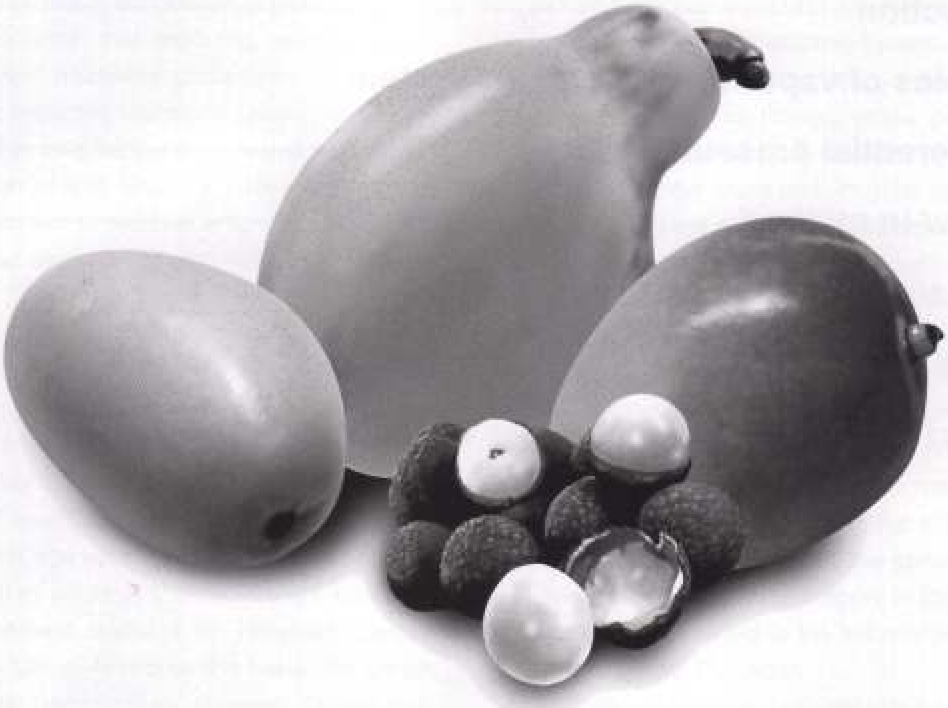
Principles and Features of the Vapor Heat Treatment System



Vapor Heat Treatment Research Group
Japan Fumigation Technology Association
(JAFTA)

Contents

Photos given by courtesy of ; Sanshu Sangyo Co., Ltd
Takenaka Corporation
Diamond Star Corporation

1 Introduction

Fruit flies, such as Oriental fruit fly (*Bactrocera dorsalis* species complex), melon fly (*Bactrocera cucurbitae*) and/or Mediterranean fruit fly (*Ceratitis capitata*), are known worldwide as destructive pests of fruit crops of major economic importance. Those countries where such fruit flies do not occur are exercising every effort to prevent the entry of such pests by stringent phytosanitary measures.

The most stringent of all is the import ban of the host plants of these pests. However, when exporting country has developed complete disinfestaion method against these pests, importation is globally accepted on the condition that exporting country undertakes pre-export treatment procedures specifically agreed by the importing country. In recent years, either vapor heat or cold temperature is mainly used for the sterilization of fruit flies. For both methods, the standard treatment procedure which is suitable for each particular species of fresh fruit is selected for use.

Vapor heat treatment (VHT) was adopted as a quarantine measure in 1929 when Mediterranean fruit fly invaded into the State of Florida. As a quarantine safeguard to prevent its spread, all fresh fruits shipped from Florida to other States were treated with vapor heat. VHT emerged in Japanese plant quarantine in 1969 when it was approved as a key condition for lifting import ban on fresh fruits of papaya from Hawaii. The treatment standard for Hawaiian papaya was drawn by USDA-APHIS on the basis of a series of experiments. Unfortunately, however, its use was suspended after only one year (1970) because live larvae of fruit fly were discovered on a certified shipment at the port-of-entry inspection. Export treatment of Hawaiian papaya then switched over to ethylene dibromide (EDB) fumigation, another effective alternative treatment for fruit flies. Due to the possible hazard to human health, EDB itself was phased out in the first half of 1980s. Vapor heat thus revived as a non-hazardous tool of disinfestation and the various modes of its application have been investigated.

The most outstanding innovation in vapor heat technology was the development of so-called 'differential pressure treatment system' which expanded the scope of vapor heat application to a wide range of fresh fruits. Treatment system of this type uses differential pressure to induce efficient circulation of vapor heat through all spaces in-between fruits so that every each individual fruit is always evenly and uniformly exposed to vapor heat atmosphere. The most sophisticated system which was developed by Japanese manufacturers is equipped with high-technology instruments, high-precision temperature sensors as well as built-in computers to control temperature exactly at 0.1℃ level and humidity at 1% level. At present, almost all fresh fruits being imported to Japan on the condition of VHT are processed with differential pressure type treatment system.

Since the lifting of import ban of Hawaiian papaya, other fruits such as mango, yellow pitaya, mangosteen and litchi were gradually ban-lifted from various countries in the world and, in most cases, VHT has been carried out successfully without any problem for many years. However, one accident arose in 2002 when live larvae of oriental fruit fly were detected on the treated papaya shipments from the Philippines. Investigations for the cause revealed that the owner of the facilities had neglected manufacturer's maintenance, frequently repeated repairs on his own and, in the course of 15 years, almost remade his facilities. It is, therefore, considered that improper maintenance seriously downgraded the performances of facilities to give rise to cold spots in the treated fruits which, eventually, led to the survival of fruit fly in the export shipment to Japan.

In order to promote understanding of the VHT system developed by Japan, VHT Research Group of Japan Fumigation Technology Association (JAFTA) has compiled in this brochure the principles of differential pressure VHT system and its features compared with the conventional blow-in type and horizontal airstream type VHT systems. We trust this will be a useful reference for those who are interested in VHT technology.

