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Design Aspects in the Precooling Process of Fresh Produce

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ABSTRACT

Temperature is the most single important factor which affects the storage life and the quality of fresh produce. The process of precooling is the removal of field heat as soon as possible after harvest since field heat arrest the deterioration and senescence process. The pre-cooling process can be achieved via different methods. Forced air precooling is the most common technique and is adapted to many commodities. The classification of the forced air precooling process includes wet deck system and the dry coil technique. Wet deck system is a mechanism which provides air of low temperature and higher level of relative humidity which minimizes the weight loss of produce during the process of cooling. Dry coil system uses a direct expansion or secondary coolant coil sized to operate at a small temperature difference which will maintain a high relative humidity of the leaving air stream. An evaluation of both systems is presented through the current study that exhibits a description of the theory behind each system and its different components. Through this study, it is aimed to promote interest in precooling and encourage its use on a more widespread basis via the illustration of the different systems details.

Keywords: design, forced-air cooling, dry coil, wet deck

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INTRODUCTION

Fresh produce (vegetables, fruits and flowers) are living biological organisms that must stay alive and healthy even after harvest and during the handling chain until they are either processed or consumed. Highly perishable produce and because of their exposure to extremes of sun heat (field heat) and due to ambient temperature contain substantially more warmness at harvest than is normally acceptable during their subsequent marketable life chain or storage. Before harvest, the parent plant, compensate losses caused by respiration and transpiration by water, photosynthesis and minerals. After separation of the parent plant (harvest), and if field heat is not properly and festally removed, it causes water loss, wilting and shriveling which leads to a serious damage in the appearance of produce (Finger *et al*. 2007). Such heat also accelerates respiratory activity and degradation by enzymes. It encourages the growth of decay-producing microorganisms and increase the production of the natural ripening agent, ethylene. A rule of thumb is that a one-hour delay in cooling reduces a product's shelf-life by one day (Hugh and Fraser 1998). This is not true for all crops, but especially for very highly perishable crops during hot weather.

Postharvest cooling was scientifically developed by US Department of Agriculture in 1904 (Ryall *et al*. 1982). The first commercial precooling facility was built in Californian in 1955 and was used for cooling grapes destined to Florida market (Watkins 1990). Several definitions for postharvest cooling can be found in the literature: the removal of field heat from freshly harvested produce in order to slow down metabolism and reduce deterioration prior to transport or storage; immediate lowering of commodity field heat following harvest; and the quick reduction in temperature of the product (Brosnan and Sun 2001).

The cold chain is a shortened term encompassing all temperature management programs and other steps and processes that perishable must pass through to ensure they reach the end-consumer in a safe, wholesome and high-quality state. The cold chain should start immediately after harvest and contentious through the packing process, pre; storage; transportation and cool storage at the receiving

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market (Artés 2004). Another definition for the cold chain is the progressive removal of heat from the produce, starting as soon as possible after field harvest, in the shortest practical time period. The cold chain program should remove all field heat from the produce down to its lowest optimum storage and/ or shipping temperature.

THE IMPORTANCE OF PRECOOLING

Within the cold chain, temperature is the greatest determent and the most significant environmental factor that influences the deterioration rate of harvested commodities. The rate of respiration, and subsequently the rate of heat production depends on temperature, the higher the temperature, the higher the rate. Rapid precooling to the product's lowest safe temperature is most critical for Fresh produce with inherently high respiration rates. Rapid precooling is the first operation of the cold chain to be started from the instant of harvest, and considered the key element in modern marketing chain of fruits and vegetables. It removes field heat after harvesting, reduce breath function, retard ripening and control microbial processes. Precooling enables to retain the nutrition composition and freshness of the product; improves cold-resisting ability; avoids chilling injury on fresh produce and reduces microbial activity or decaying process (Thompson *et al*. 1998). Due to the precooling treatments metabolic activity and consequently respiration rate and ethylene production of fruits were reduced considerably. Furthermore, precooling minimize the designed heat load needed for cold rooms and transport equipments. Investigations show that the post harvest losses of commercial fruit and vegetable is almost up to 25~30% without precooling in the whole storing and transporting chain while it is only 5-10% through precooling (Yang *et al*. 2007).

Postharvest cooling also provides marketing flexibility by allowing the grower to sell produce at the most appropriate time. Precooling is applied as an important unit operation for post heat treatment for certain fruits (Miller and Mcdonald 2000). The use of precooling after air-shipment can extend the shelf-life of certain fresh-produce for considerable periods, by reducing the loss of moisture and maintaining a better firmness and texture and by limiting the increase of fiber content (Laurin *et al*. 2003, 2005). Precooling can be ranked as the most essential of the value added marketing services demanded by increasingly more sophisticated consumers.

The primary function of a well designed precooling system is to be energy efficient and provide sufficient cooling capacity to ensure rapid pull down to desired temperature of a pallet load in certain conditions that are required by a product or process within a given space and time. A well-designed precooling system not only avoids wastage of electrical energy but also restricts the moisture loss within permissible limit. An accurate estimation of refrigeration load is the basis of designing and operating any type of precooling system. Refrigeration load is the rate of heat removal required to keep both the space and the product at the desired condition. The product-cooling load is one of the most important components of the refrigeration load, which contributes about two-thirds toward the total refrigeration load during the transient cooling period (Chourasia and Goswami 2007). To perform this function, equipment of the proper capacity and type must be selected, installed and controlled on a 24-hour basis. The equipment capacity is determined by the actual instantaneous peak load requirements.

