

FORCED AIR COOLING

A Summary of Basic Principles

Compiled by Johan Strydom

1. Why cool fruit?

1.1 Control of the ripening process

The ripening process of climacteric fruit (such as stone and pome fruit) continues after the fruit has been picked. Unless this process is controlled, the fruit will ripen within days, thereby reducing its marketability. The most effective means of controlling fruit respiration and thus ripening is by using refrigeration to cool the storage air and, hence, the fruit. Reduction of the fruit pulp temperature also limits ethylene production, and thereby retards ripening.

The ripening process can also be manipulated to extend the storage period through technologies that are additive to refrigeration like controlled atmosphere cold storage where oxygen and carbon-dioxide levels in the cold store are controlled.

In the case of certain plum varieties, the cold chain is adjusted to enhance the eating quality (ripeness) by raising and reducing the shipping temperature en route.

1.2 Reduce moisture loss

Storing fruit at any relative humidity conditions below 100% will result in moisture loss. The loss can be controlled by reducing the product temperature and keeping the relative humidity high (preferably above 85%).

Excessive moisture loss can result in defects such as dry stems in grapes and shrivel in plums.

1.3 Control of internal and external defects/diseases

Fungal diseases may develop rapidly if fruit is not cooled soon after picking. Diseases like Botrytis develop exponentially above 0°C.

Different fruit kinds react differently to cold temperatures. Whereas -0.5°C may be ideal for storing grapes, citrus will show skin disorders if stored at this temperature for long periods.

Certain plums varieties (e.g. Songold) will develop internal browning if stored for more than 10 to 14 days continuously at -0.5°C. In the case of Laetita plums, especially after a heat wave, it is advisable not to cool the plums too rapidly (say to +10°C in 24 hours) before forced air cooling to -0.5°C.

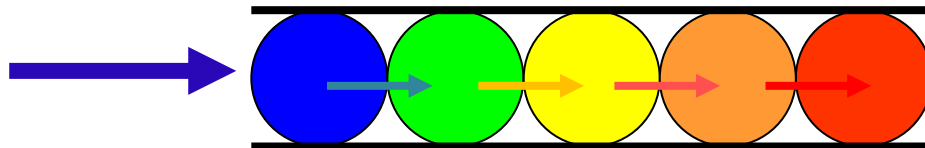
1.4 Control of pests

All fruit are exposed to pests that reside in orchards. Although controlled with pesticides and other methods, pests may still be present during the packing process. The development of these pests and their resultant damage, can be controlled (to some degree) by keeping the fruit at low temperatures as insects tend to hibernate at low temperatures.

In the case of certain pests (e.g. Mediterranean Fruit Fly) the pest can be killed if exposed to extended periods of low temperature. This concept forms the base of the cold sterilisation process stipulated by some importing countries.

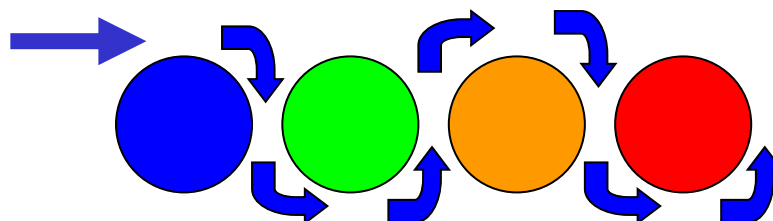
2. Principles of Forced Air Cooling

The rate of cooling of warm fruit depends on two elements, namely heat transfer by **conduction** and **convection**, as well as temperature differential between the product and the cooling medium (the greater this differential, the more rapid the cooling rate) Conduction in fruit is normally a slow process involving the heat transfer from one fruit to another, as the 'cold front' moves from one fruit to the next.



Conduction

The cooling process can, however, be speed up by ensuring that cold air reaches the fruit directly. This is where convection plays a big role as heat is transferred directly from the warm fruit to the cold air.



