第二章冷卻冷藏方法及其裝置

常用的冷卻冷藏法包括(1)送風式冷卻冷藏法 (2)人工空氣冷卻冷藏法 (3)碎冰式冷卻冷藏法 (4)減壓蒸發冷卻冷藏法 (5)半凍結冷卻冷藏法 。

第一節送風式冷卻冷藏法及其裝置

將食品放在冷藏室，利用送風機使冷卻的空氣再冷卻管與食品間循環，達到降溫的一種冷卻方法。此法廣泛應用在蔬果及肉類的冷藏法，魚類不用此方法。此法最大缺點為食品容易發生乾燥脫水。

表 1　冷風的流速與牛肉微生物含量之關係

冷風流速（米／分）	牛肉降至0.8°C所需小時	細菌數
45以上	9	略爲減少
27～36	5	保持不變
18～36	3	略爲增加

冷風流速越高，雖然時間稍長，反而微生物略為減少

一、Unit Cooler(冷卻機組)的優點

1. 空氣與冷卻管或食品的熱交換效果較佳，因此冷卻速度較快。
2. 可以保持冷空氣較高的相對濕度 ，因此食品發生乾燥的機 會 較少。
3. 冷卻管表面易於除霜，因此不影響冷凍力。
4. 冷藏室內溫度分佈較自然對流式冷卻裝置平均，因此庫內各方位的食品較能維持均一的溫度。
5. unit cooler 體積較小，因此室內容積可有效利用。
6. 冷媒的使用量較少，因此可降低運轉成本。

二、Unit Cooler的種類

表 2　unit　cooler　的種類

分類事項			說明
冷媒別	氨	用	使用以氨爲冷媒的蒸發器。
氟氯烷	Freon	用	使用以 Freon 爲冷媒的蒸發器。
	鹽水（Brine）	用	使用冷卻鹽水代替冷晶通過蒸發器。
	冷　水	用	散佈冷水以冷卻空氣。
溫度別	高　溫	用	空氣冷卻溫度在 10°C 以上者，冷氣冷房用
	中　溫	用	空氣溫度在0°C前後者，冷卻冷藏或貯冰用。
	低　溫	用	空氣溫度在 −10°C 以下者，凍結，凍藏用。
場所別	倒　吊	型	倒吊在天花板，能力較小者(1～2冷凍噸)。
	壁　掛	型	吊掛在牆壁，能力中型者（1～5冷凍噸）。
	床　置	型	置於地面，能力大者（3～10冷凍噸）。
送風機別	螺旋槳	式	空氣流通距離較小，形式較小者。
	渦　輪	式	空氣流通距離較長，形式較大者。