Thus, the refrigeration capacity in addition to cooling medium movement and operation control of the precooling process makes it different than just storing products in a conventional cold storage room. Therefore, precooling must be considered independently from the cold storage and is typically a separate operation that requires specially designed equipment.

APPROACHING THE OPTIMUM PRECOOLING METHOD

The capital investment and the running costs vary significantly among different precooling methods. As an added value service, the expense of the selected technique must be covered through selling prices or other economic benefits. Various possible trades-offs can occur concerning the selection of certain method. Such practices may be based on certain conditions such as: amount and mix of produce handled, duration of precooling season and its regional location, physical characteristics of the produce and its tolerance, specific market requirements, allowable pull down time and the final desired temperature, sanitation level required to reduce decay organisms, packaging applied, further storage and shipping conditions, energy cost and availability, labor requirement, interest rates, building and equipment capital cost and its maintenance (Baird *et al*. 1988; Gaffney and Baird 1991). These factors if not properly optimized, can lead to precooling systems that do not achieve the required objectives or the cost benefit associated with the whole process is not feasible (Becker and Brian 2006).

The process of heat removal from fresh produce can be achieved by several different methods; all involve the rapid transfer of heat from the product to a cooling medium, such as water, air, or ice. Such methods include as natural air cooling or room cooling method, forced air cooling, hydrocooling, ice cooling, slurry ice, vacuum cooling, and evaporative cooling, liquid nitrogen, mobile pre-cooler and in line precooling (opti-flow cooling tunnels); each one is differing in heat removal efficiency and processing cost. One of the main advantages of hydrocooling is that, unlike air precooling, it removes no water from the product and may even revive slightly wilted products (Elansari 2008a). However, not all kinds of products tolerate hydrocooling (Elansari and Hobani 2002). The most common method being utilized for precooling of fresh product is forced air-cooling. It is one of the few fast-cooling methods used with a wide range of commodities (Guillou 1960; Parsons *et al.* 1972; Kader *et al*. 1992; Thompson *et al*. 1998).

Fresh produce is usually cooled down to its maximum shelf life temperature with various techniques. Forced-air cooling is the most common method adapted for many types of vegetables fruits and cut flowers (Kader 2002). Hydro-cooling uses water as the cooling medium and therefore one of its advantages is that it removes no water from the produce and may even revive slightly wilted product (Thompson 2004). Vacuum cooling has been traditionally used as a precooling treatment for leafy vegetables that release water vapor rapidly allowing them to be quickly cooled (Brosnan and Sun 2001). Precooling with top icing is a common practice with green onions and broccoli, where the flaks of ice are placed on top of packed containers. **Table 1** indicates the optimum precooling methods for selected types of vegetables and fruits.

Table 1 Recommended precooling methods for selected fruits and vegetables*.

Vegetables	Fruits	Precooling method
Strawberries, raspberries, celery, Chinese vegetables, peas, Saskatoons (fresh use), spinach, cauliflower, Brussel sprouts.	Grapes, berries, apples, stone fruits	Forced-air cooling
Lettuce, melons, green onions, turnip, parsnips, cucumbers, rhubarb	Stone fruits	Hydrocooling
Brussel sprouts, cauliflower, sweet corn, greens or leafy products.		Vacuum cooling
Tomato, turnip, rutabagas, pepper, okra, eggplant, cabbage, snap beans, potatoes, pumpkin, squash (summer), zucchini	Apples	Room cooling

* (Gast and Flores 1991; Edeogu 2003; Rahaman 2007).

MECHANISM OF FRESH PRODUCE PRECOOLING

1. The temperature of the air inside the cooling facility is lower than the load of fresh produce, so the heat is moving out of the fruit to the surrounding air.
2. During rapid heat transfer, a temperature gradient develops within the product, with faster cooling causing larger gradients. This gradient is a function of product properties, surface heat transfer parameters, and cooling rate.
3. The evaporator contains refrigerant boiling at low pressure and temperature. As the refrigerant boils or evaporates it absorbs a lot of heat. This heat is removed from whatever surrounds the evaporator, usually air or secondary refrigerant.
4. As the refrigerant flows inside the evaporator, it makes it always colder than the air in the cooling facility, thus the refrigerant is absorbing the heat carried out by the air that is drawn over the evaporator through the fans. The refrigerant is transferred from the liquid state to the vapor state.
5. As the time goes, heat contained on the air is absorbed and the temperature of the produce is getting lowered.
6. The refrigerant is sucked from the evaporator as superheated low pressure gas and is compressed to a higher pressure passing through the compressor of the refrigeration system. Compressing the refrigerant gas increases it temperature and heat content and does not remove any of the heat transferred from the cooling facility.
7. The high pressure superheated vapor flows into the condenser where it changes from a gas to a liquid and heat is released. The process is the reverse to what is taking place in the evaporator. The cooling of this process is achieved by using ambient air (air cooled condenser) or water (evaporative condenser). Even on a 45°C day, the outside ambient air or cooling water temperature from the cooling tower is lower than the condenser pipes and fins temperature and so the heat is transferred from the refrigerant through the pipes and fins of the condenser to the ambient or water.
8. Now the heat load is pulled out of produce and released to the atmosphere outside the cooling facility and cooling of the fruit has accomplished.

