to discern due to the low final coliform counts which accounted for only a small percentage of the total population.



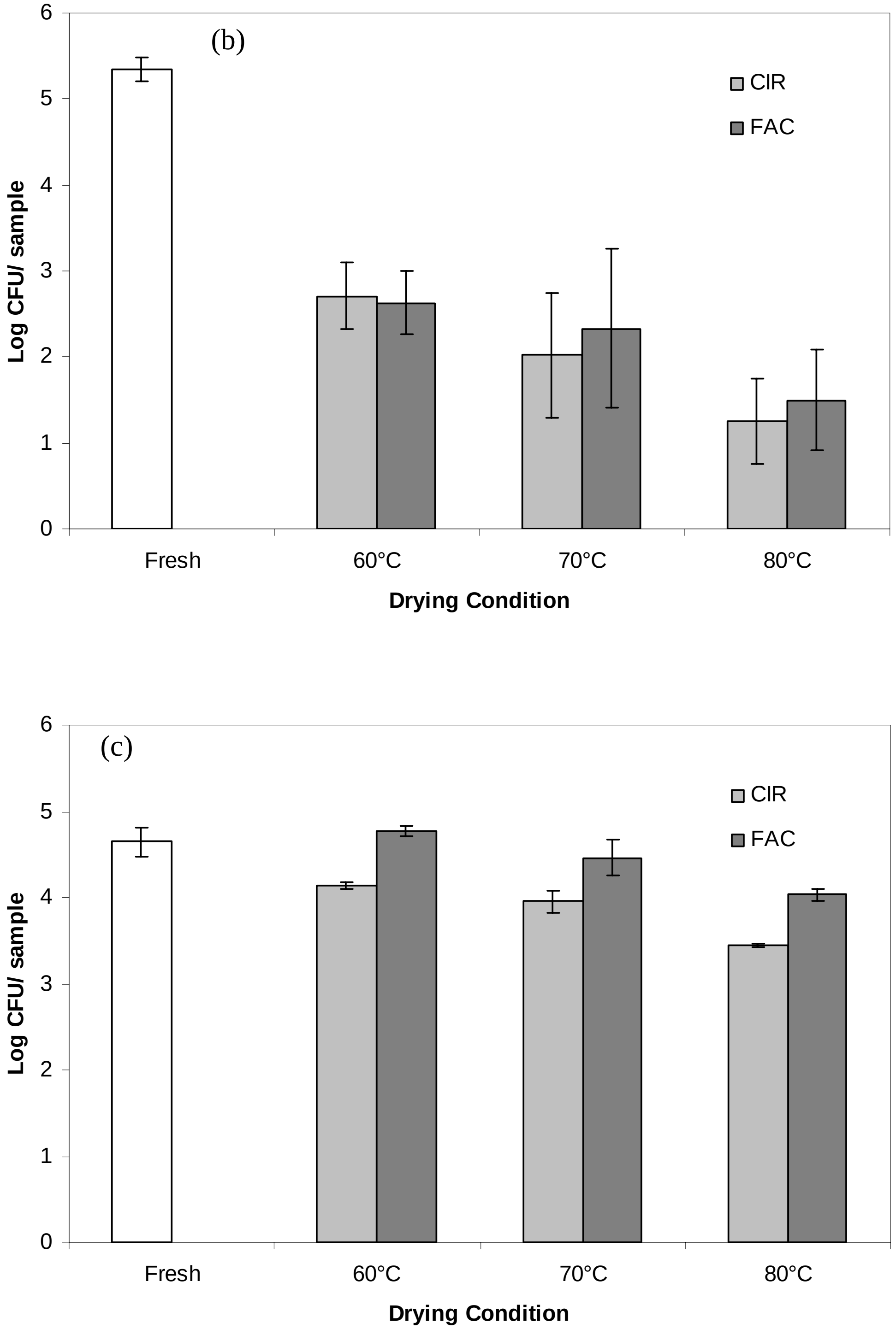


Fig. 2.20. Effect of drying methods and temperatures on (a) Aerobic plate counts (b) Coliform counts, and (c) Yeast & Mold counts

Yeast and mold counts, unlike coliform, were not accounted for on the APC. Yeasts and molds do not grow fast enough to appear on APC agar. It is important not to correlate APC and yeast and mold counts. In the experiments yeast and mold counts were significantly different for the two drying methods with greater reductions in samples dried in the CIR dryer (Fig. 2.10(c)). Greater reductions in the CIR were probably a result of greater heat fluxes from the CIR emitter. The reduction of yeast and mold in the dried samples with either drying method was no less than 1.4 log.

For the yeast and mold counted some dried samples had greater counts than the fresh samples. This might be a result of replication of organisms after drying, although properly dried product should be free of microbial multiplication (Rahman and Perera, 1999). Another reason could be that fresh onions contained antimicrobial agents that were lost after drying and resulted in lower count for the fresh onion samples. Wei et al. (1979) determined that addition of potassium sulfate could inhibit this antimicrobial action and allow for more accurate microbial counts. But this action was not taken for our experiments.

Due to the nature of the experiment, it is very difficult to have homogeneous dried sample. The variation between the trials was a result of different amount and type of microflora represented on each of the samples used. Large standard deviations were a result of averaging the results of the variable trials.

As a summary, aerobic plate counts (APC) had similar results for the samples dried with both drying methods at all three temperatures. Coliform counts were similar for both drying methods but the counts decreased as drying temperatures increased. The yeast and mold counts were lower for the CIR dried samples than for those dried with the FAC. There was also a decrease in the yeast and mold as the drying temperature increased for both of the drying methods.