三、Unit Cooler的冷卻性能

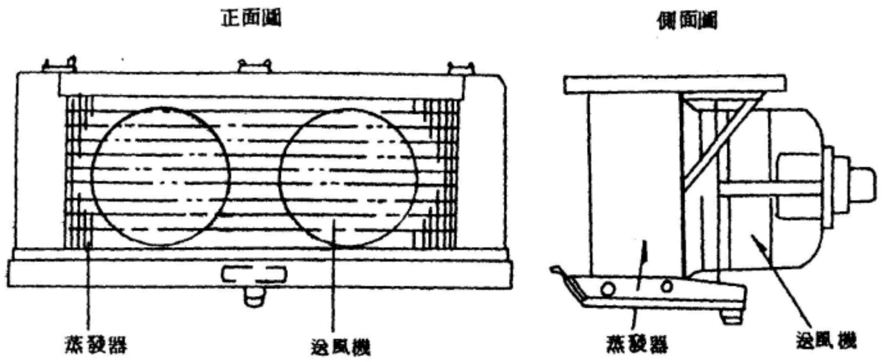

圖 1　unit　cooler　的模式圖

Unit Cooler 的實體圖

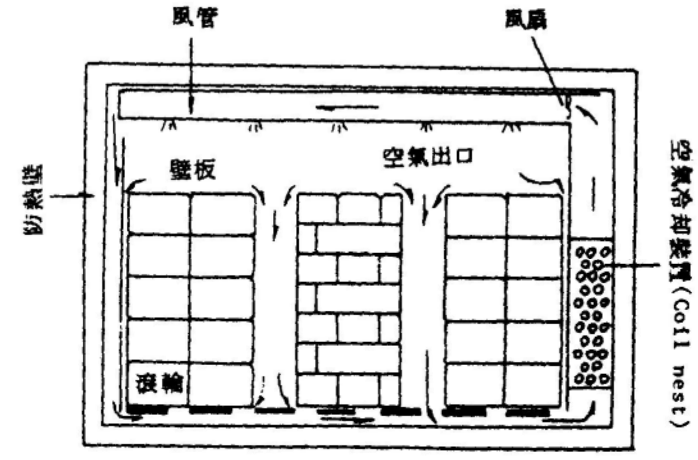

圖 2　空氣冷印裝置的熱傳效果

第二節 人工空氣冷卻冷藏法

原理　大氣的組成:氧21%，氮氣78%，二氧化碳約0.03%，稀有氣體0.9%。

將大氣中空氣以不同比例的氣體組成置換的保藏方法，貯藏過程不再控制其氣體組成。

修飾氣體包裝

- *Modified-atmosphere packaging (MAP)*: the replacement of air in a pack by a different mixture of gases, where the proportion of each component is fixed when the mixture is introduced, but no further control is exercised during storage. 控制氣體包裝
- *Controlled-atmosphere packaging (CAP)*: packaging in an atmosphere where the composition of gases is continuously controlled throughout storage. This technique is used primarily for the bulk storage of products and requires constant monitoring and control of the gas composition.

將大氣中空氣以不同比例的氣體組成置換的保藏方法，貯藏過程必須控制其氣體組成。

蔬果以不同比例的氣體組成充入包裝容器中，之後因其呼吸作用而達到平衡的保藏方法。

平衡修飾氣體包裝

- *Equilibrium-modified atmosphere (EMA)*: used primarily for fruit and vegetables; either the pack is flushed with the required gas mix or the produce is sealed within the pack with no modification to the atmosphere. Subsequent respiration of the produce and the gas permeability of the packaging allow an equilibrium-modified atmosphere to be reached.
- *Vacuum packaging (VP)*: the product is placed in a pack of low oxygen permeability, air is evacuated and the package sealed. The gaseous atmosphere of the vacuum package is likely to change during storage (from metabolism of the product or microorganisms) and therefore the atmosphere becomes modified indirectly.

真空包裝:包裝容器抽走空氣，之後因代謝或微生物作用產生氣體，而間接達到修飾氣體包裝的保藏方法

Role of gases

MAP主要的三個氣體:氧，氮氣，二氧化碳。

The three major gases used commercially in MAP are oxygen, nitrogen and carbon dioxide, although several other gases have been investigated, e.g. carbon monoxide, sulphur dioxide, nitrous oxide, ozone and chlorine. However, the use of these has been limited by safety concerns, legislation, negative effects on organoleptic properties and cost.

一氧化碳、二氧化硫、一氧化二氮(笑氣)、臭氧、氯氣

Oxygen (O_2) will generally stimulate the growth of aerobic bacteria and can inhibit the growth of strictly anaerobic bacteria, although there is a very wide variation in the sensitivity of anaerobes to oxygen (Farber, 1991). Oxygen is very important in fresh meats to maintain myoglobin in its oxygenated form (oxymyoglobin), which gives fresh meat its bright red colour. Its presence may cause problems with oxidative rancidity or colour in some products (e.g. fatty fish and cured meats, respectively).

Nitrogen (N_2) is an inert tasteless gas with low solubility in both water and lipid. It is used to replace oxygen in packs so as to delay oxidative rancidity and inhibit the growth of aerobic microorganisms (Farber, 1991). Because of its low solubility, it is used as a filler gas to prevent the pack collapse which may occur in high CO_2-containing atmospheres.

Carbon dioxide (CO_2) is both water- and lipid-soluble and is mainly responsible for the bacteriostatic effects seen on microorganisms in modified atmospheres (Farber, 1991). The overall effect on microorganisms is an extension of the lag phase of growth and a decrease in the growth rate during the logarithmic phase (Farber, 1991). This bacteriostatic effect is influenced by the concentration of CO_2, the age and load of the initial bacterial population, storage temperature and the type of product to be packaged (Reddy *et al.*, 1992). Although the bacteriostatic effect of CO_2 has been known for many years, the precise mechanism of its action is still not clearly understood. Farber (1991) summarised the theories regarding the influence of CO_2 on the bacterial cell as:

靜菌作用

- alteration of cell membrane function including effects on nutrient uptake and absorption;
- direct inhibition of enzymes or decreases in the rate of enzyme reactions;
- penetration of bacterial membranes, leading to intracellular pH changes;
- direct changes to the physicochemical properties of proteins.

With high-moisture/high-fat foods such as meat, poultry and seafood, excessive absorption of CO_2 can lead to the phenomenon known as 'pack collapse' (Parry, 1993). Increased in-pack drip is also caused by dissolution of the gas into the surface of fresh muscle foods which reduces their pH values sufficiently to weaken the water-holding capacity of the proteins (Parry, 1993).