Fresh fruits which can be imported to Japan on the condition of VHT (as of March, 2009) are given in the following table.

Fresh fruits which can be imported to Japan on the condition of VHT in the countries of origin(as of March, 2009)

Fruits	Country/Region	Year /Ban-lifted	Variety/Cultivar	Treatment standards
Papaya	Hawaii	1969	Solo type	Fruit-core temperature is raised up to 47.2℃ with saturated vapor.
	Philippines	1994	Solo type	Fruit-core temperature is raised up to 46℃ with saturated vapor and treated for 70 min. at 46℃ or above.
	Taiwan	1982	Solo type	Under relative humidity of 40-60%, fruit-core temperature is raised at a constant pace up to 43℃ and then continuously treated with saturated vapor up to 47.2℃.
Mango	Philippines	1975	Manila Super	Fruit-core temperature is raised up to 46℃ with saturated vapor and treated for 10 min. at 46℃ or above.
	Thailand	1987	Nan Klarngwan	①Fruit-core temperature is raised with saturated vapor up to 46.5℃ and treated for 10 min. at 46.5℃ or above. ②Fruit-core temperature is raised at a constant pace up to 43℃, then with saturated vapor up to 47℃ and treat for 20 min. at 47℃.
			Nam Dorkmai Pimsen Daeng Rad Mahachanok	Fruit-core temperature is raised at a constant pace up to 43℃, then with saturated vapor up to 47℃ and treat for 20 min. at 47℃.
	Taiwan	1982	Irwin Harden	Fruit-core temperature is raised with saturated vapor up to 46.5℃ and treat for 30 min.
	Australia	1944	Kensington R2E2 Keitt Kent Palmer	Fruit-core temperature is raised up to 47℃ with saturated vapor and maintained for 15 min. at 47℃ or above.
	Hawaii	2000	Keitt Haden	Fruit-core temperature is raised with saturated vapor up to 47.2℃.
	India	2006	Alphonso Kesar Chausa Banganpalli Mallika Langda	Chamber is heated with saturated vapor up to 50℃ or above. Fruit-core temperature is raised up to 47.5℃ and maintained for 20 min. at 47.5℃ or above.
Yellow pitaya	Colombia	1999		Fruit-core temperature is raised with saturated vapor up to 46℃ and maintained for 20 min. at 46℃ or above.
Mangosteen	Thailand	2003		Using vapor of 50-80% relative humidity, fruits are heated at a constant pace up to 43℃ and then fruit-core temperature is raised up to 46℃ with saturated vapor and maintained for 58 min. at 46℃ or above.
Litchi	Taiwan	1980		(1) Vapor heat treatment Fruit-core temperature is raised with saturated vapor straight from 30℃ to 41℃ within 45 min. and then up to 46.2℃, and treat for 20 min. at 46.2℃ or above. (2) Cold treatment After vapo rheat treatment, fruit-core temperature is cooled down to 2℃ within 6 hours and treat for 42 hours at 2℃.
	China	1994		(1) Vapor heat treatment Fruit-core temperature is raised with saturated vapor-straight from 30℃ to 41℃ within 50 min. and then up to 46.5℃, and treat for 10 min. at 46.5℃ or above. (2) Cold treatment After vapo rheat treatment, fruit-core temperature is cooled down to 2℃ within 6 hours and treat for 40 hours at 2℃.

2 Principles of vapor heat treatment system

1.Differential pressure method

●Sanshu Sangyo Company

a) Panel type facilities

In the interior of treating chamber, fruit containers of plastics with perforated bottom are stacked onto a pallet up to several layers thereby forming a chimney-shaped processing space (hereafter referred to as 'chimney'). This chimney is covered with a bell-shaped hood having an axial fan on top. By running axial fan, the chimney turns into a differential pressure unit. The panel type system consists of plural number of differential pressure units accommodated in a panelized treatment chamber which is provided with temperature and humidity conditioned air by forced circulation.

One unit load of fruits usually involves 42 containers (6 containers/layer×7 layers). About 530 kg of average-sized mango can be treated per one unit.

The amount of fruits that can be treated at one batch depends on the number of differential pressure units housed in one treatment chamber. (In case of a chamber having 10 differential pressure units: 530 kg ×10 units = 5,300 kg/batch)

When fruit load/batch is smaller than the maximum capacity, only fruit-loaded unit may be subjected to the treatment for economy.

b) Container type facilities

Plastic containers of similar standards are stacked onto a pallet up to several layers to form a chimney-shaped processing unit. Plural numbers of this unit are set in one containerized treatment chamber. By operating plural fans, temperature and humidity controlled air envelopes all the fruits in each unit in one treatment chamber. In case of the container type facility, all the interior of one containerized chamber turns into a differential pressure condition.