Convection

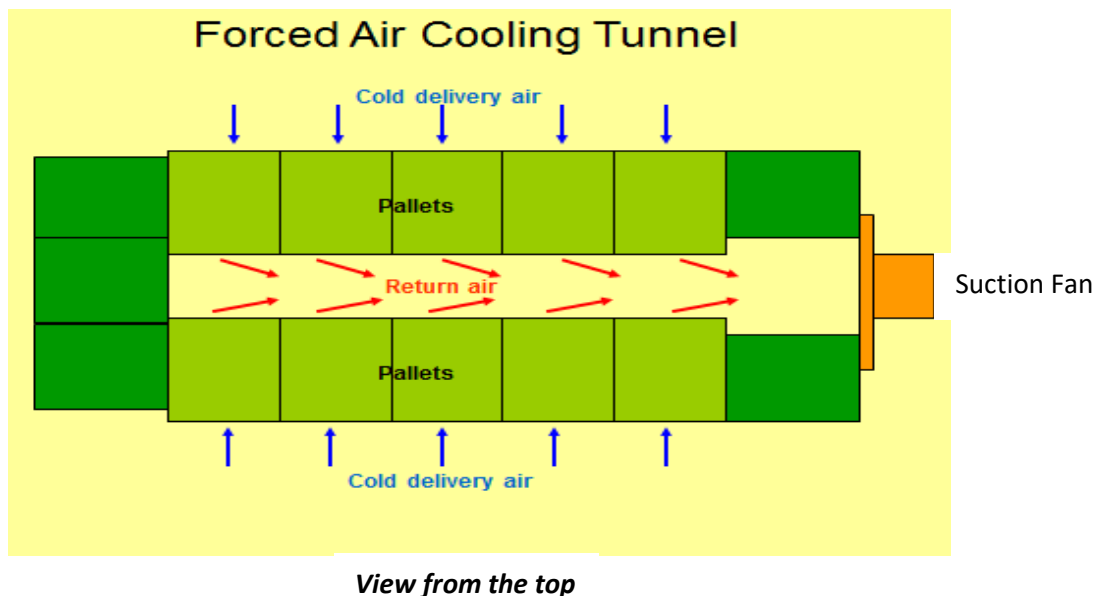
If fruit is left in a cold store with no or little air movement the temperature of the fruit will eventually stabilise at the temperature of the cold room. However, to cool the fruit down to the target temperature within a short time, the cold air must move over the fruit. Considering that the fruit is inside a carton that is inside a pallet load, the cooling rate will be slow as air takes the path of least resistance and will not find its way to the fruit on the inside of the pallet. Unless there is sufficient ventilation in the pallet load/cartons convective cooling will not take place. But even if the ventilation is adequate, cold air will not move through the cartons unless forced to do so. This is where force air cooling plays a vital role.

3. Methodology

The most common method of forced air cooling of fruit is to 'suck' cold air through the pallet loads and cartons. This is achieved by stacking two rows of pallets leaving a 'tunnel' (called the plenum) between the two rows. By covering the roof of the 'tunnel' and tops of the pallets with a tarpaulin and placing a suction fan at the end of the tunnel, a 'vacuum' can be created in the 'tunnel'. The cold air will move through the pallet loads thereby inducing convective cooling and speeding up the cooling process.

In fixed pre-cooling tunnels the exhaust fans are often positioned above the tunnel in the false ceiling of the room. In these instances both ends of the tunnel are then sealed.

An effective method to close gaps on the outside of the tunnel, is to use vertical custom-made 'curtains'. The latter consists of solid strips of tarpaulin to cover gaps between pallet loads and also the pallet base. Netting is attached to the strips to allow air to move freely through the pallet loads.





Fixed Forced Air Cooling Tunnel

Tarpaulin covers front and top

Extraction fan at the back



Picture of a forced air cooling tunnel

4. Factors influencing Forced Air Cooling Effectivity

There are a number of factors and sub factors that play a role in the effectivity of the forced air process. Some of these factors are obvious but in the case of some technical issues, it is recommended that the advice of a refrigeration engineer or cooling expert be sought for guidance.

4.1 *Delivery air Temperature (DAT)*

- Target temperature
- Refrigeration capacity
- Defrosting installation design
- Defrost cycle time
- Coil surface
- Air volume

- Air volume bypassing the coils
- Heat generated by fan motors
- Other surfaces including tunnel insulation
- Ambient air infiltration (e.g. open doors)
- Fruit temperature (Difference between DAT and fruit temperature)
- Return Air Temperature (RAT)

4.2 Air Flow/Vacuum level

- Extraction Fans
 - Number
 - Size
 - Speed
 - Number of blades
 - Blade pitch
 - Position
 - Cyclone design for air intake
- Tunnel
 - Length
 - Width between legs
 - Distance between tunnel leg and wall or next tunnel
 - Design of curtains
 - Sealing of gaps
 - Tunnel insulation
 - Height – number of pallets high e.g. 2 or 3 pallets

