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COMPUTER ASSISTED MONITORING AND CONTROL IN FLORIDA CITRUS DEGREENING

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Abstract. **A personal computer-based data acquisition system was configured to monitor and control environmental conditions for Florida citrus degreening. Variables targeted initially for monitoring included: fan operation, temperature, relative humidity, ethylene concentration, ethylene flow rate and carbon dioxide levels. Copper-constantan thermocouples were used for sensing temperatures throughout the room while a lithium chloride sensor was utilized for relative humidity. The installation was configured for either local dedicated control or remote location access through a personal computer unit. The system was evaluated in a pilot plant degreening facility functioning either to monitor or monitor and control the degreening process. Data acquisition boards were interfaced through the computer's parallel printer port sampling at a maximum single channel throughput of 2KHz with 12-bit resolution, under Windows 95-based software. Heated air was controlled within a ± 0.5°C while relative humidity was controlled at ± 0.9% RH. Appropriate transducers for the ethylene gas concentration range of 0 to 10 ppm encountered in citrus degreening were not identified. Ethylene was regulated only by the flow rate and room air exhaust rates. Carbon dioxide levels were measured at 2 to 4 times normal background concentrations, which should not impede degreening.**

Citrus fruit degreening is an essential operation to market fruit which has met internal maturity standards but has poor surface color. Temperature, humidity and ethylene gas concentrations have been investigated for Florida citrus (Grierson and Newhall, 1960) and generally accepted practices have been established (Wardowski, 1989). However, minimal advancement has been made in real-time monitoring and control of these parameters. Restrictions have been economic and the low yearly utilization of degreening facilities. Quality control program implementation and reduced risk assessment with equipment failure in large degreening facilities are features available with monitoring and control systems. Also, with the advancements in sensor technologies and personal computer (PC) systems, the ability to automate degreening operations is more economically viable. A general review of this PC-based approach is described by Logan (1996) while Studt (1996) details the specifics of the Windows 95 operating system for data acquisition. Zdankiewicz (1997) recently reviewed gas detection techniques applicable to monitoring systems.

PC-based monitoring and control has merit for environmental storage of numerous fresh fruits or vegetables. Landry and Norris (1995) describe automated control for potato storage and Black (1994) detailed an controlled atmosphere apple facility. In the need to measure gas concentrations, citrus, bananas and tomatoes are exposed to ethylene under controlled environmental conditions. Objectives of this research and development project were to:

1. Develop a package of electronic sensors to measure temperature, humidity and gas concentrations important in citrus degreening.
2. Interface these sensors with a PC-unit for automated monitoring and control of the degreening environment.
3. Evaluate the system in a pilot plant degreening facility.

Experimental Configuration

Sensors. Sensors were selected for this project based on general availability and electronic data acquisition capability. Instrumentation accuracy, repeatability (Doeblin, 1966) and price range were considered also. A list of the parameters measured, sensors selected, and their electronic output and range was compiled in Table 1. Copper-constantan thermocouples were selected because of their low cost which allowed measurement of multiple locations within the test room. These thermocouples also provide versatility for other uses such as temperature monitoring of refrigerated storage rooms. Disadvantages are the low, nonlinear output signal. Humidity measurements were made with a lithium chloride sensor employed for commercially available humidistats (Newport Scientific; Jessup, MD) with selection of a narrow range unit, 81 to 99% RH with ± 1% accuracy.

Gas concentration of carbon dioxide was measured with a single wavelength non-dispersive infra-red gas sensor. Two units were evaluated. In the first unit (Techni-System, Chelan, WA) having 0 to 5000 ppm range, sampled air was drawn from the room through an infra-red sample module. The second unit from a different source (Vaisala; Woburn, MA) ranged from 0 to 3000 ppm CO_2 and was placed directly within the degreening room and energized with a 24 V_{DC} power supply. No ethylene sensors were identified specific to the required range of 0 to10 ppm recommended for citrus degreening. A semiconductor unit based on a selective alumina substrate integrated with a platinum heater was tested at higher ethylene concentration. The heater driver secondary circuit required for this unit produced a non-linear output of %/ppm^0.5 sensitivity.

