PHYSICAL AND THERMAL PROPERTY MEASUREMENTS IN FLORIDA CITRUS PACKINGHOUSES

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To optimize the process and handling operations while maintaining fruit quality from grove-to-consumer, it is critical that the conditions which fresh citrus encounter are monitored and controlled. These conditions may be chemical, physical or thermal in nature. In many instances, the conditions must be maintained or monitored jointly, e.g., pH (chemical) and temperature.

The major emphasis of this presentation will be to detail means of measuring temperature, humidity, airflow and mechanical parameters. Also, it is important to address how such sensor data are utilized. Data may be used to monitor only, monitor/control or monitor/control/archive. The era of the personal computer has made the latter possible and such systems may provide valuable database information. Two references should be noted for those who would like more detailed information on instrumentation; they are Mitchell 1983 and Malmstadt *et al*. 1981. Complete citations are given in the references at the end of this manuscript.

Temperature, Humidity and Airflow

Temperature, humidity and airflow are factors in:

1. Degreening rooms
2. Color-add process
3. Packingline dryers

4. Refrigerated storage and transport
5. Quarantine treatments

Temperature

Temperature is one of four fundamental quantities (along with mass, length and time). To measure temperature, a reference point and a rule for measuring temperature differences must be established. The Fahrenheit scale has values of 32°F and 212°F at freezing and boiling points of water with absolute zero at -459.7°F. The Celsius scale has values at 0°C and 100°C for ice and boiling points of water and absolute zero at -273°C.

Two temperature sensors that are used extensively but do not produce an electrical output are the bimetallic and expansion liquid-in-glass types. In the bimetallic type, two metal strips with different coefficient of expansion values are bonded together. The metal strip will distort in proportion to a temperature difference. The bimetallic type is very popular in low cost thermostats and dial type thermometers. The liquid expansion type is very popular in laboratory and industrial applications. They can usually be immersed in any fluid media and very high accuracies are achievable.

There are four types of temperature sensors that are used in electronic circuitry, either active or passive. These sensors are IC (integrated circuit) sensors, RTD (resistance temperature detector) devices, thermocouples and thermistors.

All are widely used and each has certain advantages and disadvantages. For example, thermocouples are very low in cost but the output is very small (microvolts) and non-linear. External circuitry is needed for cold junction referencing, linearization and signal conditioning. Thermistors have a limited temperature range, typically 0 to 100°C. RTD's are more expensive but are highly accurate and can be used over a broad temperature range. IC units provide a direct voltage output but they must be calibrated and their interchangeability is poor. For all of the above-mentioned sensors, general installation procedures should consider (Stroik 1986):

1. Selecting a location where the temperature of the measured media is representative, i.e. avoid stagnated locations.
2. Providing sufficient insertion into a media when penetrating a containment to avoid thermal losses.
3. Avoiding radiant heat from surrounding areas.
4. Avoiding frictional heat by the measured media.
5. Isolating measuring circuits from power circuits or from the influence of power circuits.
6. Providing periodic in situ testing and convenient replacement.

Another type of temperature sensing technique is radiation thermometry where the emitted radiation in the infrared spectrum is measured. The major advantages in infrared measurements are that the technique is nonintrusive and that high temperatures can be measured.

An unknown for many biological materials is the emissivity of the material but such values are normally high, greater than 0.85. A summary of advantages/ disadvantages for the above transducers has been summarized in Table 12.

Humidity

Humidity is that property dealing with the amount of moisture in air-water vapor mixture. The maintenance of a high humidity is critical in preventing desiccation of fresh fruits and vegetables. In drying, a low humidity is essential to expedite the drying process. The water holding capacity of air exhibits a non-linear relationship with air temperature. Therefore, either graphical or computer based techniques are commonly used to describe air-water properties.

The graphical technique is the well-known psychrometric chart (Figure 11). Common terms that are used in describing water vapor in air include:

absolute humidity--mass of water vapor per unit weight of dry air

relative humidity (RH) --ratio of actual water vapor in air to water vapor at saturation for the same temperature, typically expressed as a percentage.

dew point temperature--temperature to which, if air is cooled, condensation or dew formation will occur.

wet-bulb temperature--when cooling air via evaporation of

Table 12. Advantages/disadvantages of various temperature sensors.