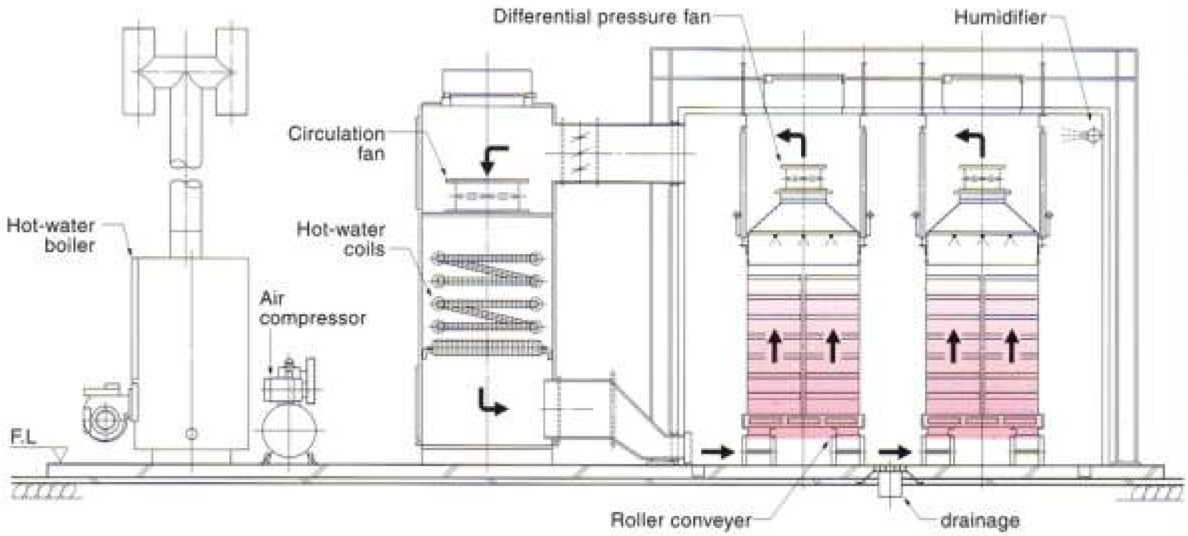
One unit load of fruits usually involves 36 containers (6 containers/layer×6 layers). About 460 kg of average-sized mango can be treated per one unit.

The amount of fruits that can be treated at one batch depends on number of units accommodated in one containerized treatment chamber. (In case of a chamber having 10 differential pressure units: 460 kg ×10 units = 4,600 kg/batch)

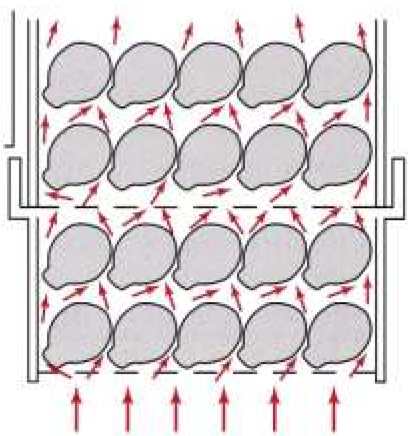
When the load of fruits/batch is smaller than the maximum capacity, fruit load/unit is coordinated and approximately equal amount of fruits should be divided into each processing unit.

※Overview of the vapor heat treatment system of Sanshu Sangyo Company

Overview of Vapor Heat Treatments System of Sanshu Sangyo Type

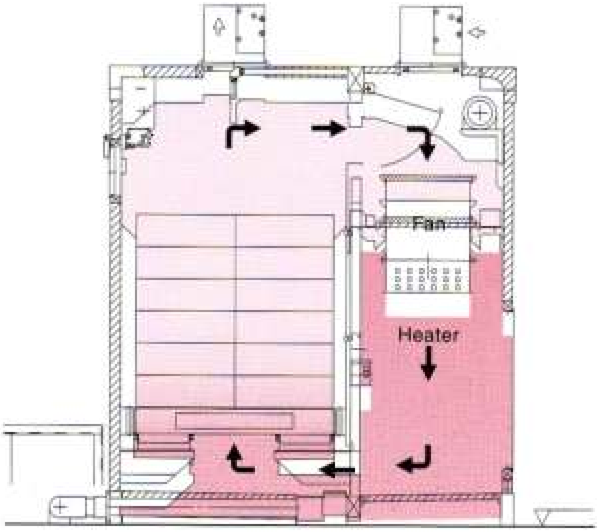


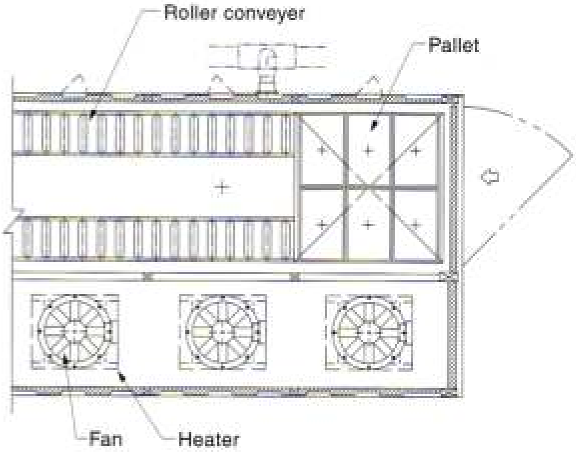
Panel type EHK-500MP

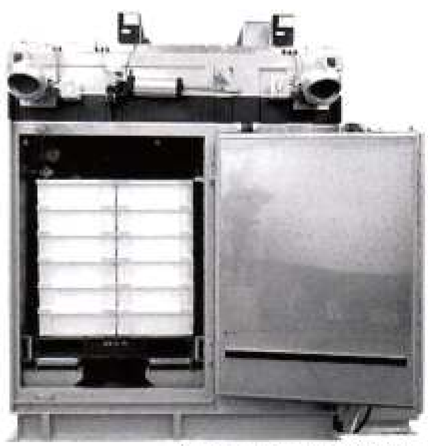


■ Panel type

Model		EHK-500MP	EHK-1000MP	EHK-1200MP
Treatment capacity (Mango fruits)		5,000 Kg/batch	7,500 Kg/batch	9,000 Kg/batch
Treatment pallets		10 pallets	15 pallets	18 pallets
Treatment chamber (mm)		L4,200×W7,200×H3,500	L6,000×W7,200×H3,500	L6,000×W8,400×H3,500
Performance	Operating temperature range	Room temp. +10℃~60℃		
	Operating humidity range	55%~95%RH		
	Temperature control accuracy	0.1℃		
	Humidity control accuracy	0.1%RH		
Rating	Power source	3Φ 50/60Hz 200V		
	Maximum power consumption	94Kw	140Kw	150Kw
	Maximum water consumption	116 ℓ /hr.(during VH treatment)	165 ℓ /hr.(during VH treatment)	194 ℓ /hr.(during VH treatment)
		630 ℓ /min.(during cooling time)	945 ℓ /min.(during cooling time)	1134 ℓ /min.(during cooling time)
	Maximum oil consumption	20.0 ℓ /hr.(during VH treatment)	26.4 ℓ /hr.(during VH treatment)	40.7 ℓ /hr.(during VH treatment)