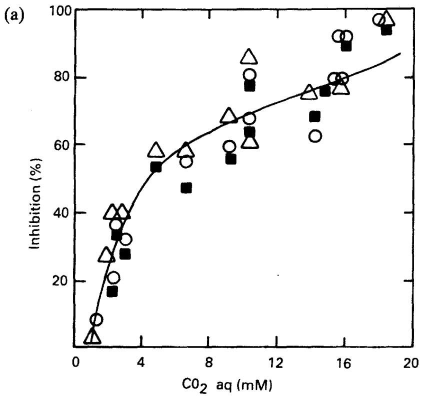

圖3說明跑掉了

Fig. 3. Effect of carbon dioxide and bicarbonate ion concentrations on the growth of *Pseudomonas aeruginosa* in nitrate broth at various temperatures: Dissolved carbon dioxide (a) or bicarbonate (b) concentrations determined from the medium pH using a pK_a value of 4·75. Inhibition was measured as a percentage decrease in turbidity compared to a control without carbon dioxide/bicarbonate at the same pH. Incubation temperatures were 20°C (■), 25°C (○) and 37°C (△).

二氧化碳濃度與微生物抑制作用成正比。

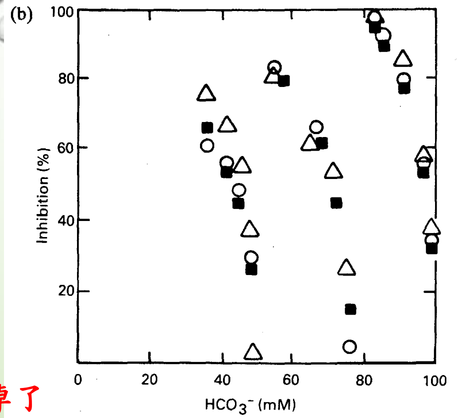

圖3說明跑掉了

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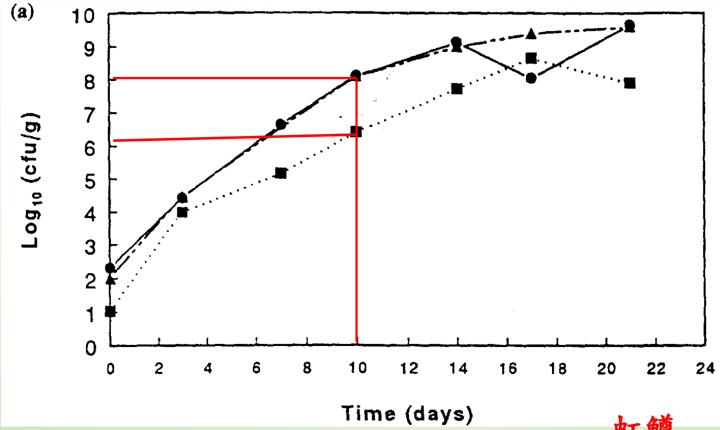
二氧化碳溶於水成碳酸，碳酸濃度增加(二氧化碳濃度變小)反而與微生物抑制作用成反比。



虹鱒

Figure 14.2 Microflora of (a) aerobic and (b) MAP (80% CO_2, 20% N_2) rainbow trout stored at 5°C. ■–■ = *Enterobacteriaceae*; ▲–▲ = *Pseudomonas* spp.; ●–● = lactic acid bacteria.

產氣菌 假單孢菌 乳酸菌

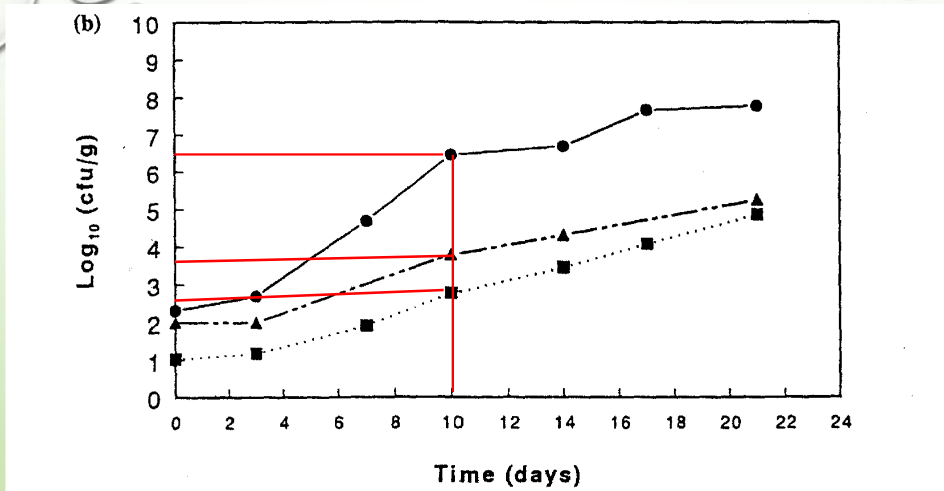


Figure 14.2 Microflora of (a) aerobic and (b) MAP (80% CO_2, 20% N_2) rainbow trout stored at 5°C. ■–■ = *Enterobacteriaceae*; ▲–▲ = *Pseudomonas* spp.; ●–● = lactic acid bacteria.