2.4. Conclusions

Based on the experimental results from the thin-layer IR drying and FAC drying of onions, the following conclusions have been made:

(1) The CIR drying with and without air recirculation had higher drying rate, especially at early drying stage before the moisture reaching 75% (db), than the FAC drying. The drying rates increased with the increase of drying temperature for both CIR and FAC dryings. The use of air recirculation in the CIR dryer reduced the drying rate. The Page model provided accurate prediction of moisture change CIR drying.

(2) Pungency degradation was similar for both drying methods except that samples dried at 80°C with the CIR drying significantly lowered pungency at the end of the drying process. This loss was attributed to increased product browning. Moisture content of the sample primarily was closely related to the pyruvate levels during drying. Drying temperature also affected the final pyruvate content. Increasing drying temperatures of FAC drying led to greater retention of pungency.

(3) Color data showed more development of color (lower L values and greater b values) at increased drying temperatures for the CIR dyer and decreased air temperatures for the FAC dryer. Color development in the CIR was most likely caused by greater radiant intensities of the higher temperatures while development in the FAC was caused by

prolonged drying times of the lower temperatures. CIR dried samples generally had better color except at 80°C. Drying temperature for optimal color quality are 70°C for CIR and 80°C for FAC.

(4) Microbial loads reduction tests showed little difference in aerobic plate counts for samples dried in the CIR and the FAC. It was postulated that all remaining organisms after drying were aerobic sporeformers. The decreases in coliform counts were greater in the CIR dried samples than the FAC dried samples although the difference was not statistically significant. Yeast and mold counts were also lower in the CIR dried samples than the FAC dried samples.

(5) In general, CIR heating is more effective than FAC for onion drying. The recommended product temperature for CIR drying is 70°C and 80°C. 80°C should be used at the beginning of drying to achieve maximum drying rates while product degradation is minimal. 70°C should be used for the remainder of drying because it has high drying rates but does not have such adverse effects on quality factors, especially pungency and color, as does 80°C heating. Further research is needed to determine the point at which the temperature should be reduced from 80°C to 70°C. Additional studies are also necessary to determine drying characteristics and quality changes that occur to onions below 10% MC.

2.5. Acknowledgements

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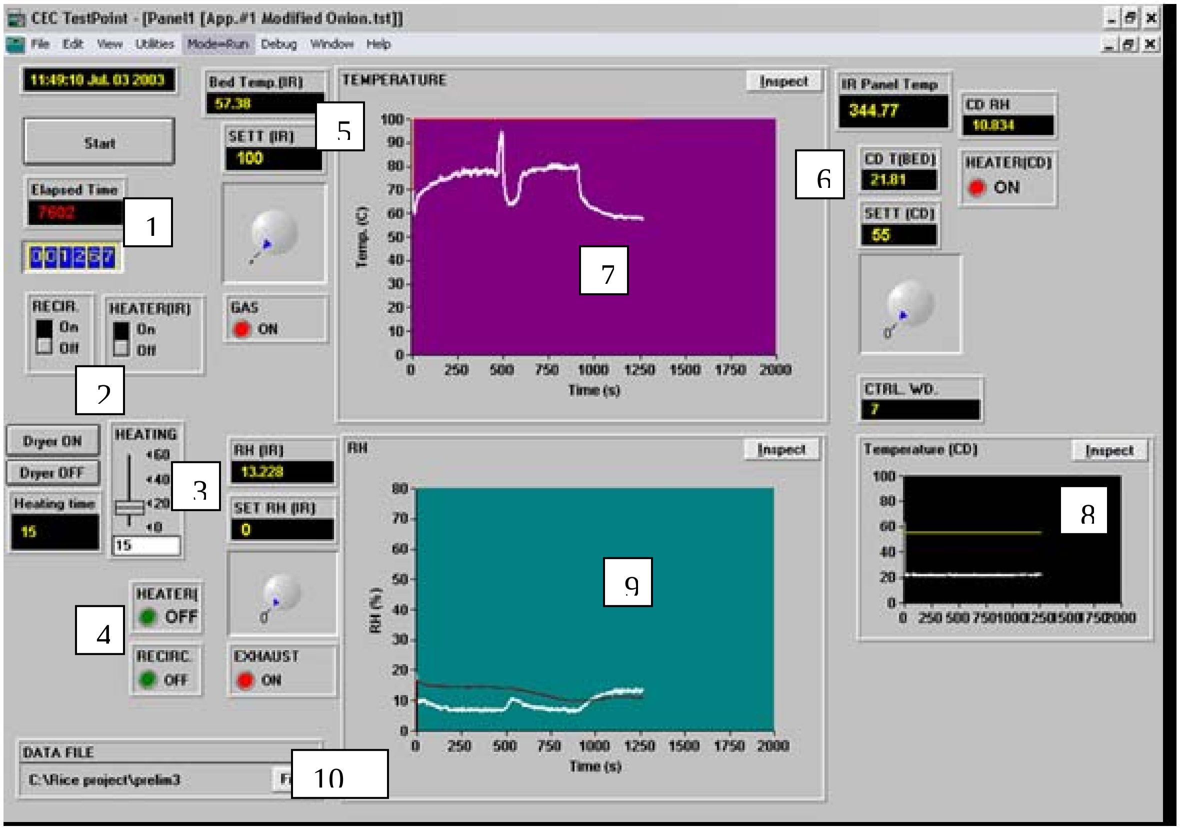
2.7. Appendix B

Fig. B1. Catalytic infrared (CIR) set up for drying onions

System control

The control program for operation of the CIR and FAC dryer was developed using Test Point software package (Capitol Equipment, Bedford, NH). The program was developed by Sanath Amaratunga (Biological Systems Engineering, University of California, Davis). The graphic user interface is shown in figure B1.