Fan operation was monitored with a differential pressure cell with the high pressure side tube placed in the drop ceiling air duct and the low pressure part at the fan inlet. Ethylene consumption rate was measured with an in-line flowmeter (McMillan; Copperas Cove, TX) arranged in series

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Table 1. Parameters, sensors and electronic measurements.

Parameter	Sensor	Range	Voltage output	Manufacturer
Fan operational status	Differential pressure	0-2.5 in H_2O	0.1-5.1 VDC	Setra
Ethylene consumption	Flowmeter, in-line	10-50 ml/min	0-5 VDC	McMillan
Ethylene consumption, tank level	Load cell	0-150 kg	ca. 2 mV/V	RL Electronics
Temperature	Thermocouple, Cu-Co	-200 to 350°C	low mV, non-linear 4.277 mV @ 100°C	Omega
Relative humidity	Lithium chloride	75-100% RH	0-1 VDC, non-linear temperature-dependent	Hygrodynamics
Carbon dioxide	Infra-red, single wavelength	0-3000 ppm	0-10 VDC	Vasisala
Ethylene	Semiconductor	0-500 ppm	with sec. circuitry ca. 0.75-1.25 VDC	Capteur

with a micro-metering valve and bubble count canister. The ethylene tank was placed on a load cell platform for continuous weighing to measure the consumptive rates. Low-pass capacitive filtering was added to the load cell's Wheatstone bridge output circuitry.

Monitoring and control. To monitor output from above-mentioned sensors, data acquisition boards (Strawberry Tree; Sunnyvale, CA) were interfaced with a personal computer. Both hardware and software were considered to provide maximum flexibility in configuring the various transducers. Although the first stage was monitoring only, digital input (I/O) was specified to allow direct computer control. All digital I/O connections were channeled through optically isolated modules. This allowed a configuration where only transducer or low voltage DC (<5 V) signals were wired into the control computer data acquisition system. A modular configuration using Strawberry Tree Data Shuttle boards was configured in parallel and connected to a 66 MHZ Pentium™ personal computer. The software package was Programmer's Work Bench for Windows (PWW) running under Windows 95. The interface between the Data Shuttle boards and the computer utilized the printer parallel port. In caching data and logging to disk, the sampling interval was set at 20 sec with these 20 sec values averaged over 5 min. Average readings for each channel were then logged to disk at a 5 min interval. Analog to digital conversion was conducted at 12-bit resolution, low noise (60 Hz rejection) rate. This sampling configuration was programmable from the PWW software. Features included: sampling rate control, linear and non-linear calibration, averaging, disk storage plus a real-time color monitor display.

Control loops were set up for either local or remote (computer) control of temperature and humidity. Room carbon