TABLE 1

Anaerobic Growth Rates of Different Bacteria in High (100%) and Low (5%) Carbon Dioxide

Organism	*Maximum specific growth rate* (h^{-1})		*% inhibition by high* CO_2
	5% CO_2/95% N_2	100% CO_2	
Aeromonas hydrophila	0·34	0·16	53
Bacillus cereus	0·24	0·08	67
Brocothrix thermosphacta	0·08	0·06	25
Citrobacter freundii	0·43	0·28	35
Clostridium sporogenes	0·20	0·12	40
Escherichia coli	0·40	0·27	33
Lactobacillus 173	0·13	0·12	8
Lactobacillus viridescens	0·13	0·11	15
Staphylococcus aureus	0·17	0·09	47
Streptococcus faecalis	0·41	0·29	29
Yersinia enterocolitica	0·27	0·20	26
Yersinia frederiksenii	0·25	0·12	52

Data from Molin (1983)

高二氧化碳濃度下微生物生長受到抑制，因其靜菌作用。

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TABLE 4

Dominant Microbial Flora of Vacuum or Modified Atmosphere Packed Meats Stored at Chill[a]

Meat	*Vacuum*	*Gas phase*					*Refs*[b]
		CO_2	CO_2/N_2	CO_2/O_2	$CO_2/N_2/O_2$	*Air*	
Beef	L	L	L or L/Co/Ps	L or L/Ps	L	L/Ps	1
						Ps/B	2
high pH	L/B	L	Ps/B/L			Ps	2
Pork	L	L	L/Le	L or Le	L/Ps	Ps	3,4
cured		L				Y	5
Luncheon meat 午餐肉	L/En						6
Lamb 羊肉		B/L	B/L/E	B	B/Ps/E	B/Ps	7,8
Poultry	L					Ps	9,10
Cured ham/turkey	B/L						10

[a] Organisms in order of frequency but only those comprising more than 10% flora at end of storage period are listed. Key to flora: L, lactic acid bacteria; Ps, pseudomonads; Co, coryneforms; B, *Brocothrix thermosphacta* 熱殺索絲菌; Le, *Leuconostoc*; En, *Enterobacter* sp.; E, Enterobacteriaceae; Y, yeasts.

棒狀桿菌

[b] (1) Christopher *et al.*, 1979a. (2) Erichsen & Molin, 1981. (3) Christopher *et al.*, 1979b. (4) Enfors *et al.*, 1979. (5) Blickstad, 1984. (6) Bell & Gill, 1982. (7) Newton *et al.*, 1977. (8) Grau *et al.*, 1985. (9) Jones *et al.*, 1982. (10) Mead, 1983.

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Table 14.1 Potential advantages and disadvantages of MAP **MAP的優缺點**

Advantages
- Shelf-life increase of 50–400% possible
- Economic losses reduced (longer shelf-life to spoilage)
- Products can be distributed over longer distances and with fewer deliveries, leading to decreased distribution costs
- Provides a high quality product
- Easier separation of sliced products
- Centralised packaging and portion control
- Improved presentation – clear view of product and all-round visibility
- Little or no need for chemical preservatives

Disadvantages
- Visible added cost
- Temperature control necessary
- Different gas formulations for each product type
- Special equipment and training required
- Product safety to be established
- Increased pack volume – adversely affects transport costs and retail display space
- Benefits are lost once the pack is opened or leaks

Adapted from Farber (1991) and Parry (1993).

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14.3.2 Microbial safety **MAP的安全性**

Whilst the ability of MAP to extend the shelf-life of many products is well recognised, concern has been expressed by regulatory authorities, food industry groups and others that MAP may introduce undue safety hazards. The concerns are that suppression of the normal spoilage flora may result in an organoleptically acceptable product whilst either allowing or enhancing the growth of pathogenic organisms. Historically, the non-proteolytic, psychrotrophic strains of *Clostridium botulinum* have been the major safety concern. These strains can grow and may produce toxin without producing overt signs of spoilage, which may also be absent as a result of an inhibition of the normal spoilage flora. More recently, concerns have been expressed about the ability of the other psychrotrophic pathogens, e.g. *Aeromonas*, *Listeria* and *Yersinia*, to grow in MAP products.