11:49:10 Jul. 03 2003

Elapsed Time 7602

Bed Temp.(IR) 57.38

SETT (IR) 100

GAS ● ON

IR Panel Temp 344.77

CD RH 10.834

CD T(BED) 21.81

SETT (CD) 55

HEATER(CD) ● ON

CTRL. WD. 7

Heating time 15

RH (IR) 13.228

SET RH (IR) 0

HEATER(● OFF

RECIRC. ● OFF

EXHAUST ● ON

DATA FILE C:\Rice project\prelim3

Figure B2. Control system graphic user interface. (1) Elapsed time counter; (2) Toggles for CIR recirculation fans and CIR heater; (3) Preheat timer for CIR heater; (4) On/off indicators for CIR heater, recirculation fans, and exhaust fans; (5) CIR product temperature and set temperature indicator with set temperature adjustment knob; (6) FAC product temperature and set temperature indicator with set temperature adjustment knob; (7) Plot of CIR product temperature; (8) Plot of FAC air temperature; (9) Plot of CIR drying cabinet (not used); (10) Data file location.

Operation procedures of CIR control and data collection system are as follows:

Dryer setup:

- Turn on gas line to CIR dryer
- Plug-in the two cords to the FAC dryer
- Press the reset button on the front of the FAC dryer (this will need to be done every time the dryer is unplugged) you will hear a click if reset.

Computer setup:

- Open the ‘Test Point’ application and open file
- Open up ‘Hyper Terminal’ for connection of the balance to the PC. Use the settings: Com1 connectivity, Bits per second=2400; Data bits=8; Parity=None; Stop bits=2; and Flow control=None. These need to be the same settings on the dryer.

- Click the MODE= Edit option on the top menu bar; it should not say MODE= Run
- Adjust set temperatures of the CIR dryer and the FAC dryer using adjustment knobs
- Set the heater to 15 min. This is the default. This is the time that the system will preheat the emitter using the electric heating coils.
- Change the filename for the data file
- Click on Mode=Run and this will change back to Mode=Edit
- Click on the bottom left corner is a file name- double click directly on the file name NOT the FILE button
- This will bring up a new window- in the space called “filename initial value” replace the filename
- After doing this close this window
- Change Mode setting again to Run

Preheat period of dryers:

- Click on the DRYER ON button to preheat the emitter
- The “Heating Time” will count up and the “Heater” light will become red.
- The system will preheat for the 15 minutes (or time set).
- CAUTION! Do not bypass this step- CIR dryer must be preheated for the gas to react.
- After the 15 min warm-up the gas will turn on and the CIR dryer will continue heating.
- Turn on the FAC blower and set the switch to the clockwise (CW) direction.
- Press START button and allow both dryers to reach set temperatures, run the systems for a few minutes

Running trial:

- Place drying tray on balance in CIR drying cabinet and zero weight on Hyper Terminal
- Click the Mode button twice to reset the system when inserting the sample
- At this time add your samples to the CIR and the FAC dryer
- Ensure that the samples are spread evenly and that the thermocouples are positioned inside the samples
- On the compute click START once again
- Turn on recirculation fans in CIR if testing. Toggle fans off for 30 seconds if needed to make appropriate readings without lift
- Allow trial to run

Ending trial:

- Click twice on the Mode menu on the screen. Do not press the Start button again because this will erase all previous data.
- Turn off the gas
- Unplug both of CD dryer’s plugs
- Retrieve data from source location

Experimental data

Table B1. Drying rate data. First column= MC (db); Second column= Corresponding drying rate (g/kg*min)

60- Recir	Dry Rate	70-Reicr	Dry Rate	80-Recir	Dry Rate
270.839	38.5745	265.405	45.6954	282.053	56.4836
261.107	40.5539	253.998	51.8299	267.571	65.3083
250.337	39.4659	240.024	53.1487	250.45	68.2988
240.169	34.3027	226.768	51.3683	231.467	64.8698
231.346	31.9288	214.486	47.7415	214.523	59.8583
221.109	28.0712	201.785	44.3126	200.099	54.8468
217.88	25.1632	191.276	38.9054	184.94	50.8243
210.097	22.6706	181.591	36.8612	171.888	44.0983
204.771	23.6795	172.886	34.883	160.567	41.8893
199.608	22.4926	163.855	35.2127	150.731	40.9002
192.504	22.4332	155.66	32.3112	135.061	39.911
188.016	21.3056	146.693	31.6518	124.518	37.8339
181.723	19.4065	139.863	29.212	115.427	33.4158
176.491	19.7033	132.086	27.8272	105.73	28.1405
172.735	20.5341	124.934	26.6403	98.623	24.0522
168.024	17.5668	119.151	25.849	93.5455	22.9971
163.159	19.2878	112.283	24.3323	87.0225	24.6456
155.836	19.0504	105.789	21.8925	80.7357	22.1399
154.34	18.1602	101.105	19.6505	74.4491	22.7333
148.426	16.4985	96.0037	20.3759	69.8402	19.0406
144.006	16.9733	91.2095	19.9802	63.1443	17.1283
140.276	16.9733	85.9716	17.8042	59.7081	13.5015
135.024	16.4985	81.2091	17.6723	56.5655	13.5675
132.937	17.2107	77.9531	15.1665	52.6461	13.6994
127.035	13.3531	72.8963	15.5621	49.1671	11.3914
123.22	16.4392	69.9791	13.6499	45.9767	12.0508
118.582	14.8961	66.4005	13.2542	43.8386	8.55513
118.192	13.8279	62.7259	12.0013	39.8568	9.37898
112.221	12.5223	60.0618	11.3419	43.102	8.90208
108.254	15.727	57.4906	9.42961	39.7405	12.4629
105.788	11.8694	54.3	9.23178	37.4674	8.40752
102.797	12.5223	53.0616	8.63831	33.5417	5.20524
98.3805	12.6409	50.6139	10.0231	33.3497	2.26879
97.2495	11.9881	47.855	9.62743	39.4378	8.70425
92.4686	10.8605	45.5825	8.96802	35.1176	7.51731
89.8456	11.8101	43.4452	7.51731	33.181	6.33037
87.6748	8.90208	41.194	7.45137	33.7769	5.73689
84.6796	10.6231	40.034	7.05572	30.3505	9.69337
82.3608	9.79228	37.8797	7.71513	28.8608	5.73689
81.2338	8.4273	35.9404	7.05572	26.4772	6.13254
76.4513	9.13947	34.2231	4.9456		
75.3243	9.31751	32.6413	4.41807	24.2426	1.58259
74.0476	6.52819	32.2551	2.96736	27.0731	-1.54579
70.8291	8.24926	30.9484	3.06178	24.8385	3.3193
69.4868	8.72404	30.3799	2.77928		
68.2085	7.4184	33.7689	5.04451		
64.9196	9.85163	31.9579	5.44016		
63.0579	9.25816	30.9825	4.74777		
61.4745	7.89318	29.62	2.57171		
57.0691	8.18991	28.3303	3.65974		
56.5367	8.78338	29.0144	3.46192		
54.9687	5.63798	26.8221	5.24233		
52.7228	5.75668	25.6666	2.484		
50.3983	6.4095	24.9825	0.61027		
49.9492	5.93472	19.4472	-0.74094		
49.2785	5.40059	20.1756	-2.29835		
46.8804	5.69733				
45.2315	5.57864				
43.5875	6.11276				
42.7598	5.22255				
42.2323	4.03561				
39.174	3.38279				