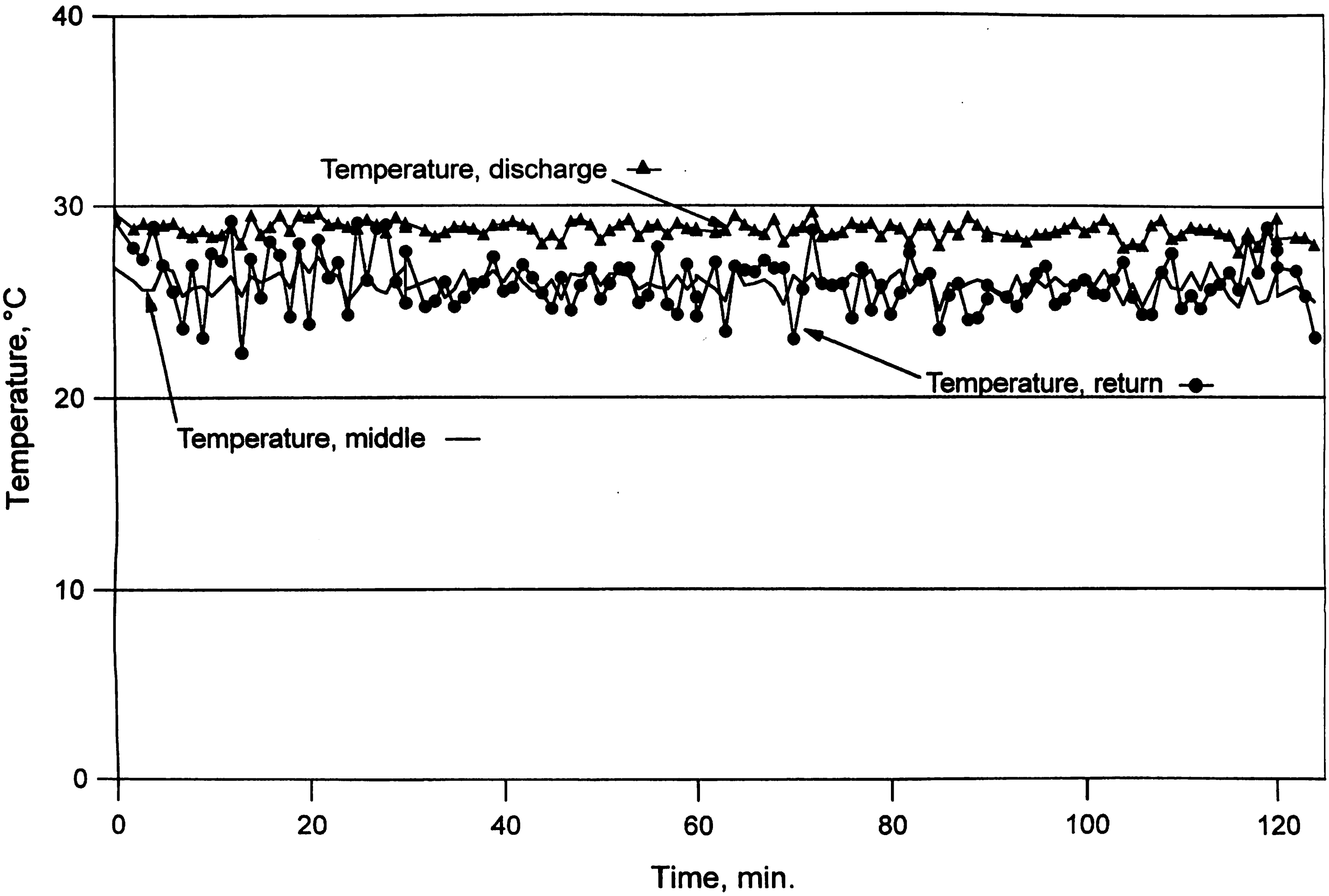

Figure 1. Temperature monitoring at return, discharge and mid-room locations in pilot plant citrus degreening facility.

dioxide could be controlled only via the computer system. Standard off-on control strategies were utilized for the temperature (deadband of ± 0.4°C) and relative humidity (deadband of ± 2% RH) under local control. The CO_2 control functioned only in PC-based control to reduce the CO_2 room levels to preset thresholds. Small muffin fans, ca. 100 cfm capacity, were energized when above the threshold level introducing additional ambient air into the degreening room.

Results

This first phase of the project was directed toward monitoring of the degreening room variables. Typical measurements of temperature at various room locations are plotted in Fig. 1. The return air, a mix of outside ambient and room air, exhibited the largest variation. Variation in the return air was $T_{avg.}$ = 25.6°C with $T_{s.dev.}$ = 1.5°C (C.V. = 5.9%). After heating, the discharge conditions were $T_{avg.}$ = 28.0°C with $T_{s.dev.}$ = 0.5°C (C.V. = 1.9%). These values represent data collected for 4 one-day experiments conducted with a minimal fruit load of <10% of 5000 kg maximum room capacity. Typical temperature and humidity results with greater fruit loads, ca. 20% full capacity, are plotted in Fig. 2. Both discharge temperature and humidity exhibited only small variation. Corresponding values for computer control were similar. Return air conditions were $T_{avg.}$ = 25.7°C, $T_{s.dev.}$ = 1.8°C (C.V. = 6.9%) while the discharge conditions were $T_{avg.}$ = 28.8°C, $T_{s.dev.}$ = 0.6°C (C.V. = 2.1%). Relative humidity values averaged 93.6% RH with $RH_{s.dev.}$ = 0.9% (C.V.= 0.9%) in local control while corresponding values of $RH_{avg.}$ = 92.0%, $RH_{s.dev.}$ = 0.6% (C.V.= 0.7%) for computer control.