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14.3.3 Clostridium botulinum

Historically, MAP of fish and fish products has been the greatest cause for concern with respect to *Cl. botulinum*, and resulted in the US National Academy of Sciences recommending that, until the safety of the system was established, fish should not be packed in MAP (Davis, 1993). This resulted from the isolation of all types of *Cl. botulinum* from marine environments, which, although highly variable by geographic location and season, is frequent enough that processors must assume its presence.

Strains of type E and the non-proteolytic types B and F are the major concern in MAP as they are able to grow at temperatures as low as 3.3°C, albeit slowly, and, as they do not putrefy proteins, may not cause obvious signs of spoilage. Numerous studies have examined the relationship between time to toxin production and signs of organoleptic spoilage for MAP fish, and these have been reviewed (Reddy *et al.*, 1992; Stammen *et al.*, 1990). Unfortunately, because of the many variables between studies, e.g. fish type, size and site of inoculum, temperature, season, atmosphere, etc., direct comparisons between the studies cannot be made. However, Stammen *et al.* (1990) in their review, concluded that

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'with few exceptions, at temperatures above 20°C, organoleptic spoilage coincided with toxin production in many fresh fishery products, regardless of the modified atmosphere used. However, at lower temperatures, organoleptic

spoilage preceded toxin development in all fresh fish products except cod and whiting fillet held in either an air, vacuum or CO_2 atmosphere. This trend was seen at storage temperatures from 4–12°C. The time interval between toxin development and organoleptic spoilage of MAP fish products generally decreased as storage temperatures increased. In contrast toxin development preceded organoleptic spoilage in cod and whiting fillets packaged in 100% CO_2 and held at refrigeration temperatures. These products were still acceptable for consumption even though botulinal toxin was found in them.'

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表 18-13 一些作物對高二氧化碳及低氧氣濃度之敏感性

作　物	最低氧氣耐量（％）	最高二氧化碳耐量（％）	症　　狀
白花菜	—	5	烹煮時過度軟化及變色
青花菜	0.25	20	高耐性
馬鈴薯	5	10	失去癒傷能力
菠　菜	0.5	2～4	主葉脈變成棕紅色

註：表中數據因品系、栽培條件及儲藏溫度而變。
（引用自：Fennema，1985）

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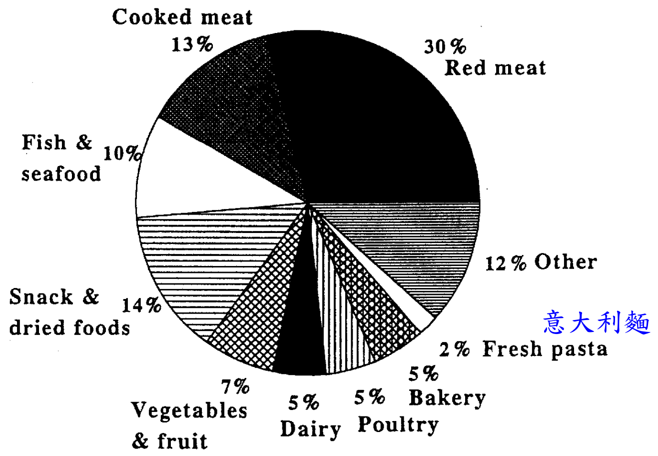

Figure 14.1 Segmentation of the UK MAP retail market by food product sector, 1992. Reproduced with permission from Day B.P.F. Recent Developments in MAP. *European Food and Drink Review*, Summer, pp. 87–95.

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一、 人工空氣的配置

(1)密閉的冷藏室中蓄積植物呼吸作用所產生的二氧化碳。(2)密閉的冷藏室內另行添加二氧化碳。

二、人工空氣冷藏裝置

正常呼吸作用下，空氣中的O_2+ CO_2常維持21%，呼吸作用繼續進行， O_2減少CO_2增加達到所需濃度時，可將多出的CO_2利用新鮮空氣置換使CO_2維持一定濃度，此稱控制大氣貯藏法(Control atmosphere)。