38.6521	4.03561
38.4895	3.02671
38.5129	4.03561
37.1481	5.04451
35.3495	4.98516
33.5501	5.22255
32.1334	5.22255
32.2014	2.49258
30.5597	2.72997
28.7588	3.79822
30.3955	2.1365
28.6859	1.1276
27.4092	3.62018
27.8607	3.38279
27.3259	1.60237
25.8315	2.84866
24.4173	3.32344
25.3809	2.64278
24.2579	1.1373
23.1349	2.54509
26.7094	1.06825
27.4618	1.78042
27.3113	1.18694
28.0637	2.37389
25.9569	2.49258
25.2045	3.91691
24.4521	2.1365
24.1511	2.49258
23.0977	2.0178
23.2482	1.89911
22.0443	0.47478
21.8938	1.42433
21.7433	1.54303
22.4958	2.49258
21.4424	1.30564
20.088	2.49258
18.7336	1.42433
20.088	0.94955
19.3355	0.11869
19.6365	1.30564
18.8841	0.11869
18.5831	1.89911
18.4326	1.18694
19.1851	0.71217
17.2287	1.54303
17.3792	2.0178
17.6802	1.18694
16.4763	0.59347
16.6268	1.66172
15.7239	0.83086
16.6268	0.59347
15.5734	0.23739
15.4229	0.71217
15.8744	0.35608
15.4229	0.83086
15.7239	0.94955
15.1219	1.30564
14.3695	0.59347
14.6705	1.18694
13.7676	0.71217
14.9714	0.94955
13.6171	0.59347
13.4666	1.66172
13.4666	0.83086
13.0151	0.59347
12.8646	0.59347
12.5637	0.71217
12.7142	0.35608
12.1122	0.83086

12.4132	0.83086
11.6608	0.35608
11.6608	0.71217
13.6171	0.23739
11.9617	0.59347
11.8112	1.66172
11.3598	1.06825
10.9083	0.71217
11.5103	0.59347
10.9083	0.94955
10.6073	0.11869
12.4132	0.23739
10.4569	1.42433
10.6073	0.23739
10.6073	1.18694
10.3064	0.35608
9.10248	1.18694
10.1559	0.35608
8.80151	0.35608
9.70443	2.1365
9.70443	0.71217
9.40346	1.30564
9.25297	0.59347
8.80151	0.35608

60 NR	**Dry Rate**	**70 NR**	**Dry Rate**	**80 NR**	**Dry Rate**
254.139	41.9333	270.049	60.825	270.081	66.76
245.263	40.1583	254.893	55.8853	253.426	75.6677
234.365	37.4547	241.288	50.8408	234.127	80.91
225.772	33.8279	228.275	47.5767	213.197	81.5035
217.54	31.1902	216.888	44.4115	192.487	78.2394
210.241	29.4758	205.723	42.6311	172.706	73.6894
203.729	28.1569	195.075	39.5648	154.181	67.6558
196.645	27.4975	185.019	36.4985	136.799	59.9407
190.419	25.9149	176.146	33.8279	121.552	50.8408
184.121	24.9258	167.791	32.3442	108.85	42.9278
178.607	24.0026	159.731	30.6627	98.3944	36.7953
172.882	23.2773	151.968	28.5856	89.1241	32.9377
167.155	22.8157	144.869	26.9041	81.0596	29.4758
161.999	22.2222	138.363	24.728	73.5235	26.8051
156.414	22.1563	131.856	23.541	66.8957	24.1345
151.403	21.4309	126.385	21.9585	60.8733	21.1672
146.034	20.5737	120.765	21.0682	55.3742	18.3976
141.091	20.178	115.442	19.7824	50.9882	12.2596
136.438	19.1889	110.636	19.09	47.0486	9.28948
131.641	18.7273	105.978	18.4965	53.4608	13.2542
127.345	17.6723	101.172	18.002	50.3026	12.2651
123.119	17.1447	96.8095	16.6172	47.2879	12.2651
119.036	16.881	92.5212	16.5183	44.5604	11.0781
114.957	16.4194	88.7506	15.5292	41.4021	10.4847
110.946	15.2324	84.4623	15.2324	39.2488	8.50643
107.082	15.0346	80.9135	14.1444	36.9519	3.49996
104.294	14.1774	77.3647	13.3531	35.2293	0.50217
100.135	14.7709	73.8896	12.6607		
96.8406	13.6499	70.9324	11.9683		
93.2603	13.5839	67.9012	11.9683		
90.1803	12.8586	64.9438	11.0781		
86.8876	12.5948	61.9864	10.9792		
84.0229	12.1991	59.6206	10.1879		
80.9442	11.9354	56.7372	10.3858		
78.0808	11.3419	54.3714	9.49555		
75.2895	10.8803	51.8577	8.80317		
72.711	10.3528	49.6397	8.56138		
70.206	10.0231	47.7914	6.57636		