In sensing ethylene, temperature drift and sensor instability of the solid-state metal oxide unit resulted in unacceptable variation and poor repeatability in concentrations <50 ppm. The load cell arrangement functioned adequately to indicate total level of ethylene in a cylinder but was not accurate in indicating real-time consumptive rates. The small turbine meter, with a 10 to 50 ml/min range, provided satisfactory results and should adequately operate in larger degreening facilities as the flow rates would be closer to mid-scale readings.

The first generation CO_2 sensor was unreliable as temperature interaction, changes were evident and baseline levels were found at 1.5 to 2× above background levels. This unit was replaced by a second unit which did not exhibit significant fluctuation with temperature changes. Background levels were higher than expected (Fig. 2) but this background concentration level varied only by 5 to 10%. Carbon dioxide may retard degreening but the levels required are relatively high: >10,000 ppm (Grierson and Newhall, 1960), >25,000 ppm (Cohen, 1973). Levels encountered in the partially load-

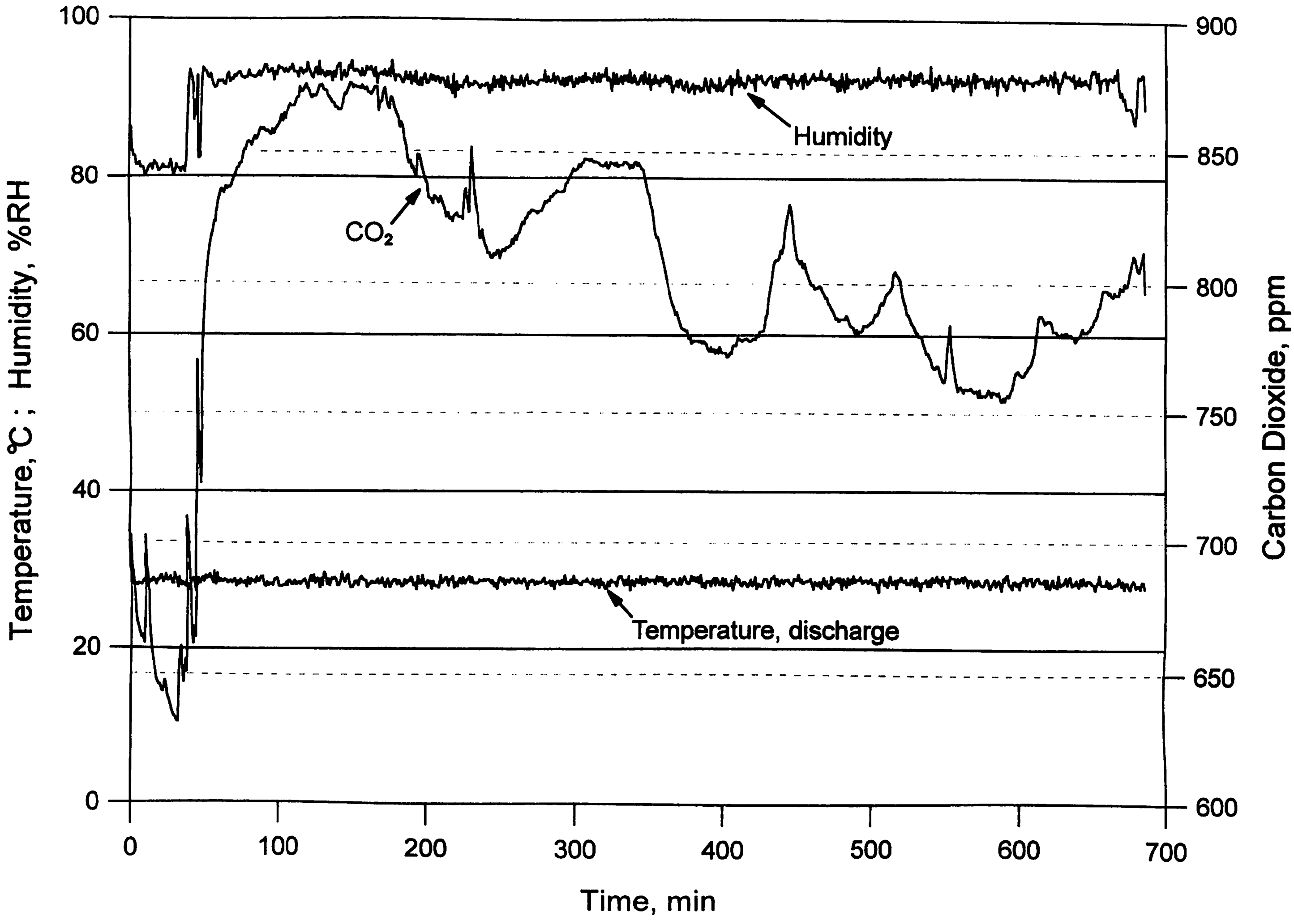

Figure 2. Temperature (discharge), relative humidity and carbon dioxide monitoring in pilot plant citrus degreening facility.

ed pilot plant degreening rooms of this study were <1500 ppm. Using the personal computer control system, levels could be maintained at <850 ppm via energizing the muffin fans added to the degreening room creating a higher fresh air exchange rate. However, this level would be elevated with greater fruit loads. In measuring fan capacity, the differential pressure transducer yielded consistent results when under load by fruit in the degreening room. However, under free air conditions, significant positive to negative fluctuation was noted.

Conclusions

Monitoring and control of citrus degreening was implemented in a pilot plant degreening facility for temperature, relative humidity, airflow and carbon dioxide levels. Discharge temperatures were controlled ± 0.5°C and relative humidity at ± 0.9% RH. This control was accomplished through either dedicated local controllers or through a remote PC-based control system. Principal advantage of the PC approach is the capability for data logging, interfacing to remote locations, alarming and coupling monitoring or control strategies. The system could be extended to multiple rooms typically found in commercial operation. An economic sensor system for ethylene at 0 to 10 ppm was not identified. Carbon dioxide was monitored at < 2000 ppm with an infra-red detection system. For economic viability, a multi-port sampling system would be required for both ethylene and carbon dioxide sensing for packinghouse implementation. Control of such a multi-port configuration is adaptable to the digital I/O capability of PC-control.