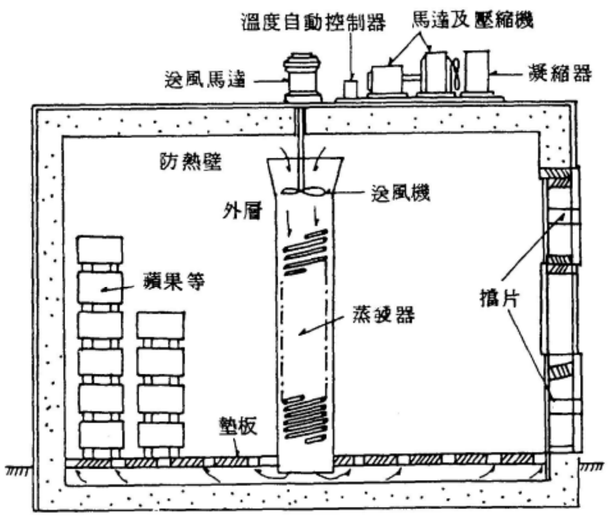

圖 3 人工空氣冷藏室（未附空氣洗淨器）

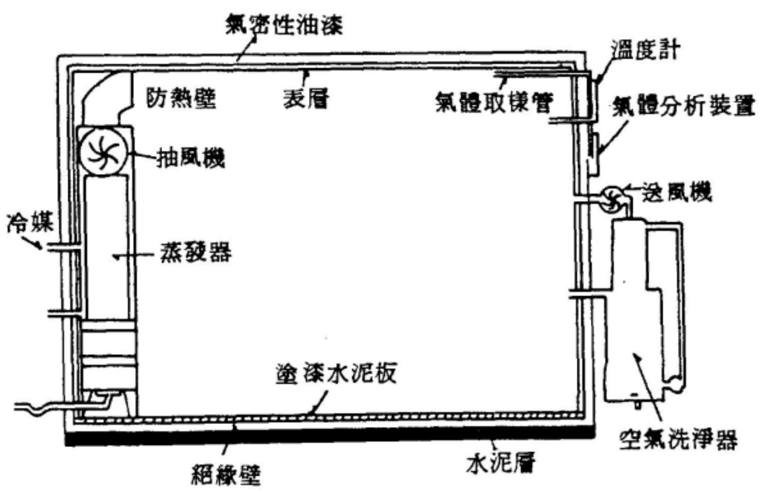

圖 4 人工空氣冷藏室（附空氣洗淨器）

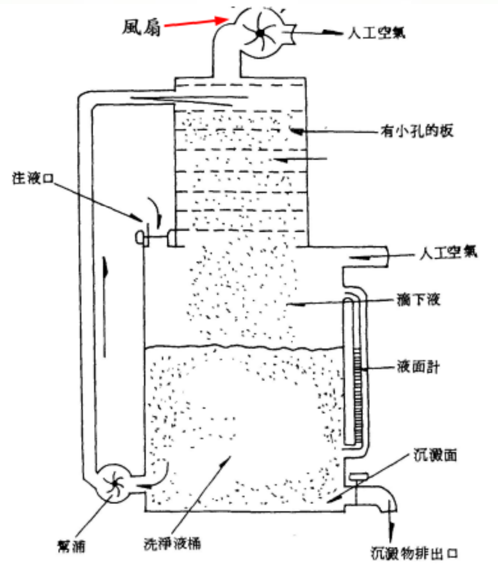

圖 5 空氣洗淨器的構造

三、人工空氣冷藏的優缺點

表 3 人工空氣冷藏的優劣點

優點	缺點
1. 可以降低低溫機能障害	1. 作業與管理不便
2. 可以延長冷藏期限	2. 保持氣密性困難
3. 冷藏後的貯藏性較佳	3. 設備費較貴
4. 可以利用較高溫冷藏	4. 無法產生低溫與人工空氣的雙重效果
5. 冷藏中重量的損失較少	5. 蘋果的燒傷病（Scald）會增加
6. 可以抑制好氣性微生物繁殖	6. 冷藏費用較貴