67.6997	9.49555	45.5734	6.05642
65.41	9.42961	55.0374	8.11078
63.1912	8.50643	52.8205	7.12166
60.9028	8.83614	51.3425	6.52819
59.4756	8.11078	49.7168	6.13254
56.7527	8.50643	47.9432	5.93472
54.9632	7.84702	46.7609	5.14342
52.8888	7.64919	45.2829	4.9456
51.1006	6.79196	44.1005	4.74777
49.2402	6.26442	43.066	5.14342
47.5939	6.52819	41.7358	5.14342
46.4464	6.8579	40.2579	4.9456
44.4481	6.72601	39.2233	4.1543
42.8765	6.0666	38.0409	4.35213
41.3732	5.53907	37.1542	3.95648
40.0156	5.2753	35.9718	4.54995
38.7289	5.20936	35.085	3.95648
37.5132	5.01154	33.7549	3.95648
36.1556	5.07748	33.0159	3.56083
35.0842	4.54995	32.1291	3.75865
33.8697	4.48401	31.0945	3.75865
32.8693	4.1543	30.2078	3.36301
31.8675	4.1543	29.321	3.16518
30.7961	4.02242	28.582	2.96736
29.8679	3.69271	27.843	2.76954
28.9396	3.49489	27.1041	2.76954
28.0822	3.29707	26.5129	2.57171
27.2971	3.09924	25.7739	2.37389
26.4397	3.23112	25.1827	2.76954
25.7977	2.96736	24.7393	2.37389
24.8694	2.90142		
24.297	2.57171	23.4092	2.17606
23.6549	2.70359	24.1482	2.37389
23.0116	2.63765		
22.2986	2.30795	21.6356	2.17606
21.7287	2.17606	21.1922	1.97824
21.369	2.242	20.4533	1.97824
20.7283	2.242	20.1577	1.38477
20.0862	2.17606	19.7143	1.78042
19.7291	1.97824	19.4187	1.78042
19.087	2.11012	18.8275	1.78042
18.659	1.78042	18.3841	1.58259
18.1588	1.64853	18.0885	1.58259
17.8016	1.51665	17.6452	1.38477
17.4458	1.71447	17.2018	1.38477
17.0874	1.58259	17.054	0.98912
16.6606	1.38477	16.6106	1.18694
16.4466	1.45071	16.4628	1.18694
16.1604	1.51665	16.1672	0.39565
15.6627	1.64853	15.7238	0.39565
15.2347	1.31883	16.1672	0.39565
14.8776	1.121	15.8716	0.75393
14.5926	0.39565	15.4282	0.53742
14.4495	0.92318		
14.0924	0.76152		
13.8088	1.14087		
13.596	0.34304		
16.0119	0.7913		
15.7283	1.58259		
15.4446	1.58259		
14.8773	1.18694		
14.5937	1.18694		
14.5937	0.7913		
14.0264	1.18694		
14.0264	0.7913		
13.7427	0.98912		
13.4591	1.18694		
13.3173	0.98912		
12.8918	1.18694		
12.75	0.98912		