HEAT LOAD CALCULATIONS

The most common term used to quantify refrigeration capacity or heat load is the refrigeration ton. One ton of refrigeration is defined as the energy removed from one ton of water so it freezes in 24 hours. It is equivalent to 3.5 kW. The refrigeration capacity needed for precooling is much greater than that required for holding a product at a constant temperature. Therefore, the efficient design of precooling systems that pull-down the heat load requires accurate estimation of the precooling times of fruits and vegetables as well as the corresponding refrigeration capacity. However, it is uneconomical to have more refrigerating capacity available than is needed. The total heat load comes from the product, surroundings, air infiltration, containers, and heat-producing devices such as motors, lights, fans, and pumps. Product heat accounts for the major portion of total heat load on a precooling system. Product heat load depends on product initial and desired final temperature, cooling rate, weight of product cooled in a given time, and specific heat of the product. Heat from respiration is part of the product heat load, but it is generally small. No rule of thumb can be followed in that regard although that some figures are available in the literatures (Thompson 2006). It is has been a usual practice to have a safety margin to overcome the peak load of the theoretical calculation. Nowadays and with modern numerical techniques a more practical cold store operation, the safety margin can be reduced to a more realistic level (Nahora *et al.* 2005; Chourasia and Goswami 2007).

TYPE OF AIR PRECOOLING METHODS

Room cooling method

Conventional refrigerated storage facility is any building or section of a building that achieves controlled storage conditions using thermal insulation and refrigeration equipment (Becker and Brian 2006). Such facilities are classified as coolers with commodities stored at temperatures usually above 0°C. They can be also classified into small, intermediate and large storage rooms, ranging from small rooms utilizing prepackaged refrigerator units to massive cold storage cooler warehouses. This method is the simplest and the slowest cooling method as indicated in **Fig. 1**, in which the bulk or containerized commodity is placed in a refrigerated room for several hours or days. Air is circulated by the existing fans from the evaporator coil in the room (Talbot and Chau 2002).

Room cooling is used for produce sensitive to free moisture or surface moisture and for very small amounts of produce or produce that does not deteriorate rapidly (Anon 1984; Mitchell 1985). Exposing certain type of fruit to specific durations of cold storage has been shown to enhance ripening due to increased ethylene synthesis in the tissue (Clayton *et al.* 2001). For apple, the room cooling method is very common where it kept refrigerated in rectangular bins with lateral holes to let the cool air in and the temperature is usually maintained below 1°C (Russell 2006). Citrus fruit is also used to be cooled using room cooling method (Thompson *et al.* 1998).

In this method produce is loaded into a refrigerated space where cold air is circulated within the room and around the produce by the refrigeration fans. Cold air does not circulate readily through the packaged produce. Heat exchange is mainly by conduction through the container walls to the cold outer surface. The method to be effected needs a uniform air distribution (at least 60 to 120 m.min air circulation), spaced stacking for airflow between containers and well ventilated containers (Mitchell and Crisosto 1994).

Coolers of this type generally have less ability to remove heat from the product and lack the air movement needed for rapid cooling compared with other precooling methods. The half-cooling time may be 12 to 36 hours so three half-cooling times (7/8 cooling time) will be 36 to 108 hours (Ross 1990). Due to its slow cooling rate, the produce takes long time to reach the desired final temperature. Unless the room is designed to deliver high level of relative humidity, the cooling systems will have sufficient time to remove moisture from the air, and subsequently the dry air will draw moisture out of the product, which will progressively dehydrate. Produce is largely composed of water where the loss of this natural moisture will reduce quality, taste, texture and shelf life. Most of these rooms especially

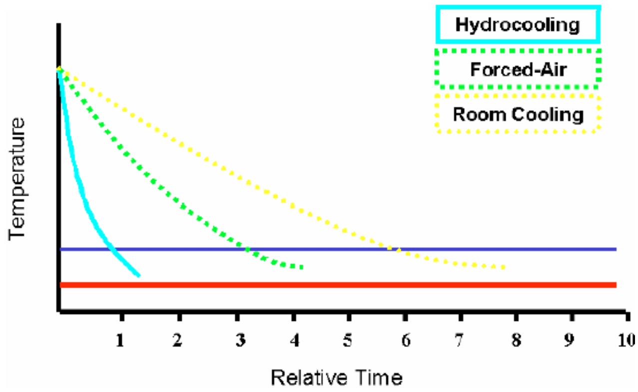

Fig. 1 Comparison between different precooling methods. Reprinted from: **Palmer M** (1999) *Forced Air Cooling*, Information kit No. 11, 8 pp, ©1999, with kind permission of the South Australian Research and Development Institute.

in developing countries are equipped with direct expansion commercial refrigeration system (DX) which is not recommending for perishable storage. The installed evaporators usually have small surface area and large ΔT (temperature difference between room air and coil) that increase the water loss from the produce. Another disadvantage is that air velocity decreases with increasing distance from the source, causing produce stacked further from the fans to have less air passage over it.

Defrost is another problem for this kind of cold room. In a typical cool store, fans circulate air over the refrigerator coils. To maintain a storage temperature of 0°C the temperature of the coils will have to be appreciably below 0°C. Moisture is therefore removed from the air and this accumulates as ice on the coils (Jobling 2002). This why a defrost system is a basic requirement since such cold rooms would sometimes run as low as -2°C for certain products like grapes. Electrical defrost introduce extra heat load to the system and cause great fluctuation in room temperature (Gameiro 1994).