Contaier type EHK-200MC

■ Container type

Model		EHK-230MC	EHK-460MC
Treatment capacity (Mango fruits)		2,300 Kg/batch	4,600 Kg/batch
Treatment pallets		5 pallets	10 pallets
Treatment chamber (mm)		L6,320×W2,350×H3,160	L12,500×W2,350×H3,160
Performance	Operating temperature range	Room temp. +10℃~60℃	
	Operating humidity range	55%~95%RH	
	Temperature control accuracy	0.1℃	
	Humidity control accuracy	0.1%RH	
Rating	Power source	3Φ 50/60Hz 200V	
	Maximum power consumption	115Kw	230Kw
	Maximum water consumption	27 ℓ /hr.(during VH treatment)	68.5 ℓ /hr.(during VH treatment)
		300 ℓ /min.(during cooling time)	600 ℓ /min.(during cooling time)

●Takenaka Corporation

The whole treatment chamber is a processing unit by creating differential pressure condition with forced circulation blowers.

Plastic containers with perforated bottom are filled with fresh fruits and stacked onto a pallet up to 7 layers thereby forming a chimney-shaped processing space.

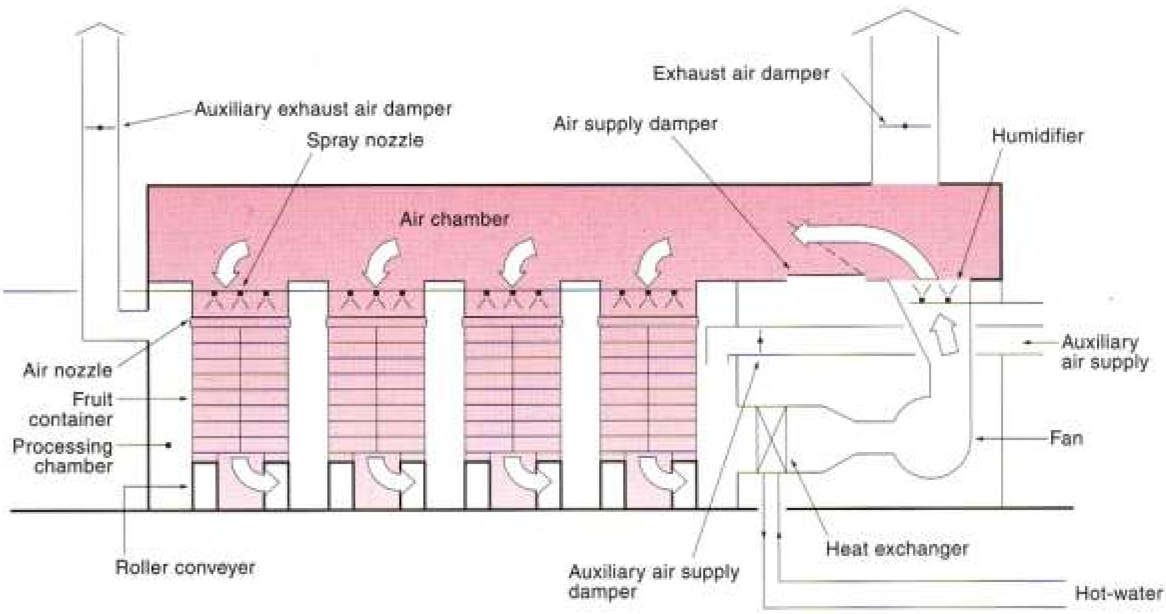
One pallet load of fruit involves 56 containers (8 containers/layer×7 layers) weighing 1 metric ton. The maximum load of 20 pallets (totaling 20 metric tons) can be treated at one batch.

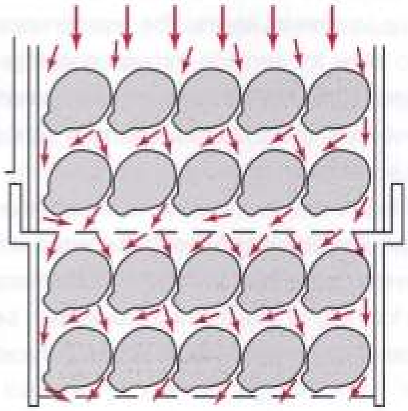
As shown in the figure below, the palletized unit of fruit containers joins with air chamber at the top. Blast-hole of air chamber is made flexible to fit securely with the top of palletized unit to ensure airtight condition which is necessary for creating differential pressure inside the enclosed processing space.