12.4663	0.7913
12.1827	0.18524
12.1827	-0.31562

60 FAC	Dry Rate	70 FAC	Dry Rate	80 FAC	Dry Rate
289.903	8.05	273.321	5.51	282.376	33.7975
286.776	10.1776	271.289	10.7354	257.584	25.4936
283.573	11.7954	268.743	14.5629	254.069	17.2848
278.038	14.3507	261.323	17.4509	246.973	16.7293
273.022	13.6841	254.975	16.3921	240.663	19.3794
266.84	15.0566	246.025	16.6654	234.948	21.6539
262.083	15.7625	239.802	17.1958	224.635	23.1897
255.465	18.135	233.17	17.7436	215.624	22.7275
248.455	17.024	226.816	17.7926	207.942	21.9498
240.929	16.2463	219.988	18.0772	198.133	20.8585
235.602	15.4686	213.301	16.3714	190.063	15.7586
229.501	15.6908	206.643	15.7837	183.81	14.1588
222.88	15.8019	201.716	15.3123	179.967	14.8746
217.297	15.0242	195.677	14.956	173.613	16.7725
211.064	15.2464	189.539	14.4363	166.403	17.4836
205.352	13.691	185.013	13.697	160.278	17.508
199.51	13.1355	179.566	13.5708	153.132	17.728
195.093	12.6911	174.25	13.9463	145.917	17.8758
190.028	13.61	169.867	14.2121	139.579	16.3948
184.704	14.2465	163.995	14.8681	132.324	16.9503
179.215	14.5279	158.381	13.9683	126.822	15.6915
173.407	14.1053	153.27	13.9609	119.833	15.9504
167.754	12.6911	148.41	13.2864	114.044	15.0616
162.759	11.743	142.814	11.3918	108.255	14.9672
158.601	11.469	138.449	9.82838	102.309	14.3478
154.055	11.9134	135.691	9.15564	96.6465	14.3478
149.378	11.469	131.818	10.3721	89.2241	13.8867
144.702	11.469	128.205	10.3105	83.2785	13.8395
140.674	10.6913	124.102	10.6375	78.14	13.5062
135.997	10.358	118.062	10.8538	73.1035	13.284
132.228	9.91356	114.088	10.5713	67.5507	12.9507
128.587	10.0247	109.741	10.1232	62.6487	12.5485
124.431	10.5802	106.27	10.0085	58.0048	11.2842
120.532	10.0247	102.791	10.2274	52.943	11.3953
116.244	9.69136	98.5735	10.8909	49.5134	11.1309
112.735	8.91366	94.8559	9.88804	44.3212	9.86146
109.226	9.31685	90.6408	8.88534	40.5539	9.30596
105.845	9.13586	87.5418	8.32719	36.9613	8.76157
101.865	9.58026	84.9423	8.65797	33.3069	8.69491
98.5672	8.51048	81.3539	9.54438	30.1456	7.21755
94.6687	8.91366	77.8797	8.2089	26.6597	6.40665
91.9357	8.02486	74.2931	7.98453	34.4975	7.66101
88.1666	8.13596	72.1979	7.87136	31.8541	7.32771
85.3055	7.91376	68.9789	8.53599	28.8072	7.21661
82.4431	7.80266	65.5151	8.2008	25.6258	6.66111
78.9336	8.13596	62.6708	7.31019	23.1169	6.32781
76.1999	7.58046	59.8297	7.64175	20.7425	5.99451
72.9493	7.80266	57.36	6.64019	17.9646	5.77231
70.0873	7.13606	54.1492	6.6386	15.8593	3.81837
67.0959	7.02496	52.4297	6.30377		
64.6231	6.46946	49.9571	6.6356	13.0814	4.88351
61.8897	6.13616	47.1189	6.52308	10.8415	4.66131
59.5471	5.80286	45.0254	5.74402		
57.4624	6.02506	42.6891	5.96491	10.8415	4.66131
55.1186	6.29726	40.7194	5.40814	9.13972	1.19783
52.5167	6.34725	38.3769	5.40692	7.4379	-0.31171
50.114	5.35846	36.6609	5.07244		
47.7113	5.19737	34.6902	4.84911		
46.2632	4.81407	32.7271	4.40361		
44.0488	5.04094	31.2509	4.29145		
42.0944	4.58076	29.7799	3.73492		
40.3804	4.35856	27.936	3.51172		
38.7029	4.78719	27.0871	2.95526		
37.0073	4.69186	25.8628	3.45413		
34.7941	4.46966	24.6437	3.00854		
33.2279	3.79506	22.5245	3.34069		

31.792	3.69196	21.8	2.67298
30.3647	3.69196	20.2042	3.00523
28.919	3.58886	19.2072	2.33748
27.4827	3.69196	18.1131	2.61413
26.1763	3.58086	16.7421	2.39099
24.6105	3.13646	15.774	2.39019
23.3028	2.91426	14.9267	2.16732
22.5149	2.69206	14.0795	1.94448
21.208	3.13646	13.3626	2.05495
20.1611	3.02536	12.764	2.05434
18.8539	1.92208	11.7971	1.94264
17.6764	0.92604	11.0737	1.83096
23.5431	2.02735	10.601	1.71929
22.8399	3.13835	9.75756	1.82983
22.1368	3.13835	9.16003	1.49599
19.8758	3.13835	8.55793	0.71605
19.1727	2.24955	8.08362	0.21498
18.4695	0.24975	9.12644	1.34609
17.2471	2.69395	8.71227	-0.40321
18.8808	2.69395	8.2981	-1.16675
15.3216	4.47155		
14.0991	2.47175		
13.6557	2.24955		
12.4332	2.69395		
11.4705	2.24955		
10.5077	2.02735		
9.80457	2.02735		
9.10144	1.80515		
8.13867	1.58295		
7.69519	1.13855		
7.25171	-0.18327		
6.80823	-0.84418		

Table B2. Pungency data. Subsample readings in column 2,3 and 4; Average of subsamples in 5; Difference from inherent, non-enzymatically produced pyruvate in 6; Divide to for actual absorption reading in 7; and mM conversion from standard curves in 8.

60-A	data	data	data	average	adj for inherent	div by 1000	to mM
F1	2802	2766	2823	2797.0	1421.7	0.142167	1.538618
F2	2747	2808	2783	2779.3	1404.0	0.1404	1.517073
Fcook	1236	1463	1427	1375.3	1412.8	0.141283	1.527846
IR1	2489	2507	2540	2512.0	1136.7	0.113667	1.191057
IR2	2522	2477	2497	2498.7	1123.3	0.112333	1.174797
IR3	2257	2192	2293	2247.3	872.0	0.0872	0.868293
IR4	2274	2222	2364	2286.7	911.3	0.091133	0.91626
CD1	2334	2538	2543	2471.7	1096.3	0.109633	1.14187
CD2	2324	2433	2391	2382.7	1007.3	0.100733	1.033333
CD3	2177	2359	2285	2273.7	898.3	0.089833	0.900407
CD4	2363	2422	2279	2354.7	979.3	0.097933	0.999187
FA	2629	2524	2745	2632.7	1257.3	0.125733	1.338211
60-B							
F1	2821	2732	2877	2810.0	1425.7	0.142567	1.543496
F2	2767	2881	2832	2826.7	1442.3	0.144233	1.563821
Fcook	1313	1383	1457	1384.3	1434.0	0.1434	1.553659
IR1	2730	2874	2860	2821.3	1437.0	0.1437	1.557317