Sensor	Advantages	Disadvantages
IC Sensor	Low Cost Linearization	Limited temperature range Initial circuitry Component matching
IR Thermometry	High temperature Portability Initial cost Non-linearity	Accuracy Meas. variables (target distance, angle of obs., ambient temp., material emissivity)
RTD	Very high accuracy Can be used for narrow span No compensation is necessary Small size, fast response	Expensive Fragile Lead-wire and contact resistance Self-heating
Thermistor	Small size, fast response No cold junction compensation Narrow span Rather stable	Non-linear output Interchange-ability Wide span Self-heating error
Thermocouple	Broad temp. range -270 to 1800°C (-450 to 330°F) Low cost Small size	Highest non-linearity ROM linearization req. Limited inter-changeability High drift (± 2°C/yr) Cold junction compensation Small signal output

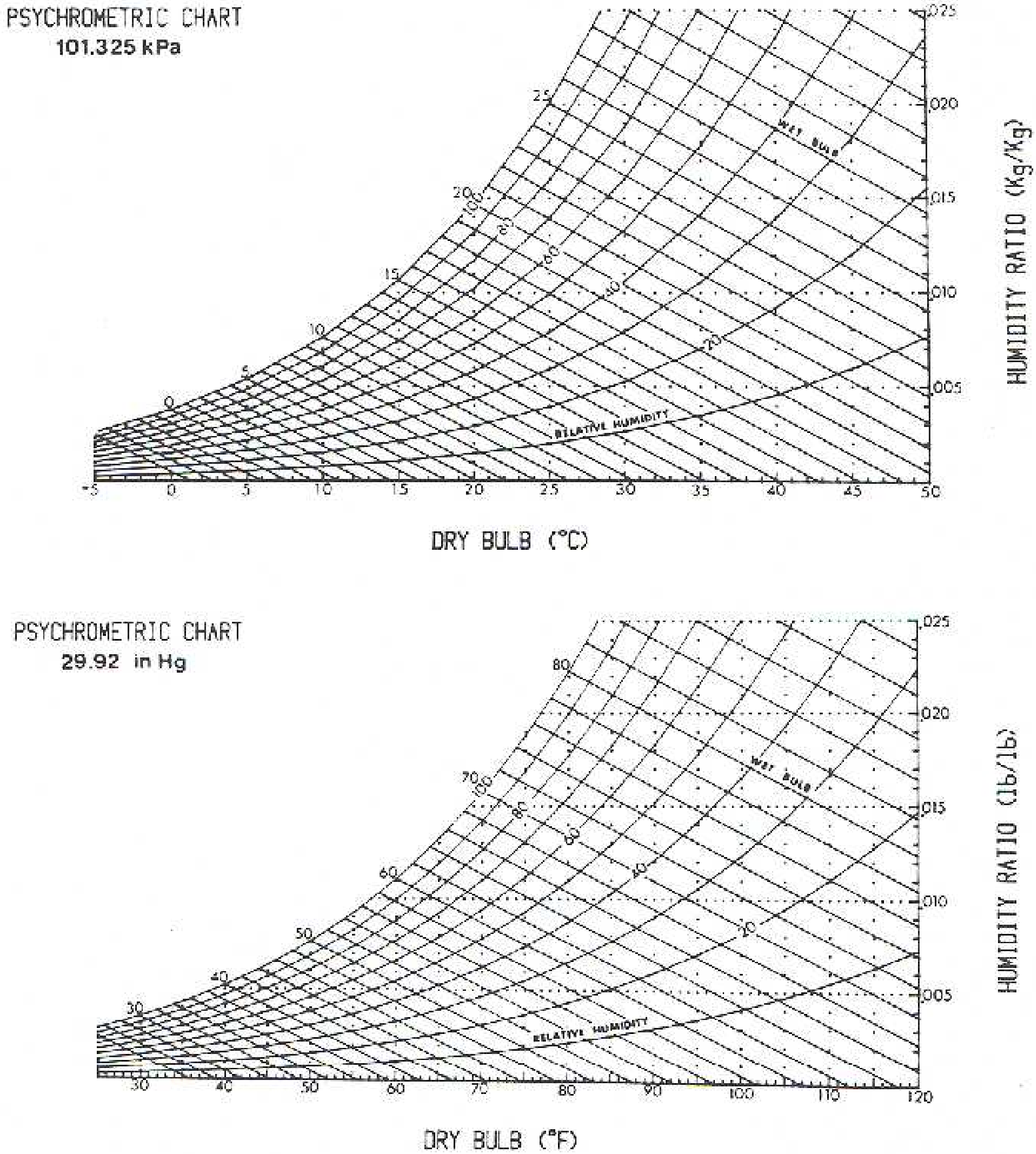

Figure 11. Psychrometric charts (°C and °F) for normal conditions (ASHRAE 1963).

moisture, the temperature to which the air is cooled and reaches a saturation condition.

When any two of the above properties are known, the other properties may be determined. Hence, one of the most common methods in measuring relative humidity is to measure dry and wet bulb temperatures and then calculate relative humidity. Having sufficient air velocity over the wet-bulb wick is critical; typically > 5 m/s (16 ft/sec). Using a chilled mirror, dew-point temperature can also be used. Saturated salt sensors (lithium chloride) are also used to determine water vapor equilibrium. These sensors are relatively low in cost but have a narrow RH range and a slow response time.

For citrus applications, degreening control is critical and conditions of 85°F and > 90% RH should be maintained (Wardowski 1989). Dryer temperatures less than 140°F are recommended (Miller 1981). However, the drying rate is dependent on the psychrometric air state and airflow rate.