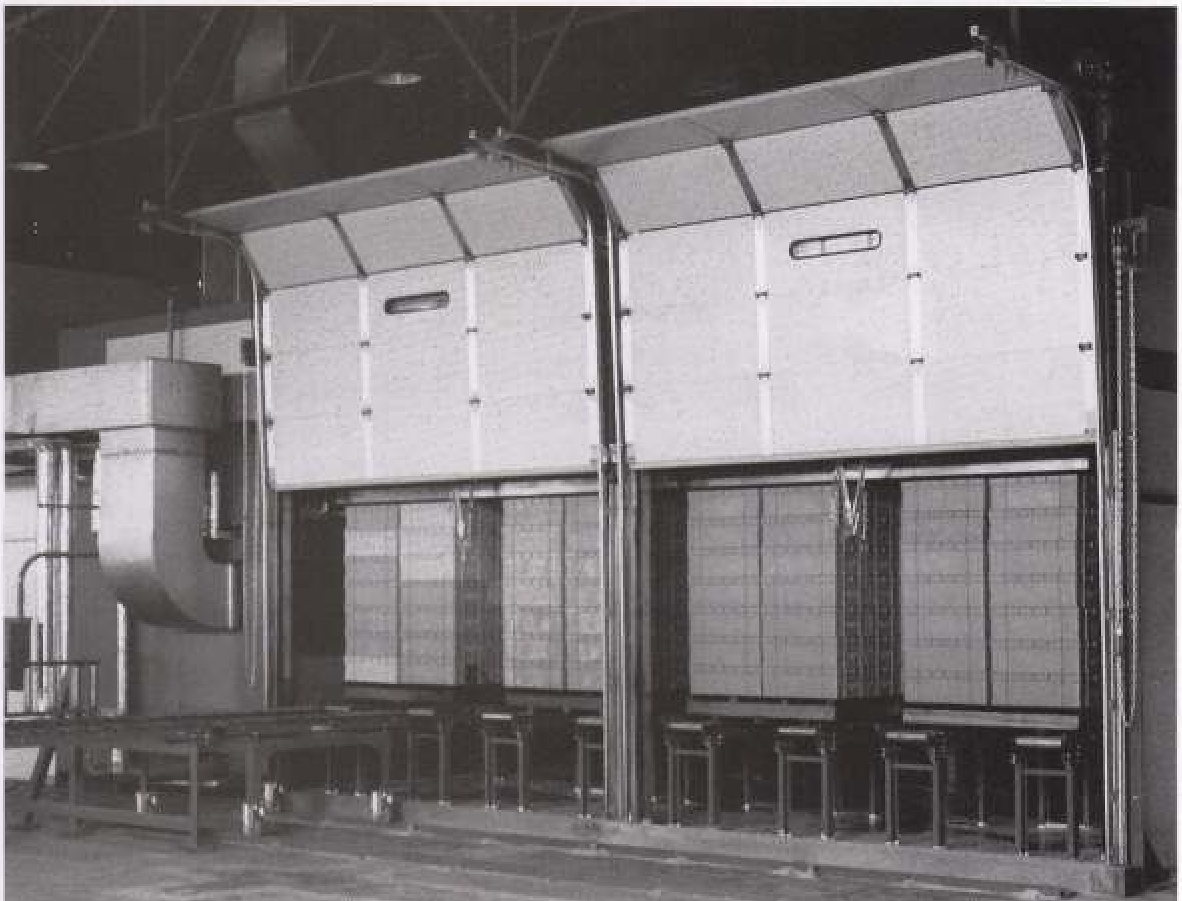
Temperature and humidity controlled air circulates from the top down to the bottom through the space in-between layered fruits. In order to obtain the best conditions for fruits under treatment, a regular volume of air is constantly supplied to ensure stable distribution of temperature and humidity so that no unevenness may arise in running up fruit temperature at every spot of fruit stacks. When the fruits have achieved the prescribed temperature, both exhaust and air supply dampers are released to introduce fresh air into the chamber for cooling down the treated fruits.

※Overview of the vapor heat treatment system of Takenaka Corporation

Overview of Vapour Heat Treatments System of Takenaka Corporation







2.Blow-in method

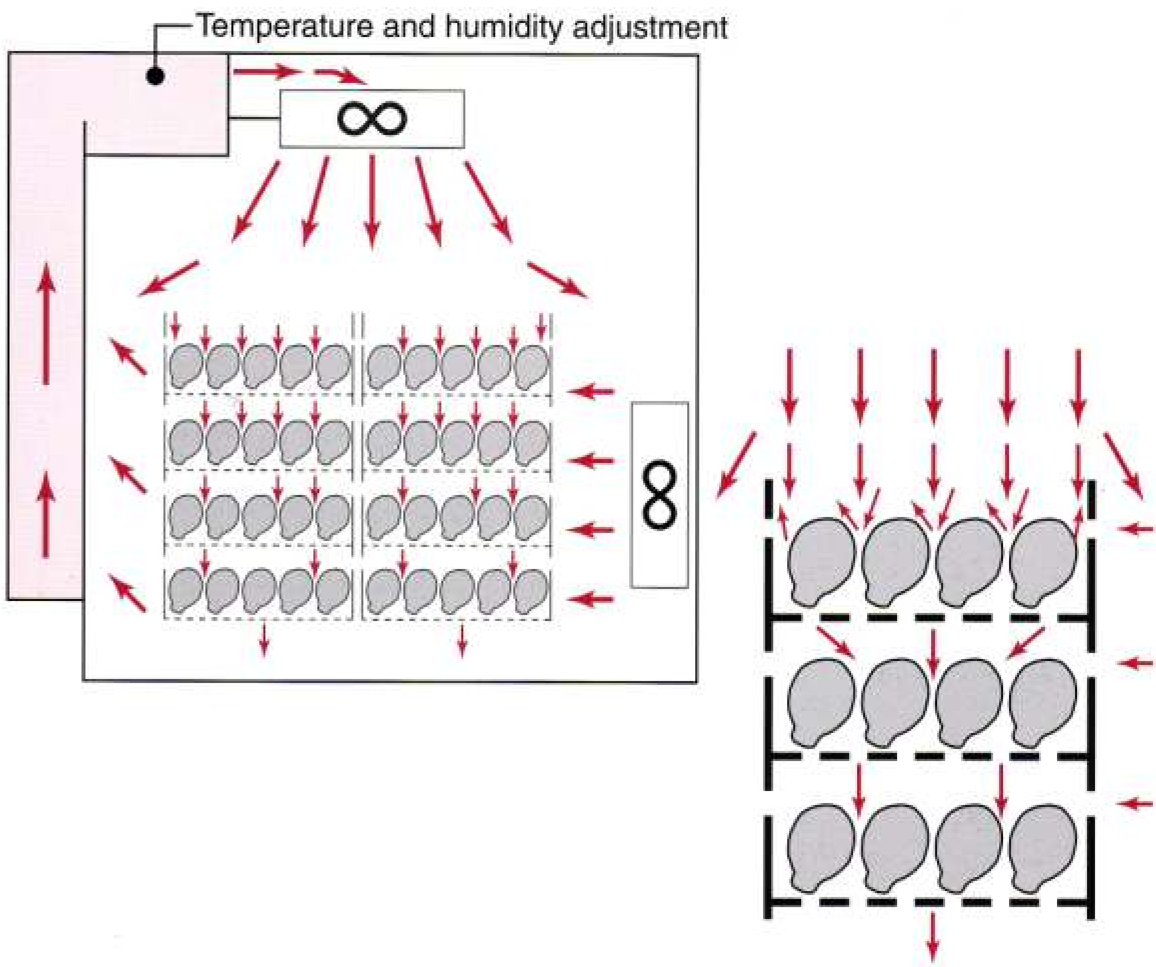
This type of treatment was used until the late 1960s. Fruit loaded wooden boxes are stacked onto a pallet up to several layers. The wooden box is designed to allow for aeration through openings at the bottom and spaces between side crosspieces. Two holes for handling the box on opposite side frames serve for aeration as well.