IR2	2551	2503	2690	2581.3	1197.0	0.1197	1.264634
IR3	2406	2480	2347	2411.0	1026.7	0.102667	1.056911
IR4	2367	2237	2266	2290.0	905.7	0.090567	0.90935
CD1	2678	2699	2570	2649.0	1264.7	0.126467	1.347154
CD2	2380	2554	2483	2472.3	1088.0	0.1088	1.131707
CD3	2663	2669	2788	2706.7	1322.3	0.132233	1.41748
CD4	2495	2376	2239	2370.0	985.7	0.098567	1.006911
FA	2897	2970	2922	2929.7	1545.3	0.154533	1.689431
70-A							0.0764x + 0.0306
F1	2973	2902	2847	2907.3	1624.7	0.162467	1.726003
F2	2947	3039	3101	3029.0	1746.3	0.174633	1.885253
Fcook	1256	1258	1334	1282.7	1685.5	0.16855	1.805628
IR1	2785	2777	2926	2829.3	1546.7	0.154667	1.623909
IR2	2564	2465	2510	2513.0	1230.3	0.123033	1.20986
IR3	2555	2585	2613	2584.3	1301.7	0.130167	1.303229
IR4	2825	2701	2844	2790.0	1507.3	0.150733	1.572426
CD1	3173	3319	3373	3288.3	2005.7	0.200567	2.224695
CD2	2436	2283	2446	2388.3	1105.7	0.110567	1.046684
CD3	2671	2651	2548	2623.3	1340.7	0.134067	1.354276
CD4	2825	2701	2844	2790.0	1507.3	0.150733	1.572426
FA	2991	3064	2877	2977.3	1694.7	0.169467	1.817627
70-B							
F1	2684	2783	2484	2650.3	1324.0	0.1324	1.332461
F2	3972	2815	2842	3209.7	1883.3	0.188333	2.064572
Fcook	1283	1350	1346	1326.3	1603.7	0.160367	1.698517
IR1	2636	2674	2791	2700.3	1374.0	0.1374	1.397906
IR2	2760	2879	2935	2858.0	1531.7	0.153167	1.604276
IR3	2665	2567	2582	2604.7	1278.3	0.127833	1.272688
IR4	2643	2681	2693	2672.3	1346.0	0.1346	1.361257
CD1	3157	2906	3014	3025.7	1699.3	0.169933	1.823735
CD2	2702	2626	2760	2696.0	1369.7	0.136967	1.392234
CD3	2509	2688	2608	2601.7	1275.3	0.127533	1.268761
CD4	2331	2426	2526	2427.7	1101.3	0.110133	1.041012
FA	2749	2743	2904	2798.7	1472.3	0.147233	1.526614
80-A							0.1009x + 0.0249
F2	5154	5121	5350	5208.3	3654.7	0.365467	3.375289
Fcook	1547	1588	1526	1553.7			
IR1	6154	5282	5897	5777.7	4224.0	0.4224	3.939544
IR2	3481	3562	3705	3582.7	2029.0	0.2029	1.764123
IR3	4303	4496	4518	4439.0	2885.3	0.288533	2.612818

IR4	3763	4144	4101	4002.7	2449.0	0.2449	2.180377
CD1	5508	4937	5629	5358.0	3804.3	0.380433	3.523621
CD2	5348	5619	5633	5533.3	3979.7	0.397967	3.69739
CD3	5550	5554	5315	5473.0	3919.3	0.391933	3.637595
CD4	5036	5123	5126	5095.0	3541.3	0.354133	3.262967
FA	4591	4782	4282	4551.7	2998.0	0.2998	2.72448
80-B							0.1082x + 0.0273
F2	5841	5839	5617	5765.7	3199.3	0.319933	2.704559
Fcook	2504	2615	2580	2566.3			
IR1	4833	5079	4808	4906.7	2340.3	0.234033	1.910659
IR2	5926	5309	4976	5403.7	2837.3	0.283733	2.369994
IR3	4815	4886	4838	4846.3	2280.0	0.228	1.854898
IR4	4631	4262	4719	4537.3	1971.0	0.1971	1.569316
CD1	4996	4892	5255	5047.7	2481.3	0.248133	2.040974
CD2	5291	5133	5375	5266.3	2700.0	0.27	2.243068
CD3	5334	5289	5519	5380.7	2814.3	0.281433	2.348737
CD4	5639	5391	5502	5510.7	2944.3	0.294433	2.468885
FA	5402	5160	5249	5270.3	2704.0	0.2704	2.246765

Table B3. Color data. L values in column 2; average (top) and SD (bottom) for L values in 3; a color values (not used) in 4; b values in 5; and avg and SD for b values in 6.

Sample	L values	Avg and SD	a values	b values	Avg and SD
60	90.59	92.5	2.02	8.29	8.655
	94.41	2.701148	1.93	9.02	0.516188
70	91.15	93.42	1.29	5.89	6.215
	95.69	3.210265	1.28	6.54	0.459619
80	86.34	88.07	1.97	12.35	13.085
	89.8	2.446589	1.79	13.82	1.039447
60NR	91.89	93.86	1.01	3.71	5.2
	95.83	2.786001	1.1	6.69	2.107178
70NR	91.22	92.87	0.86	7.26	7.71
	94.52	2.333452	0.76	8.16	0.636396
80NR	87.87	89.37	1.22	10.08	11.14
	90.87	2.12132	1.21	12.2	1.499066
60CD	86.44	83.945	3	11.65	12.175
	81.45	3.528463	2.78	12.7	0.742462

70CD	88.19	90.985	2.26	9.48	9.89
	93.78	3.952727	2.37	10.3	0.579828
80CD	91.21	93.085	1.25	7.57	7.855
	94.96	2.65165	1.08	8.14	0.403051

Table B4. Microbial load results: Sectioned into 3 trials. Results are in actual CFU/sample counts. TNTC= too numerous to count or counts greater than 250 CFU/ sample; TFTC= too few to count or counts less than 25 CFU/ sample.