Airflow

As mentioned previously, airflow is an important factor in storage and heat/mass transfer operation (cooling, drying, heating, etc.). In most instances, the starting point should be known design information. A fan will have certain operating characteristics defined by a flowrate vs. pressure curve (Figure 12). This type of information is provided by the manufacturer and the testing procedures (AMCA 1988). For packinghouse conditions, two common airflow measuring devices include the classic pitot tube method (Figure 13) and the more expensive thermal meters such as a hot wire anemometer. The pitot tube measures a pressure differential ([velocity + static]-static) to yield a resultant pressure proportional to velocity squared. The hot wire anemometer is based on a resistance change of some heated element and the variation of that resistance as influenced by airflow past the wire.

For citrus degreening rooms, the airflow requirement is based on 100 ft^3/min per pallet bin. A 200 pallet room would therefore require approximately 20,000 cfm of air. Across a cross-sectional area of 10 ft^2 (e.g. back wall ducts), the resultant velocity would then be 2000 ft/min. That velocity would be satisfactory for standard duct design. For dryers, cfm/ft^2 of conveyor surface is a logical unit for a design criteria and an approximate number from the literature (Lewis 1981; Miller 1985; Rose 1982) is 100 cfm/ft^2. Conditions for cold rooms and transportation containers can be found in (ASHRAE 1987, 1989).

Mechanical measurements

For packingline applications, mechanical measurements are relevant to proper materials handling design. For example, matching conveyor speeds to mitigate fruit "pile up" on a belt-to-belt transfer is critical. Linear velocity is readily measured by noting the transfer distance and corresponding time for any object placed on the packingline.