Another form of this method is the evaporative cooling system, the used refrigerated truck (Wilson *et al*. 1995), and tractor mounted ice bank cooler. These simple techniques have been successfully used for precooling (Thompson 2003). Evaporative cooling has been proved as an effective method of storage of fruits and vegetables of moderate respiration rates. Jain (2007) suggested a modified evaporative cooler named two-stage evaporative cooler (TSEC) that has been developed to improve the efficiency of evaporative cooling for high humidity and low temperature air conditioning. The two-stage evaporative cooler consists of the heat exchanger and two evaporative cooling chambers. It was observed that TSEC could drop the temperature up to wet bulb depression of ambient air and provided the 90% relative humidity which can enable to enhance the shelf-life of wide range of fruit and vegetables of moderate respiration rates.

The major advantage of room cooling is that the produce is cooled and stored in the same place, decreasing the handling steps required and it eliminates the capital investment needed for fast cooling.

If the facilities are to be used for rapid precooling, the capacity of the refrigeration system must be increased. The amount of increase will be determined by the rate of harvest, the desired cooling time and the required temperature drop. For the big and medium room, it is expected to have sufficient cooling capacity to pre-cool predetermined amount of produce according to its conditions. For a small room, an essential step is the determining of the capacity of the installed refrigeration system. Knowledge of the system control will be needed in addition to the produce initial temperature, final temperature, thermal properties, and the space requirements to place tunnel load. Based upon this data and the estimated cooling capacity of the storage space, the optimum amount of produce to be pre-cooled can be estimated. An auxiliary cooling fan is put in position after the pallets are placed in the room. Pallets are stacked in even numbers in set positions on the cool room floor. A tarp is rolled down over the bins to direct air flow. The forced air fan is wheeled in position against the pallets The fan is turned on which draws air through the pallets. After forced air cooling is completed the fan can simply be shut off and the pallets remain in position for room storage.

Forced-air cooling

Forced-air cooling is considered an improved technique compared by the room cooling method since the cold air is forced through produce packed in boxes or pallet bins via its venting areas. A number of airflow configurations are available, but the tunnel cooler is the most common (**Fig. 2**). In the tunnel system which is a patch type, pallets are lined up in front of a pressure fan and covered with a tarp to form a tunnel. Cold air is pulled through the tunnel of covered pallets so the air must go through the containers. The product is cooled in batches and cooling times range from 1 h for cut flowers to more than 6 h for larger fruit (Thompson 2004).

Fig. 2 Forced air cooler tunnel type.

The continuous system where product is moved through a cooler on a conveyer has largely been abandoned in favor of batch cooling due to the high cost of conveyer systems. Some recent application for that type of configuration is reported for specific application such as tying it in a production line for fresh-cut produce (Christie 2007).

Forced air precooling facility design involves a variety of tasks, including planning, site selection, architectural and structural design, refrigeration system design, equipment selection and installation, construction, supervision, inspection, maintenance and management (Becker and Fricke 2006). In addition, considerations of building and safety codes, efficient operation, and cost effectiveness make the design procedure more exhausting. The first step in a forced air precooling facility design is for the designer to develop an exact set of specifications that meets all the interests of the facility owner. Specifications for the overall facility must consider the individual product specifications, forced air arrangements, environmental conditions, and other miscellaneous aspects of the design process.

PACKAGING

The way of packaging and the packaging materials should be properly selected to avoid any blockage of air passage and allow good air flow to achieve the cooling rate desired. Packed produce with airflow restricting materials should be taken in consideration when sizing the system air flow and static head pressure of the fans. Boxes should have about 5% sidewall vent area to accommodate airflow without excessive pressure drop across the box (Kader 2002). Packing table grapes via sea shipments is an example; it needs a lot of packing materials that can not be avoided, such as consumer bags and unvented liner (Luvisi *et al*. 1995). Crisosto *et al*. (2002) reported an air flow rate of 9.35 m^3/hr/kg can overcome the heavy internal package of table grapes boxes during the precooling process. Luvisi *et al*. (1995) reported a value of 216 min for the $7/8^{th}$ cooling time of grapes that were bagged and packed in corrugated box. The corresponded initial and final temperatures were 21.1 and 1.7°C, respectively. For most systems, fans are being selected based on a maximum static pressure of 200 Pa (Hugh and Fraser 1998).

CAPACITY DESIGN

One of the critical design parameter is the required capacity for a forced air precooling facility. The capacity mainly depends upon factors such as the total production of the farm, nature of the produce and its thermophysical specifications, expected duration of production season and modes of material handling. An essential step in determining the capacity requirements of the prospective refrigerated storage facility is to acquire data concerning the traffic levels of the harvested produce. In addition, space requirements for loading docks, product handling and logistics must be estimated. Based upon this data and the estimated capital and operating costs per unit volume of the storage space, optimum dimensions may be determined.

For forced-air cooling, the refrigeration capacity requirements are much greater than just storing products in a typical cold storage room and might be as much as 5 or 6 times greater than the requirements for a standard cold room design (Freeman 1984). Sufficient cooling capacity allows room air temperature to be stable throughout the cooling process and avoids temperature rising that slows cooling rates. Cooling time in forced-air coolers is controlled by volumetric airflow rate and product diameter (Flockens and Meffert 1972; Gan and Woods 1989).