Temperature and humidity conditioned vapor heat is continuously blown into the fruit loaded boxes by fans from the ceiling and the side wall positions.

A shortcoming of this method lies in that, because the course of air stream is not restrained, most of the blown air flows through the less air-resistant space outside of wooden boxes and relatively small portion flows into the air-resistant interior of wooden boxes. More or less difference in exposure to vapor heat is inevitable between the fruits of upper layers and those at the inmost part of wooden boxes. Consequently, in short exposure treatment, significant difference in the run-up of fruit temperature arises depending on the laid position of treated fruits.

※ Diagram of the blow-in vapor heat treatment system

Diagram of blow-in type vapor heat treatment system



3.Horizontal air-stream method

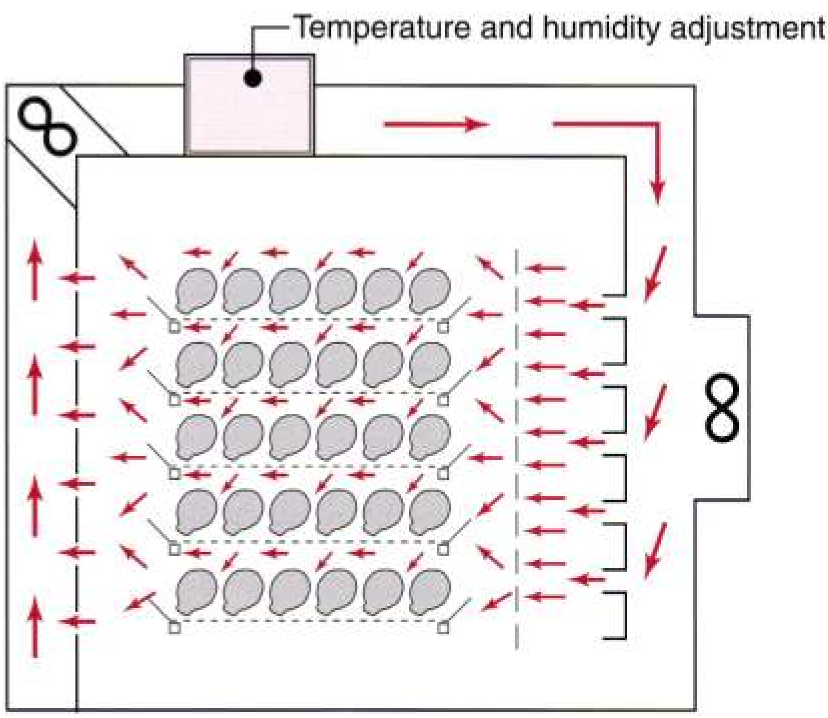
This is an improved version of the blow-in type treatment in which the original defect has been alleviated to a considerable extent. It features multi-layered treating shelves which are interspaced like the rearing shelves of silkworms used in sericulture.

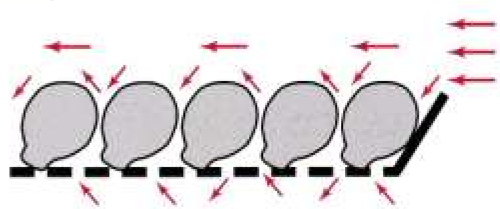
All the fruits laid in one layer in the shelf are designed for exposure to horizontal air streams. Air passes mostly on the upper surface of laid fruits and also partly on the lower surface through openings underneath the fruit layer. Fruit contact with vapor heat is better than that of the blow-in type treatment and gets closer to that of the differential pressure treatment. However, because the course of air stream is not fully restrained, the basic problem remains that more air flows over the top surface of treated fruits while the flow is much less in the air-resistant space such as the contact points between fruits and the lower side of fruit layers.

Combined use of turbulence by adequately placing baffle plates has been introduced to improve the uniformity of vapor heat distribution. However, compared with the differential pressure system, the inherent problems such as uneven thermal efficiency and non-repeatability in the rise of fruit temperature are yet to be resolved.

※ Diagram of the horizontal air-stream vapor heat treatment system

Diagram of horizontal air stream type vapor heat treatment system





3 Features of differential pressure treat

Features of the differential pressure treatment system are detailed below.

(1) The first feature of this system lies in the forced circulation of air by differential pressure. As mentioned in the preceding article, fruit containers of special designs are employed to make chimneys (or chimney bundles) which give definitely high treatment performance in combination with differential pressure generated by axial fans.