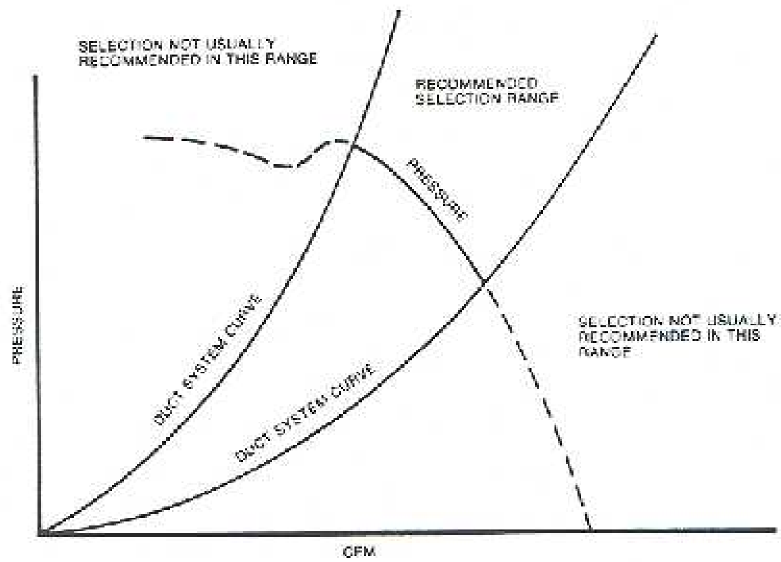

Figure 12. Typical performance curve of a centrifugal fan.

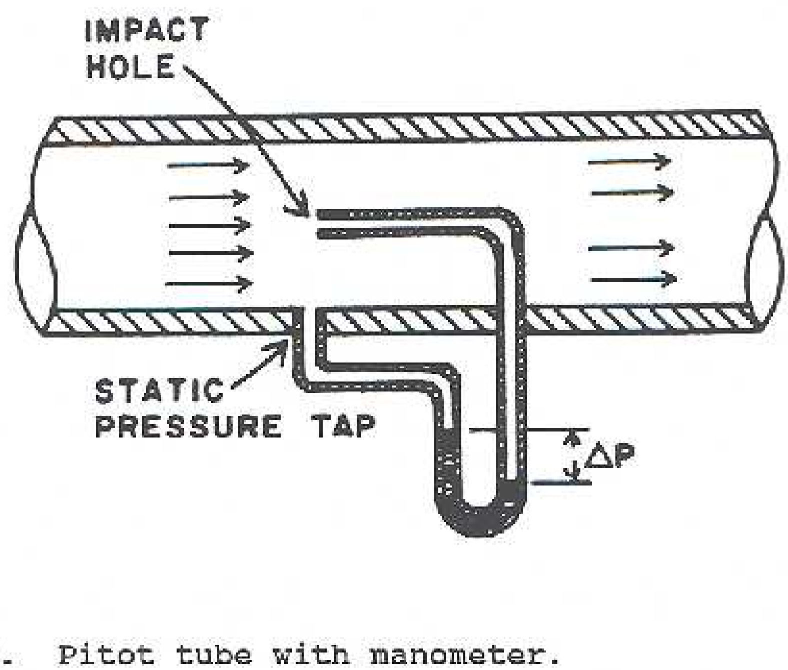

Figure 13. Pitot tube with manometer.

Linear velocity can also be calculated knowing motor speed and pulley or gear ratio between the conveyor and motor. Rotation speed is typically measured by a tachometer. These may be mechanically coupled or direct contact type similar to car speedometer or non-contact where optical or electrical (Hall effect, magnetic) proximity switches are utilized. To convert from rotation motion to linear velocity, the equation is based on the radius and rotational frequency (Wardowski et al. 1987).

A relatively new concept is the on-line assessment of potential impact damage via an instrumented sphere. Since this technique is mechanical in nature, i.e., measuring acceleration levels, it will be reported here. The unit consists of a triaxial accelerometer, signal conditioning unit and computer memory (Figure 14). Communication is through a RS-232 interface.

A threshold acceleration value, normally 35-40 g's for citrus packinghouses, was programmed into the unit and all data greater than the threshold level were stored. Upon completion of a given packingline test, the data were downloaded into a personal computer for further analysis. Typically, sampling rates were 4000 Hz. By Nyquist analysis, this means values up to 2000 Hz (0.5 msec/reading) could be analyzed. Florida citrus packinghouse data are compiled in Table 13. Dump areas along with presizers and master sizers