Forced-air cooling is considered an industrial process which operates under significantly severe conditions (Elansari and Tator 1998). At the beginning of the cooling cycle, the system is subjected to a very large heat load; while in comparison, at the end of the cooling cycle, the heat loads are very small. The typical small commercial refrigeration system (direct expansion) is not designed or capable of handling these large heat load differences efficiently. These systems are considered the least energy efficient type of cooler (Thompson 2001) and many questions remain concerning its proper design to the given produce being cooled (Silva *et al.* 2006). Industrial designed systems incorporate components and control which can handle the heat load variances effectively. In developing countries, most of the installed precooling systems are from small commercial refrigeration system.

For the estimation of the refrigeration capacity needed, Wade (1984) developed an equation for the estimation of the load required in terms of the rate of heat loss from the cooling produce. The developed model uses the seven eighth cooling times and the lag factor which is an empirical measure of the thermal properties of the product. Watkins (1990) developed a cooling load calculation method and graphs were presented that show the relationship between the air flow rate and the cooling rate required for different commodities based of a pallet load. The method was specified for the systems which use an auxiliary fan with the existing cold stores. Thompson and *et al*. (1998) reported a calculation method for the estimation of the peak refrigeration tonnage associated with product cooling based on certain assumptions. Heat from miscellaneous source such as fan motors was taken as a percentage of the product load.

SYSTEM CLASSIFICATION

There are generally two designs of forced are precooler. They are: 1) wetted-coil or spry deck style; and 2) dry-coil high humidity style. The two systems have significant differences in design concepts and philosophy. Each has advantages and disadvantages that should be considered to determine the best for a specific commodity.

Wet cooling system (ice banks)

The practice of precooling and cold storage fruits, vegetables and flowers in a high humidity atmosphere has been applied for many years in the U.S. The wet deck system (**Fig. 3**) was developed by the Institute of Agricultural Engineering in the 1970s (Farrimond *et al.* 1979; Geeson 1989; Rule 1995; Macleod-Smith *et al*. 1996; Tassou and Xiang 1998). It is the common precooling systems installed in many packhouse facilities especially in developing countries where ice cold water is brought into intimate contact with the recalculating air within a cooler (Elansari 2003). Wet Deck systems have the ability to maintain low temperatures and high relative humidities with lower running costs than conventional systems, making them suitable for long-

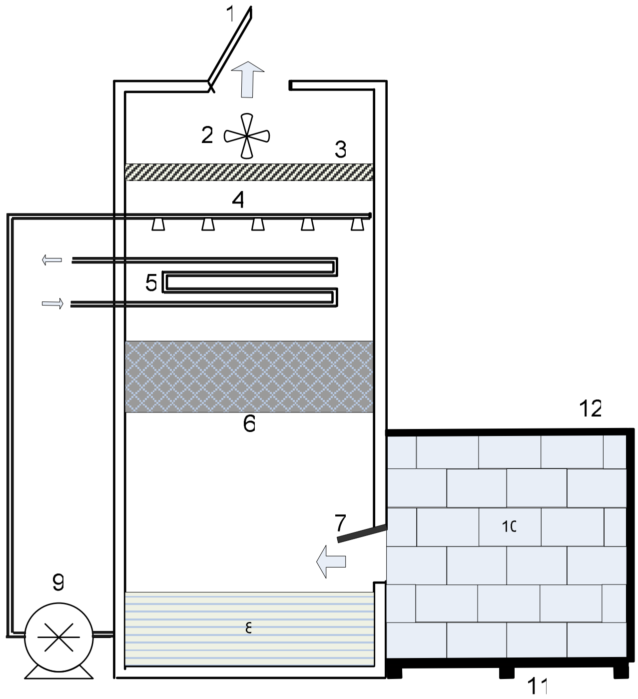

Fig. 3 Illustration of the typical wet air cooling system. 1) Damper, 2) Centrifugal fan, 3) Moisture eliminator, 4) Water spry, 5) Heat exchanger, 6) Ice chiller, 7) Water deflector, 8) Water tank, 9) Water pump, 10) Product pallets, 11) Wooden pallets, 12) Plastic tarp. Reprinted from **Elansari AM** (2003) Forced air fast cooling system of Egyptian fresh strawberries. *Misr Journal for Agriculture Engineering* **20**, 571-586, ©2003, with kind permission of the Egyptian Society for Agriculture Engineering.

and medium-term storage of a number of vegetable crops (Farrimond *et al.* 1979). Wet air cooling has been used successfully for the precooling and/or storage of: grapes, mushrooms cucumbers, carrots, cauliflowers, tomatoes, strawberries, cut flowers, white and red cabbage, brussels, spinach, potted plants, flowers, lettuce chicory potatoes, celery chicory roots, leeks.

Warm produce is loaded in the precooling room in open crates stacked to allow forced circulation of air through the crates. The cooling unit is usually located near the end of the room (**Fig. 3**). Air is circulated by the wet air cooler to the opposite end of the room where it is drawn through the stacked produce pallets and returns to unit. A false wall or a plenum chamber (Tassou and Xiang 1998) at the end of the room creates a positive pressure in the space to force cold air evenly through the produce and forms a return air passage to the cooling unit. Each cold room may have one or more unit operating in parallel based on the total capacity required. The circulation rate is typically 40 air changes per hour (Benz 1989).