4.3 Packaging

- Carton type
- Carton ventilation design
- Internal packaging
 - Wrappers
 - Trays
 - Bags
 - Punnets
 - Other
- Palletisation (neat and square)
- Orientation of pallet – stowed 1M face or 1.2M face
- Uniformity of packaging

4.4 Fruit kind/Variety

- Temperature sensitivity
- Moisture loss risks
- Shape

- Size

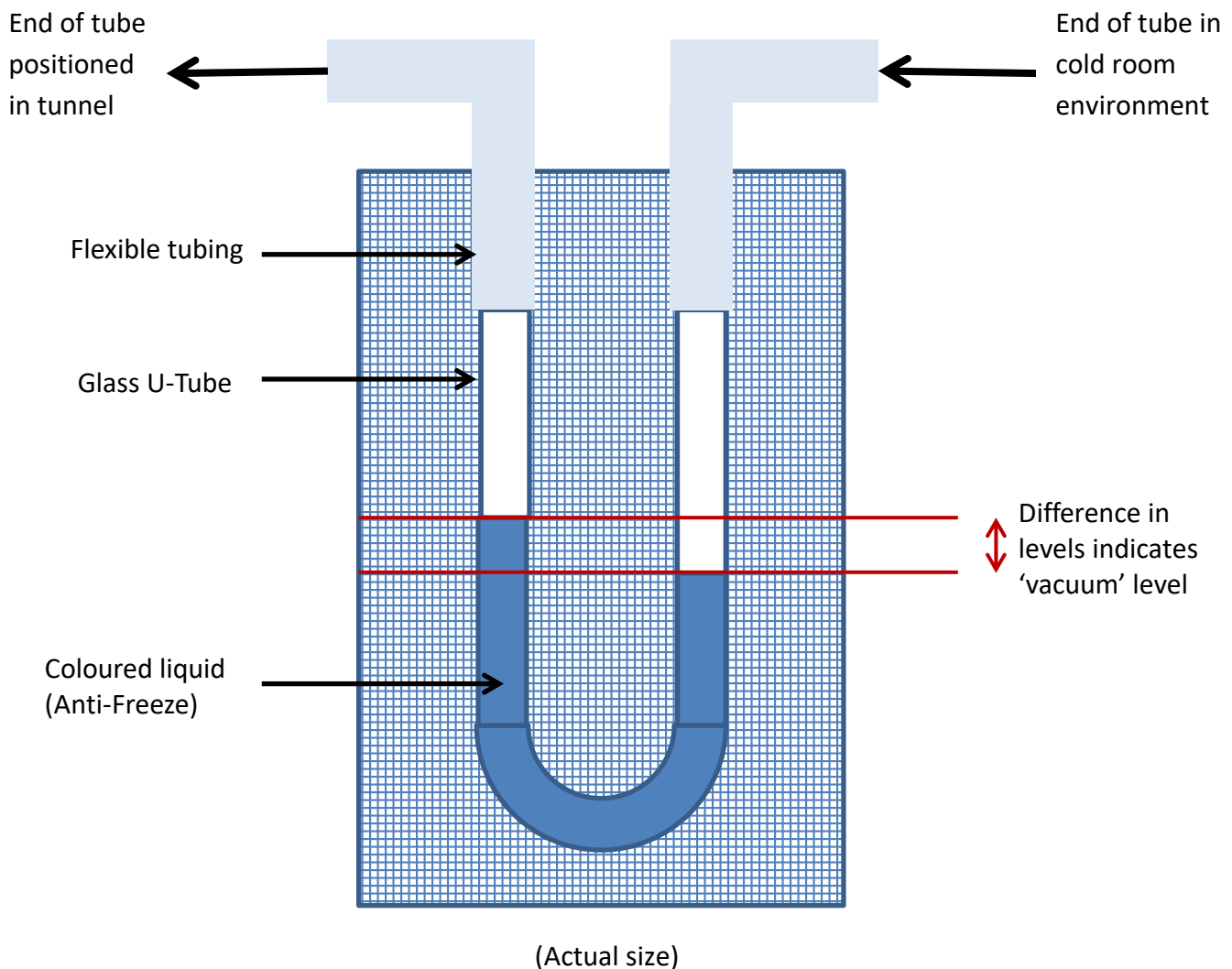
5. Forced Air Cooling Guidelines

The following steps are recommended to ensure successful forced air operations:

- 5.1 Calibrate thermometers prior to the season
- 5.2 Regularly compare thermometers against each other
- 5.3 Check thermometers at least once a week in 50:50 flaked ice/pure water slurry (the reading should be 0.0°C)
- 5.4 Ensure that workers put thermo couples in correctly when palletising loads
- 5.5 Measure fruit temperature at receipt
- 5.6 Apply sound forced air cooling principles (*See Paragraph 4*). *It is recommended that a refrigeration engineer design the forced air cooling tunnels. It is not simply a case of placing pallets and installing a fan.*
- 5.7 Avoid different packs in one tunnel where possible
 - Punnets tend to cool slower
 - Perforated bags cool quicker than non-perforated bags
 - Different pallet heights cause problems
 - Place slow cooling packs closer to the fans
- 5.8 Check Delivery Air Temperature (DAT) regularly
- 5.9 Seal tunnels properly
- 5.10 Check sealing effectivity with a manometer (*See Annexure 1*)
- 5.11 Be careful with fruit with low sugars as these fruit may freeze just below zero. (*Grape stems also freeze just below zero due to low sugar content, whereas the berries will only freeze at lower temperatures*)
- 5.12 Regularly measure and record temperatures of:
 - Thermo couples
 - Air temperature
 - Probes (if any)
- 5.13 Get to know the cold room – know where ‘hot spots’ are, coldest position, etc.
- 5.14 Keep in mind that the cooling rate will be slower the closer the fruit temperature gets to the target temperature. For example, with a delivery air of 0°C it may take 6 hours to get the fruit down from 22°C to 5°C, but it may take another 10 hours to reach 1°C.
- 5.15 Stop the forced air cooling process as soon as the target temperature is attained, as FAC inevitably leads to moisture loss in the fruit. *This may require staff to work night shifts, but will pay in the long run.*
- 5.16 Measure fruit temperature at despatch.

Descriptions of some troubleshooting cooling problems, are listed in Annexure 2

Manometer



The manometer is a very simple tool that measures the pressure difference between spaces. When one end is positioned (well-sealed) in the 'tunnel' and the other end is exposed to the cold room environment, the liquid in the tube will move towards the end positioned in the 'vacuum' (*due to lower pressure in the tunnel, resulting from the action of the extractor fan*). The difference in the height between the two vertical tube positions, is an indication of the level of the 'vacuum'. A reading of above 10mm (preferably 14mm) is indicative of a successfully sealed pre-cooling tunnel.

Forced air tunnels are designed to operate at specific pressure differentials (manometer readings) and actual readings are an indication of the effectivity of the tunnel. For example, by using a manometer a lot of pre-cooling time can be saved if a low reading, caused by gaps in the sealing of the tunnel, is found. Corrective action can take place immediately. It is needless to wait 24 hours to find that the fruit has not cooled properly because the tunnel was poorly sealed.

Troubleshooting cooling problems

Three commonly encountered problems in forced air cooling systems are the following:

1. *Room temperature rises as products are added to the cooler.*

The most likely cause of the problem is insufficient refrigeration capacity i.e. under-designed cooler. The problem also commonly occurs when large rooms with multiple cooling tunnels are filled over an extended period of time. This could lead to a decrease in the rate of cooling, and in extreme cases even a warming of the first load. A fairly straightforward solution is to divide the room into separate cooling bays, using curtains or uninsulated walls. This limits the influence that adjacent stacks have on each other, and allows each evaporator to address the cooling requirement of only one stack.

2. *Product temperature in the outer cartons of the stack decreases slowly, despite DAT being on spec.*

The cause of the problem is insufficient contact between the cooling air and the warm product. This may be due to inadequate ventilation, non-alignment of vents, packaging or product blocking vents, insufficient airflow capacity (perhaps due to excessive number of cartons placed on the cooler), and short-circuiting of air past the cartons.

3. *Product temperature in some outer cartons decreases fairly rapidly, but others cool slowly despite DAT being on spec.*

The cause of the problem is non-uniformity of airflow through the stack, due to poorly designed supply or return air channels. If the supply channels are too narrow (i.e. stack is too close to the wall or too close to an adjacent stack), cartons at the base of the pallet receive inadequate airflow and cool less rapidly than cartons in the top of the pallet. If the air return channel (plenum) is too narrow, the pallets furthest from the fan cool slowly, due to inadequate airflow. This can easily be monitored by measuring pulp temperatures and pressure drops across the stack at different heights and different distances from the fan (large differences in pressure drop indicate large variation in airflow, manifested as large pulp temperature differences).

“Thompson, J, et al., 1998. Commercial cooling of fruits, vegetables and flowers. University of California, DANR Publication 21567”