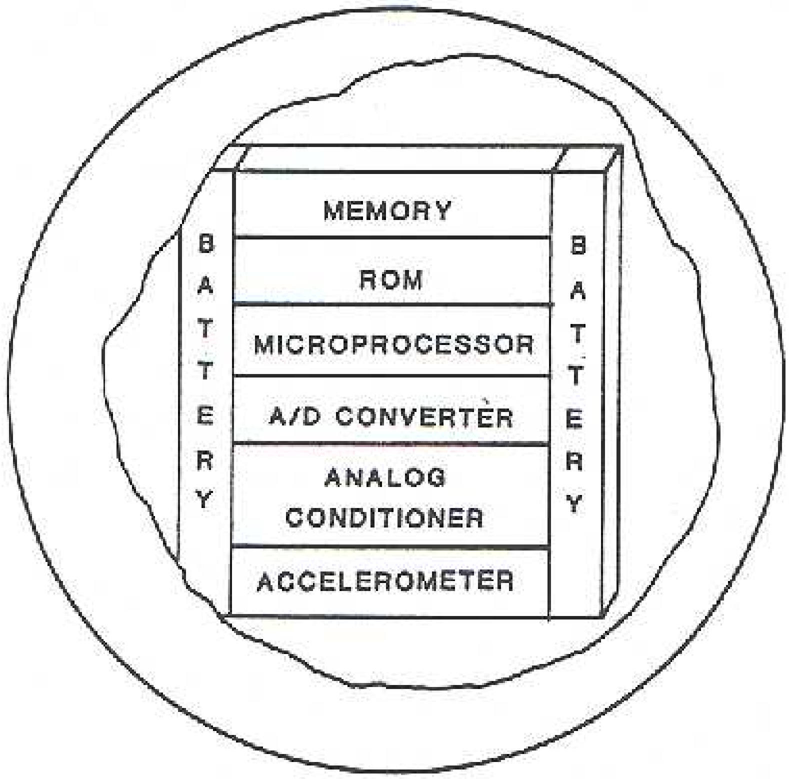

Figure 14. Instrumented sphere unit (USDA-ARS, East Lansing, MI) for measuring impacts.

were found to be locations for numerous impacts of relatively high amplitude in citrus packinghouses (Tables 13 and 14).

COMPUTER APPLICATIONS

The use of computers may be integrated at various levels. In hierarchal order, potential utilization would be a follows:

a. Unit operation/mechanical operation (process or programmable controller).

b. Distributed or supervisory (multi-operation control and integration).

Table 13. Instrumented sphere (IS) summary data for Florida citrus packinghouses; 1988-1989 and 1989-1990 seasons.

Measurement	Value
No. of packinghouses:	29.0
Avg. no. of impacts per packinghouse:	22.1
Avg. g level of impact:	100.1
Equivalent ht. (m):	0.1
Avg. no. of impacts per packinghouse above 150 g:	2.5
Avg. no. of impacts per packinghouse above 250 g:	0.4

Table 14. Instrumented sphere (IS) unit summary for Florida citrus packinghouses; 1988-1989 and 1989-1990 seasons.

Unit operation	Number of observations	Number of impacts	Average g level
Dump	29	59	139.9
Presizer	13	37	96.6
Sizing	14	43	102.3

c. Plant-wide operation (level b plus tie-in to other operations, e.g. inventory).

d. Company-wide/industry-wide operation (level c plus tie-in to other suppliers, customers, market information.

At the basic level (a), the computer, typically a dedicated microprocessor, provides control/action with the enhanced capability for ease of adjustment and ability to acquire/access data. In monitoring degreening rooms, one might query: did your degreening temperatures rise above 90°F? For how long? Did the alarm activate? If a microprocessor-based system were implemented in this application, the unit could readily regulate temperature, provide a secondary safety to shut off a heater, trigger an alarm if excess temperatures occur and provide a record of time-temperature exposure for each load of fruit that is treated.

The Florida citrus industry is now implementing bar coding, automatic sizing, bagging and palletizing. These units are based on either programmable controllers or dedicated microprocessors. The more advanced systems have communication links for operator interfacing or data transfer. The next logical steps are automatic grading and system integration. Database record keeping will become more important in discerning factors from grove-to-consumer that affect fruit quality. The era of computerization reaching packinghouses has arrived. The question is now: How to implement such technology to maximize fruit quality and enhance productivity. Perhaps the best advice that can be offered is to analyze, simplify and plan before you automate.

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