Refrigeration is supplied in the front of the water pumped from the ice water tank, which works as thermal storage unit at the top of the fill pack heat transfer surface (cooling tower), thus, cooling the air and warming the water. The formation of ice on the surface of the evaporative coil occurs when the refrigeration load is light and it melts when the load goes up. Air Cooler which can cause damage to the produce, are stripped from the air stream by directional mist eliminators. The water is prevented from freezing completely through mechanical agitation which also maintains good heat transfer rates between the refrigerated plates and the water (Tassou and Xiang 1998). The air exits the cooler at temperatures as low as 1.5°C and relative humidities as high as 98%.

Since wet spray and wet deck systems are recirculated water system, the cooler must be designed to control disease organisms that enter the system via the coming produce. The water acts as an effective air scrubber and can be very efficient in removing air borne contaminations into the water stream. Chlorine is commonly used, and requires concentrations of 100 to 150 ppm available chlorine for water near 0°C. However, chlorine is corrosive to many common metals, thus care must be taken to determine if chlorine can be used with the cooling equipment installed.

Conventional commercial refrigeration or industrial system using either semi hermetic compressors or screw working with ammonia or halocarbon refrigerant are used to supply the required refrigeration capacity to charge the ice chiller thermal storage unit. In order to reduce energy and capital cost, the ice also can be built at night or when there no load. An evaporative or air cooled condenser rejects the heat from the refrigeration system.

Tator (1997) summarizes the disadvantages of the wet deck precooling system where it is usually designed with a smaller coil surface. The coil must operate at a high temperature difference, usually 5-6°Δt. That system can only cools the fruits to usually 2.5 to 3°C or above. Cross contamination can occur unless the recirculated water is chlorinated. Elansari *et al.* (2000) mentioned that the wet deck system is not the optimum precooling technique for sea shipment produce since it is not capable of reaching the lowest recommended temperature for certain product like table grapes and strawberries.