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GRANULATION IN GRAPEFRUIT

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Abstract. **Temporal studies were conducted from mid- to late-harvest season of 'Ruby Red' and Marsh grapefruit (*Citrus paradisi* Macf.) to evaluate the effect of on- and off-tree storage, fruit size, and juice vesicle position on the development of granulation. Juice vesicle fresh and dry weights were highest at the stem and stylar positions of the fruit section and did not significantly change for fruit remaining on the tree or harvested and stored. Juice vesicles isolated from each position were subjectively evaluated for the presence of granulation. No granulation was observed in juice vesicles of Marsh grapefruit of any size. Granulation was highest in stylar juice vesicles obtained from large Ruby Red fruit (~600 g) that were harvested late in the season (March and May) and stored in air at 21°C for 60 days. Stylar juice vesicles from freshly harvested large Ruby Red fruit in March and May or fruit harvested in January and stored for 60 d had low granulation scores. Thus, Ruby Red fruit remaining on the tree until May, but of the same chronological age as fruit harvested in March and held in storage until May, were less susceptible to the disorder. Alcohol-insoluble solids (AIS), largely composed of pectins and other cell wall materials, significantly increased in juice vesicles that were granulated. The results suggest that storage itself was not responsible for the marked accumulation of AIS measured in granulated juice vesicles. Rather, some interaction of fruit size with maturation, as well as other factors, likely contributed to the development of granulation.**

Florida grapefruit have a lengthy harvest season that typically begins in October and lasts through April or May. In the latter part of the grapefruit harvest season, a physiological disorder known as granulation can appear (Bartholomew et al., 1941). A symptom of granulation is the tough, dry nature of individual juice vesicles within the segment. Grapefruit contain 10-14 sections/fruit, and 154 to 319 juice vesicles are found in each section, depending on variety (Tisserat et al., 1990). Each juice vesicle is composed of large, highly vacuolate parenchyma cells surrounded by a defined hypodermis and overlying epidermis (Burns et al., 1992). Granulated juice vesicles have been reported to be enlarged, tough in texture, discolored and lower in soluble sugars and acids (Bar-

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