Differential pressure treatment system is a system in which vapor heat forcibly passes through the space in-between fruits laid in chimneys so that vapor heat works uniformly on all the fruits loaded. Thermal efficiency increases with higher load of fruits to a certain extent.

When fruit load is smaller than the optimum, air-resistance in the empty space decreases thereby incurring a lot of air to pass through whereas the air-resistance in the loaded space oppositely increases thereby lessening the air flow which works on the rise of fruit temperature.

On the contrary, when the fruit load is large enough to spread uniformly throughout the chimney, air-resistance becomes also uniform throughout the fruit stacks whereby enabling efficient thermal exchange between fruits and air.

(2) The second feature of this system lies in the container for holding fruits for the treatment. It is a topless cube with four solid sides and many small holes regularly punched on the bottom which allows air to pass freely. Size and number of this hole is subject to change with the kind and size of fruits to be treated. It is natural that diameter of the hole must be smaller than that of fruits. When the fruit is laid across the hole, it blocks the hole and prevents air flow through the hole. In order to avoid this disadvantage, the hole is configured in such a way as to afford aeration even if it is covered with the laid fruit.

Thus, the use of unique fruit containers specially designed for the treatment holds a key for high performance of differential pressure system.

The following relationships exist between the hole and the velocity of air passing through it.

(a)The volume of vapor heat passing through the container is proportional to the velocity of air passing through the hole.

(b)The differential pressure is in proportion to the square of velocity of air passing through the hole.

(c)The volume of aeration is in inverse proportion to the rise of fruit-core temperature.

On the basis of such relationships, it can be said that, even if the volume of air is increased to accelerate the rise of fruit temperature, it only adds to the pressure with relatively little effect on the fruit temperature. Performance of differential pressure treatment also varies with factors such as the size of fruits due to the species and the height of stacking fruit containers, etc. There is an optimal condition for the treatment of each different fruits. It is, therefore, necessary that the most suitable treatment condition for each kind of fruits should be sought after by repeating experiments.

(3) Third feature is the possibility of quick run-up treatment (to raise fruit temperature in short time). Quick run-up is not possible by the conventional treatments. When a long exposure treatment of 12 hours is satisfactory, any type of treatment can afford uniform rise of fruit temperature. When the treatment is to be finished in 5 hours, however, aberrance in the warm-up speed of fruit temperature is unavoidable with the conventional methods of treatment. Also, it is entirely beyond hope to minimize the treatment time any further without recourse to the differential pressure treatment.

The differential pressure treatment can uniformly raise temperature of papaya which is relatively larger than other fruits within 100~120 minutes. Such a high performance can provide diverse treatment patterns thereby enabling the choice of a best treatment procedure which is completely effective yet non-damaging to the fruit quality.

(4) The forth feature is scarce irregularity in the run-up of fruit temperature. Irregularities in the rise of fruit temperature was compared between the differential pressure treatment and the horizontal air-stream treatment of papaya fruits

Papaya fruits of ca. 470 grams were treated for 6~7 hours to achieve the fruit-core temperature of 47.2℃. The lapse of time needed for all individual fruit finally attaining 47.2℃ after the initial single one was, respectively, 40 minutes for differential pressure treatment and 90 minutes for horizontal air-stream treatment. Such difference in time factor has a significant impact on the possible outbreak of heat injuries. It also directly influences numbers and patterns of distribution of thermal sensors required for monitoring fruit temperature during the treatment. In the horizontal air-stream treatment, cold spots occur unpredictably at various spots in each treatment so that the rising patterns of fruit temperature are not reproducible. Therefore, the number of thermal sensors required is considerably greater than that of the differential pressure treatment. If the number of sensors for use is insufficient, cold spot may not be detected and, in the worst case, may cause incomplete sterilization of contaminated shipments.

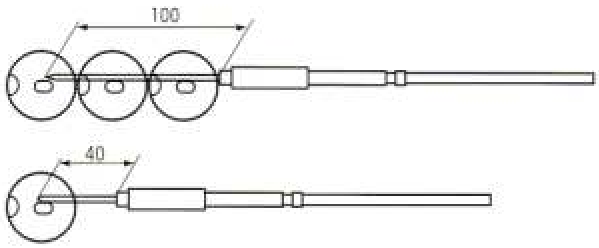
(5) Quick post-treatment cooling can be cited as the fifth feature of differential pressure treatment. To cool treated fruits quickly down to the normal temperature and, if necessary, to a certain cold storage temperature is vital for preserving fruit quality. In the differential pressure system, treated fruits can be cooled down more quickly than other methods by forced circulation of cold air. Furthermore, shower cooling (hydro-cooling) can be done easily by making use of the chimney-type structure.

(6) Container for treatment can also serve as container for transport thereby increasing transport efficiency of post-harvest fruit packing operation. This may be cited as an additional feature of differential pressure treatment system.

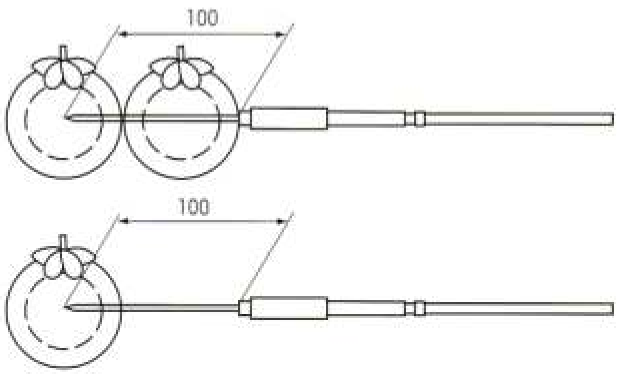
Installing thermal sensor probe into various fruits

Thermal sensor probe must be installed into the inmost center of fruit to be treated.
In the diagrams below, sensing point lies at the tip of the instrument.