		Trial 1				Trial 2				Trial 3	
APC	10.2	10.3	10.4		10.2	10.3	10.4		10.2	10.3	10.4
Fresh	19.0	38.0	TFTC		71.0	142.0			DATA		
	23.0	46.0	TFTC		102.0	204.0	173.0		LOST	3.50E+05	
	10.1	10.2	10.3		10.2	10.3	10.4		10.1	10.2	10.3
60 IR	TNTC	6.0	TFTC	1.0	177.0	TFTC	TFTC	1.0			
	TNTC	4.0	TFTC		150.0	TFTC	TFTC				
70 IR	TNTC	4.0	TFTC	3.0	102.0	TFTC	TFTC	3.0			
	TNTC	8.0	TFTC		91.0	TFTC	TFTC				
80 IR	TNTC	5.0	TFTC	5.0	83.0	TFTC	TFTC	5.0			
	TNTC	3.0	TFTC		102.0	TFTC	TFTC				
60 FAC	TNTC	6.0	TFTC	2.0	110.0	TFTC	TFTC	2.0		DATA	
	TNTC	16.0	TFTC		130.0	TFTC	TFTC			LOST	
70 FAC	TNTC	TNTC	21.0	4.0	107.0	TFTC	TFTC	4.0			
	TNTC	TNTC	1.0		119.0	TFTC	TFTC				
80 FAC	TNTC	7.0	TFTC	6.0	127.0	TFTC	TFTC	6.0			
	TNTC	10.0	TFTC		85.0	TFTC	TFTC				
	10.2	10.3	10.4		10.2	10.3	10.4		10.2	10.3	10.4
Fresh	14.0	TFTC	TFTC		TNTC	101.0	TFTC		DATA		
	14.0	TFTC	TFTC		TNTC	85.0	TFTC		LOST	3.20E+05	
Coliform											
	10.1	10.2	10.3		10.2	10.3	10.4		10.2	10.3	10.4
60 IR	0.0	0.0	0.0	1.0	9.0	TFTC	TFTC	1.0	2.0	TFTC	TFTC
	0.0	0.0	0.0		13.0	TFTC	TFTC		3.0	TFTC	TFTC
70 IR	0.0	0.0	0.0	3.0	3.0	TFTC	TFTC	3.0	1.0	TFTC	TFTC
	0.0	0.0	0.0		0.0	TFTC	TFTC		4.0	TFTC	TFTC
80 IR	0.0	0.0	0.0	5.0	1.0	TFTC	TFTC	5.0	0.0	TFTC	TFTC
	0.0	0.0	0.0		0.0	TFTC	TFTC		0.0	TFTC	TFTC
60 FAC	0.0	0.0	0.0	2.0	4.0	TFTC	TFTC	2.0	2.0	TFTC	TFTC
	0.0	0.0	0.0		14.0	TFTC	TFTC		3.0	TFTC	TFTC
70 FAC	0.0	0.0	0.0	4.0	14.0	TFTC	TFTC	4.0	3.0	TFTC	TFTC
	0.0	0.0	0.0		5.0	TFTC	TFTC		0.0	TFTC	TFTC
80 FAC	0.0	0.0	0.0	6.0	TNTC	1.0	TFTC	6.0	0.0	TFTC	TFTC
	0.0	0.0	0.0		TNTC	1.0	TFTC		0.0	TFTC	TFTC
	10.2	10.3	10.4		10.2	10.3	10.4		10.2	10.3	10.4
Fresh	4.0	TFTC	TFTC	366.0	183.0	50.0	TFTC		DATA		
	4.0	TFTC	TFTC	350.0	175.0	55.0	TFTC		LOST	6.90E+04	

Y&M

	10.1	10.2	10.3		10.2	10.3	10.4		10.2	10.3	10.4
60 IR	40.0	TFTC	TFTC	1.0	144.0	30.0	TFTC	1.0	124.0	27.0	TFTC
	50.0	TFTC	TFTC		147.0	28.0	TFTC		126.0	28.0	TFTC
70 IR	25.0	TFTC	TFTC	3.0	76.0	TFTC	TFTC		150.0	26.0	TFTC
	23.0	TFTC	TFTC		61.0	TFTC	TFTC	3.0	103.0	30.0	TFTC
80 IR	36.0	TFTC	TFTC	5.0	27.0	TFTC	TFTC		90.0	TFTC	TFTC
	34.0	TFTC	TFTC		28.0	TFTC	TFTC		108.0	TFTC	TFTC
60 FAC	116.0	TFTC	TFTC	2.0	TNTC	52.0	TFTC	5.0	26.0	TFTC	TFTC
	84.0	TFTC	TFTC		TNTC	53.0	TFTC		29.0	TFTC	TFTC
70 FAC	111.0	TFTC	TFTC	4.0	TNTC	43.0	TFTC		27.0	TFTC	TFTC
	127.0	TFTC	TFTC		TNTC	55.0	TFTC	2.0	TNTC	70.0	TFTC
80 FAC	58.0	TFTC	TFTC	6.0	120.0	TFTC	TFTC		TNTC	58.0	TFTC
	59.0	TFTC	TFTC		129.0	TFTC	TFTC		TNTC	68.0	TFTC
								4.0	208.0	53.0	TFTC
									207.0	54.0	TFTC
									197.0	59.0	TFTC
								6.0	117.0		TFTC
									92.0	25.0	TFTC
									90.0	30.0	TFTC