第三節碎冰式冷卻冷藏法及其裝置

一、冰的冷卻作用

1公斤冰溶解成水需吸收80 kcal熱量。

1公斤20℃的魚(水分含量80%)降溫至0℃需移除

1x0.8x(20-0)=16 kcal熱量，故魚體降溫後，冰尚未完全融化。

二、碎冰的種類

有雪泥狀、豆腐狀、鱗片狀、細管狀、圓柱狀、長帶狀等，
也有普通冰、海水冰、藥品冰等。

三、製冰裝置

台灣大多冰罐先製造300磅塊冰，再用碎冰機細碎之，

美國則使用Turbo Plate Ice Marker來製作碎冰。

四、碎冰冷卻冷藏法

冰藏法在魚類保鮮上常用(1)散裝法(2)棚積法(3)箱裝法。

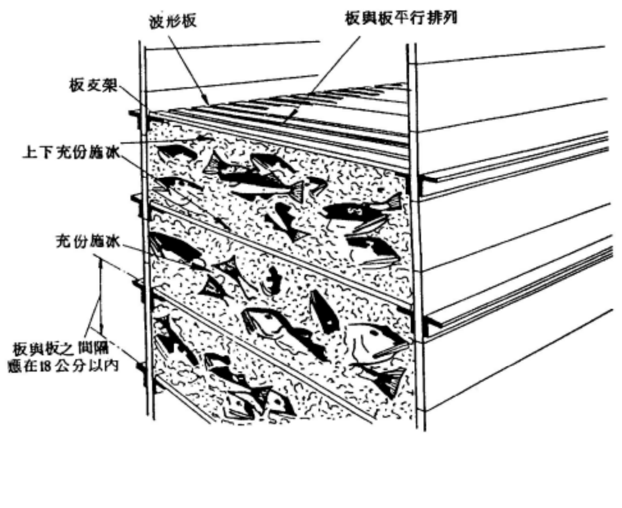

圖 8 散裝冰藏法之正確冰藏方式

表 5 碎冰與食鹽的混合比與溫度之關係

混合物中食鹽的比率（%）	溫 度（°C）
0	0
5	－2.8
10	－6.8
15	－11.7
20	－16.6
25	－21.1

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第四節減壓冷卻冷藏法及其裝置

係將食品置於密閉容器內，將容器內空氣抽除，隨著壓力降低，食品表面水分隨之蒸發。蒸發時潛熱被取走，食品溫度隨之下降達到冷卻目的，又稱為真空冷藏法。

表 6 真空度，冷卻溫度與冷卻所需時間之關係

青果物	真空度（mmHg）	冷卻時間（分）	溫度變化（°C） 處理前	溫度變化（°C） 處理後
波 菜	4.6~4.9	20	18	1.1
甜玉米	3.3	10	15	2.2
蕃 茄	4.5	10	23	3.3
西洋白菜	4.0	10	24	1.1
芹 菜	4.6~4.9	20	20	5.5

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第五節半凍結冷卻冷藏法及其裝置

將食品置於零下3℃左右，食品呈半凍結狀態，此種方式稱半凍結冷卻冷藏法(Partial freezing)，較冰藏法多出7天的保鮮時間。半凍結雖然會到達最大冰晶生成帶(零下5℃)，但對組織傷害、蛋白質變性卻較零下10或20℃為低。故就2~3星期之保鮮，其效果較冰藏法或凍藏法為優。

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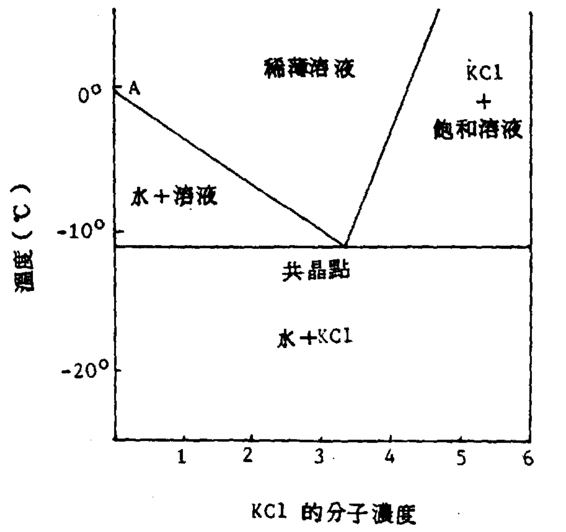

圖14 KCl 濃度與共晶點之關係

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第六節夾層式冷藏法或凍藏法(Jacket Cooling)

一、原理

在普通冷藏庫的內面四周，再施以一層防濕氣密性的一層材料，使冷空氣在夾層內循環以保持冷藏室內食品在低溫狀態並以防止乾燥的一種冷藏或凍藏方法。

在一定的冷藏室將空氣冷卻時，因爲 KF 值一定，因此如Q值變大時，從 $Q=KF(Q_1-Q_2)$ 的關係式中可知，必須將 Q_1-Q_2 值變大，亦即必須將冷藏室內的空氣與蒸發器表面的溫度差變大，但相對的空氣在蒸發器表面的脫濕量將增加，此時冷空氣的相對濕度將降低，所以食品在此冷藏室內冷藏或凍藏時，較容易發生乾燥，而夾層式冷藏庫不但可以維持較低溫度且可維持冷藏室內空氣較高的相對濕度，而達到防止乾燥的目的。玆將其原理說明於後。

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當與冷藏庫同溫度的食品，收容在冷藏庫時，由冷藏庫四周侵入的熱量，因爲夾層中冷空氣的冷卻作用而變成 0，由內侵入的熱量亦因風的遮斷作用而變成 0，因此外部熱可以說變成 0，又冷藏庫內如無作業熱存在，其內部亦變成 0；所以理論上冷藏庫內空氣與食品以及蒸發器表面沒有熱的傳遞發生。因爲沒有溫差發生，所以食品理論上沒有乾燥現象發生。但理論歸理論，實際上並不能完全防止內部熱與外部熱的發生。一般冷藏庫的蒸發器表面與冷藏庫內空氣的溫度差大約爲 7～10°C，但夾層式冷庫內的冷空氣的溫度 t_1 與夾層內冷空氣的溫度 t_2 的溫度差爲 $-t_1$ 約爲 1°C 左右，因此空氣脫濕非常少而能保持較高的相對濕度。又因夾層面與空氣的溫度保持同溫度的關係，因此空氣的流動亦較自然對流式的冷藏庫較少，所以食品的乾燥得以防止。