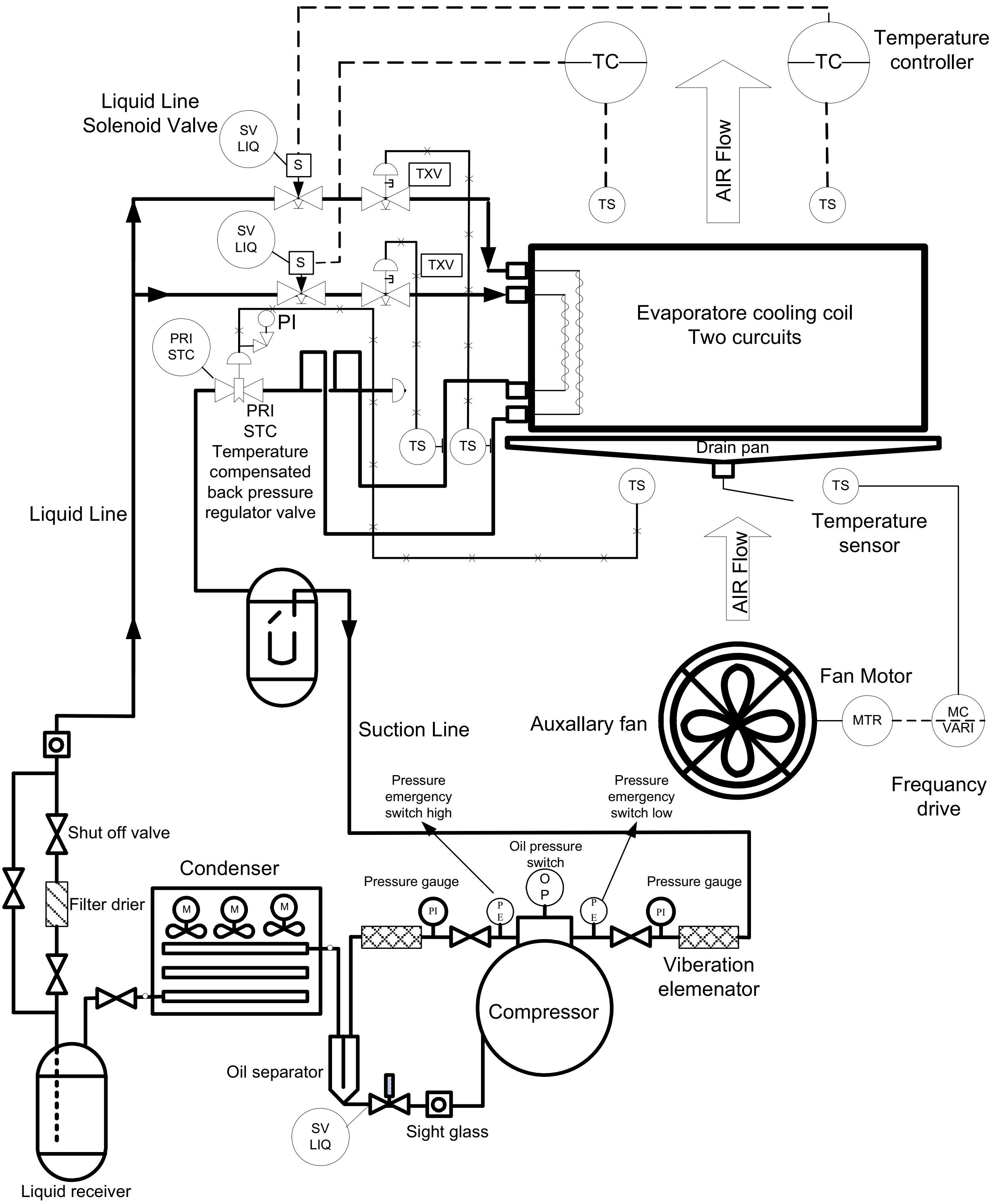

Fig. 4 The refrigerant main loop for a dry system. Reprinted from **Elansari AM** (2009) Design of portable forced-air precooling system. *Journal of the Saudi Society of Agricultural Sciences* **2**, 38-48, ©2009, with kind permission of the Saudi Society for Agricultural Science.

Dry system

This system uses a direct expansion or secondary coolant coil sized to operate at a small temperature difference between room air and coil (ΔT) which will maintain a high relative humidity of the leaving air stream. The dry-coil system can maintain 85 to 90% relative humidity during the precooling process if properly designed and operated. The DX system is not recommended for the precooling of high humidity fruit. However, growers sometimes, due to economical reasons, buy according to the lowest price, and then they have to compromise the quality of the system. For a bigger size a flooded ammonia systems is an obvious choice for different reasons. A flooded ammonia system achieves less temperature fluctuation which is especially critical for the precooling process. Another reason is mainly for its lack of oil separation problems and better efficiency, providing the plant with less cost for Kwh.

In the case of a DX system using commercial type style it must incorporated in its refrigeration loop different components that maintain high level of relative humidity to enhance its efficiency. Elansari (2008b) indicated different details for the dry-coil concept that utilizes a semi-hermetic condensing unit working with R-134a. The refrigerant main loop for each tunnel (**Fig. 4**) includes a liquid receiver; a thermostatic expansion valve; and a plate-finned tube evaporator coil. Each compressor is equipped with a capacity control that controls the delivered cooling capacity by 50%.

The evaporator coil should match the same capacity and conditions of the condensing unit with two circuits. A separate axial auxiliary fan is used to circulate the designed amount of air against 400 Pa static pressure.

A wide fin spacing evaporators is used (1.575 cm/fin) to guarantee a good supply of air through the precooling cycle and to avoid any blocking of the coil by dirt or frost. In order to maintain a relative humidity level not less than 85%, the coil is designed to have larger facing area. The installation includes a temperature compensated back pressure regulator valve. Its function is to maintain the evaporating temperature at the required setup conditions and preventing it from falling down at the end of the precooling cycle. Therefore, the system minimizes the dehydration effect might happen due to the big difference in ΔT.

The air flow rate supplied by the auxiliary fan in each precooling tunnel is controlled via a variable frequency drive (VFD). VFDs are an electronic motor controller that is used to reduce fan speed after the heat field has been pulled down to storage temperatures. By other word, as the precooling process nears its end, water loss from product should be avoided by minimizing air flow which can be reduced as low as 50%. The VFDs offer very attractive energy savings. At half fan speed, the fans will consume only about 15% of full speed power (Morton and McDevitt 2000). A safety cut-off arrangement is installed at the front of the air return channel to sense the return air temperature and stop the auxiliary fan if the temperature is less than 0°C. That is to prevent any freezing might happen for the produce being pre-cooled.

MOBILE PRECOOLING FACILITIES

A mobile pre-cooler is one which removes the field heat at the farm and during transit period. Commercial mobile precooling system had been previously designed, in which three-precooling unit container loads of product could be pre-cooled simultaneously (Green 1997). The capital investment and running cost of the system are very high due to its capacity which exceeds the production of the average size facilities. It consumes about eight gallons of fuel per hour to run the ammonia screw compressors.

Talbot and Fletcher (1993) utilized a trial mounted cooling unit equipped with two 10.5 kW packaged air conditioner units, a high pressure blower and a self constructed cooling chamber for cooling a pallet of containerized product as a mobile precooling facility. Boyette and Rohrbach (1990) promoted a similar idea that applies two to three tons refrigeration air conditioning with integrated fan unit to supply the cooled air through the length of insulted flexible duct which holds the product being pre-cooled. The cooling rate reported for previous units were slow and the product load exceeded the design load by 30% apart from the very limited capacity which is only for one pallet. The water loss was a major concern for both units. The used air conditioning systems were to comfort the human body rather than the fresh product.

Elansari *et al*. (2001) designed a portable forced air precooling unit using 40" high cube bottom air delivery reefer container. The precooling unit was modified by using a bulkhead door, and the floor T-sections were blocked in order to short cycle the cooled air around the pre-cooled pallets. The average pallets grapes temperature was lowered by 18°C in 8 hrs. The product load exceeded the available load for the unit by about 50% which caused longer cooling time. The designed refrigeration capacity of the reefer container was to hold and maintain the temperature of the shipment and not to pull down the field heat of the shipment.