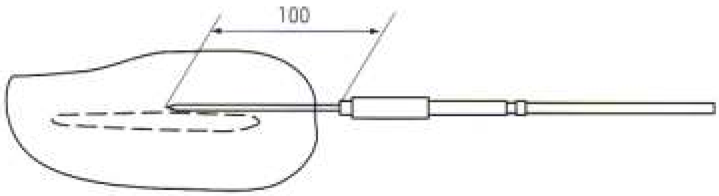
Litchi



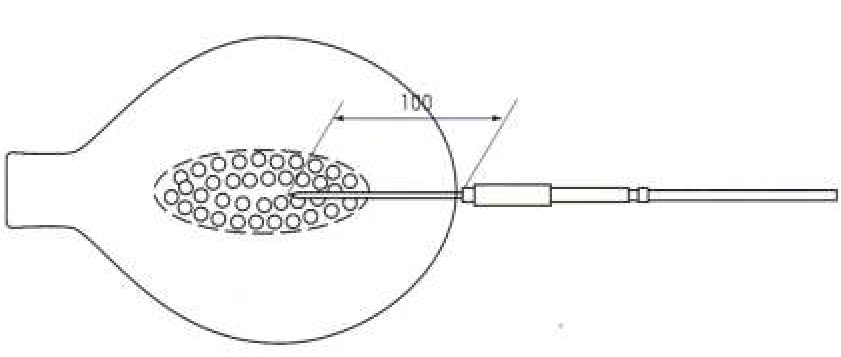
Mangosteen

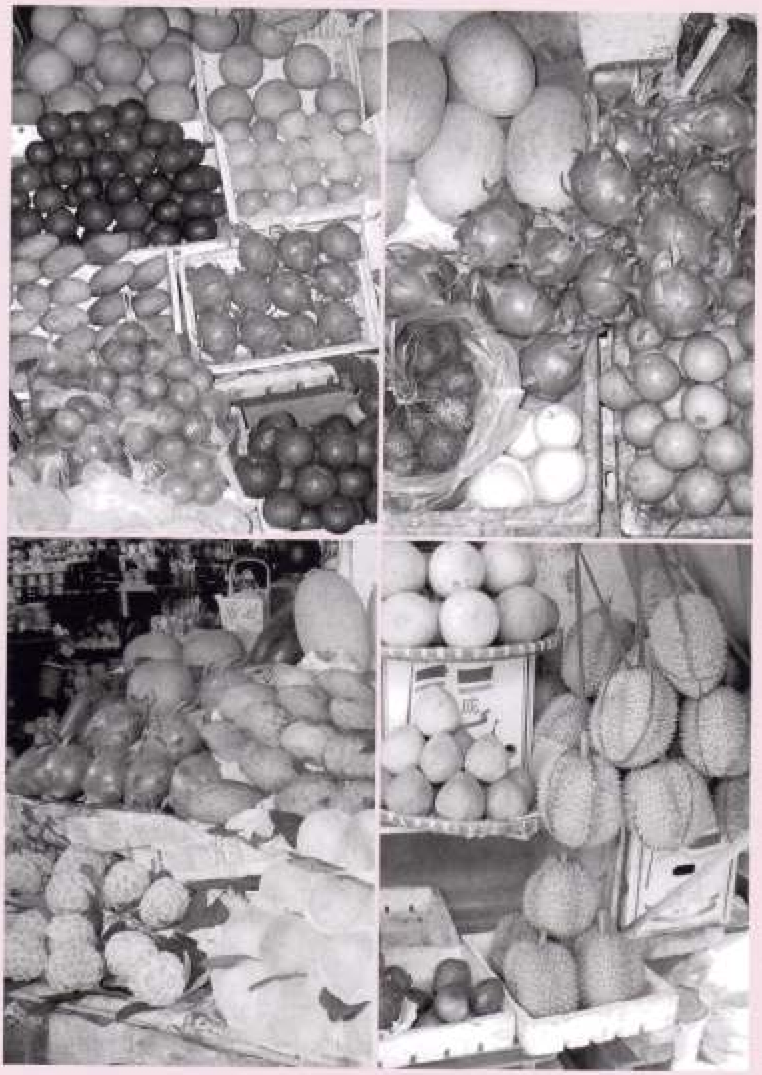


Mango



Papaya





Published: March, 1995
Revised: June, 2004
March, 2009
Publisher: VHT Research Group
Japan Fumigation Technology Association (JAFTA)
1-26-6 Taito, Taito-ku, Tokyo, Japan 〒110-0016
T e l . 03-3833-6923
F a x . 03-3833-6925

Comparison of features among differential pressure, horizontal air-stream and blow-in methods

Item	Differential pressure method	Horizontal air-stream method	Blow-in method	Remarks
Ratio of fruit surface exposed to vapor heat	Maximum	Moderate	Minimum	Factors relating to the speed of heating up treated fruits
Velocity of air flow in-beween treated fruits	High	Moderately slow	Low	
Uniformity in run-up of fruit-core temperature	Uniform	Nearly uniform	Not uniform	Relates to number of sensor probes for reading fruit-core temperature
Reproducibility of cold spot	Reproducible	More or less reproducible	Not reproducible	Cold spot occurs seldom in differential pressure method. If it does occur, it reccurs at the same spot of fruit stacks.
Recurrence of cold spot	Very few	Occasional	Frequent	
Speed in run-up of fruit-core temperature	High	Moderate	Slow	High speed in running up fruit-core temperature provides practical quick treatment procedure. It also affords choice of treatment patterns not damaging to fruit quality.
Ease of setting treatment time	Easy	Difficult	Relatively easier	Relates to number of sensor probes for reading fruit-core temperature
Usability of treating container for transport	Usable	Not usable	Usable	Treating container can be used for transporting fruits
Load ratio of treated fruits	Large	Small	Small	
Cooling time	Short	Moderate	Relatively longer	
Cost for construction	High	Low	Low	