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又爲發揮夾層式冷藏法的效果，夾層內的冷空氣必須能將四周侵入的熱量迅速冷卻，爲達到此一目的必須利用強制循環的方式，使空氣內的冷空氣保持一定的流速及一定的溫度。又夾層內空氣的流量，會影響冷藏室內的溫度，間接的亦會影響到空氣的相對濕度，關係爲 $Q=WC(T_2-T_1)$ 式中

Q	＝單位時間內由蒸發器吸收的熱量	kcal/hr
W	＝單位時間內空氣循環量	m^3/hr
C	＝空氣的比熱	kcal/kg. °C
T_2	＝進入蒸發器的空氣溫度	°C
T_1	＝由蒸發器吐出的空氣溫度	°C

亦即當空氣流量 W 增大時，室內的熱量 Q 將增大，要不然就得降低 (T_2-T_1) 值。夾層式冷藏的理想狀態是被收容的食品品溫應與冷藏庫或凍藏庫的品溫相同，且無呼吸熱等反應熱或作業員進出的作業熱產生；但事實上並不可能達到此理想狀態，因此夾層式冷藏設備應另行裝置 unit coller 以便將此等熱量排除，方能充份發揮其優點，否則如果應用不當反而會造成不良結果。

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二、構造

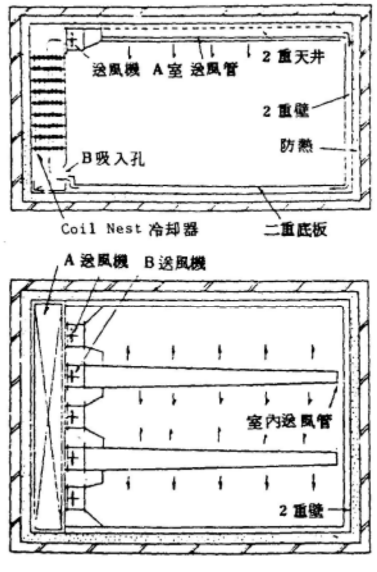

圖15 夾層式冷藏庫的構造

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三、凍結肉的夾層式凍結法

表 7　夾層式凍藏法在凍藏中肉類的失重現象

食肉種類	最初重量 (kg)	失重量：減重	失重量：失重率 (%)	普通凍藏法失重率(%)
牛　肉	194,100	1187.9	0.61	1.11
羊　肉	125,090	888.9	0.71	1.30

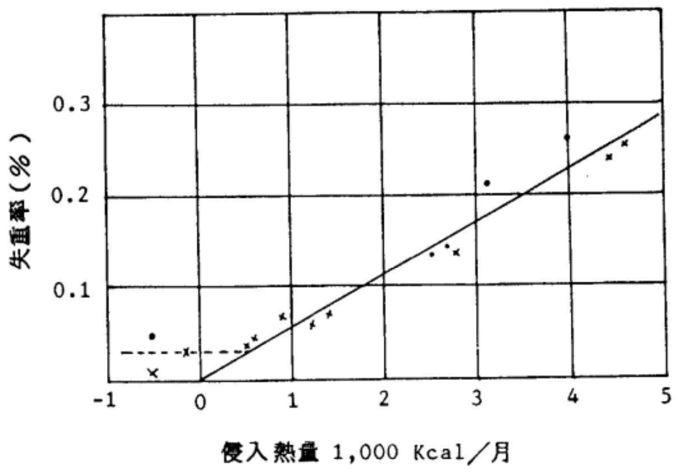

圖16　夾層式凍藏庫外部熱量侵入量與凍結肉失重之關係

外部熱量侵入越多，產品失重越多

四、夾層式冷藏法或凍藏法的優缺點

優點：

1. 冷藏庫內溫度的平均非常均一。
2. 冷藏庫內的相對濕度較高。
3. 冷藏庫內幾乎沒有空氣的流動。
4. 冷藏庫內結霜較少。
5. 由於①～④項優點的關係，因此食品在冷藏中脫水率極低，可以確保優良的品質。

缺點：

1. 因需要設置夾層因此設備費較貴。
2. 因有夾層存在因此容積降低，收容量較少。
3. 應先將冷卻或凍結食品的溫度降至與冷藏室或凍藏室相同的溫度，否則將無法發揮夾層式冷藏庫的優點，又會產生大量呼吸熱的青果物較不適於利用夾層式冷藏法冷藏。