Elansari (2009) described the development and performance of a portable forced air cooling unit exclusively designed to satisfy different precooling requirements. It took 150 mins to cool down 2.3 tons of strawberries from 22°C initial temperature to 1-4°C final temperature. The unit is simple and use on-shelf refrigeration components. The cooling system uses Scroll compressor that has proven to be efficient and reliable with respect to the precooling requirements. The unit is an insulated container (8590 × 2990 × 2940 mm) divided into three sections as shown in (**Fig. 5**), a machine room; a cooling chamber which represents the false wall and finally the main cooling area that holds the stacked produce pallets. The dimensions and weight of the unit were to accommodate highway regulations. The unit can run with a separate motor generator fueled with diesel/electrical portable power unit for keeping it running while off the road.

CONCLUSION

This review highlights the importance of precooling as it is an essential part of the cold chain for all horticultural crops. Precooling process is defined as heat removal of the perishable produce immediately after harvest. In conjunction with the proper cold storage and refrigerated transportation, precooling allows to extend the storage life of the horticultural produce with an objective to minimize the postharvest loss and to increase in salable price for the fresh produce by retaining the overall quality.

Many variables have to be taken in consideration when designing and selecting a precooling technique. Two different techniques exist for use in the horticultural industry; wet deck and dry coil system. Each of these individual techniques has special design characteristics and concepts to achieve high level of relative humidity.

Mobile precooling is an important concept that has many different applications and applicable for developing countries. This concept can be a substantial aid to enhance the cold chain in difficult circumstances of small producers.

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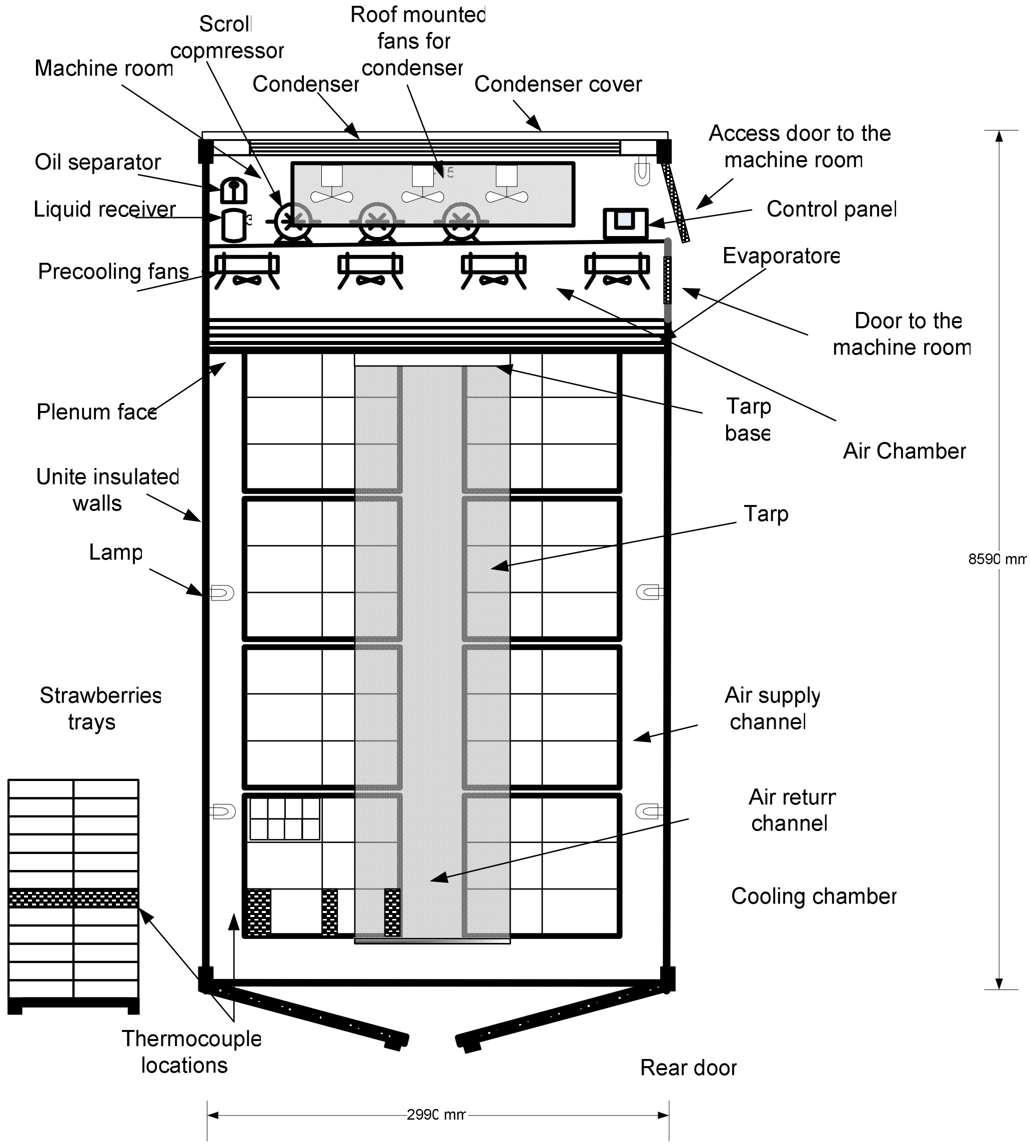

Fig. 5 Details of the portable precooling unit with its different sections. Reprinted from **Elansari AM** (2009) Design of portable forced-air precooling system. *Journal of the Saudi Society of Agricultural Sciences* **2**, 38-48, ©2009, with kind permission of the Saudi Society for Agricultural Science.

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