2004 CORNELL FRUIT HANDLING AND STORAGE NEWSLETTER

Items of Interest for Storage Operators
in
New York and Beyond

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SmartFresh^{TM} (1-MCP) – an update

Chris Watkins and Jackie Nock

1-Methylcyclopropene (1-MCP), sold under the commercial name of SmartFresh^{TM}, needs little introduction to storage operators in New York. 1-MCP has quickly become a major component of our industry. Its effects on delaying apple ripening, and especially on maintaining texture quality of fruit, continue to amaze. 1-MCP is impacting sales both domestically and internationally. We receive telephone calls from retailers wanting to know how 1-MCP works because they cannot believe the quality of Empire apples that they are selling. The UK market has also responded extremely positively to the beneficial effects of 1-MCP on fruit quality. The advantage that 1-MCP confers on apple fruit is that it maintains firmness throughout the whole marketing chain, in contrast to air and CA storage alone where fruit can deteriorate and soften rapidly after leaving the packing house.

However, there are positives and negatives to the 1-MCP story, some of which can be addressed by research. Others, such as the effects of 1-MCP on consumer expectations for certain varieties, are ultimately ones that the industry must resolve. We are doing as much as we can o understand the strengths and weaknesses of 1-MCP, but rapid adoption of the technology by New York industry means that problems are being identified more quickly than solutions. In the case of the last major breakthrough in storage technology, controlled atmosphere (CA) storage, implementation took place over many years, and problems are still common today. With 1-MCP, we as an industry are fast-tracking adoption of a new technology that still has many unknowns. In this article some of the major issues that are facing users of 1-MCP are outlined. We do not have all the answers yet and some of the opinions below must be regarded as speculative.

Effects of Variety

There are two aspects that are important when considering variety responses to 1-MCP.

First, 'what are the inherent qualities that the consumer expects from a particular variety, and will 1-MCP increase or decrease these qualities?' In low aroma apple varieties, such as Empire and Delicious, the most important attributes for consumers appear to be texture and the sugar/acid balance. Consumer responses to such varieties when treated with 1-MCP are usually overwhelmingly positive. Exceptions can occur because consumers do expect apples to soften to at least an edible texture, and there have been occasional reports of 1-MCP-treated apples of some varieties being too hard!

The situation with high aroma varieties, such as McIntosh, may be more complex. Inhibition of ethylene production by 1-MCP can inhibit production of aroma volatiles. Therefore, consumer expectations for an aromatic and flavorful fruit may not be met. On the other hand, the market segment for traditional 'soft' apple varieties is declining and it is possible that a less flavorful but firmer McIntosh may create new market opportunities for the industry. Market expectations for a variety must be considered as part of the decision making process regarding 1-MCP use.

The second aspect is the variability among and within varieties in responsiveness to 1-

MCP. In theory, every apple variety can respond to 1-MCP, but in practice this response is affected by fruit ethylene production. Our research shows that there are few examples of absolutely no response to 1-MCP, but rather that there are 'degrees of response'. The effects of 1-MCP can be long-lived or short-lived depending on many pre- and post-harvest factors that affect ethylene production by the fruit.

To understand the reason for this, it is important to remember that apples are natural producers of ethylene, the compound that is responsible for softening, red color development, and other ripening processes. Ethylene production can occur in fruit while on the tree as well as after harvest, and it occurs autocatalytically, meaning that a small amount of ethylene in the fruit results in increasingly greater amounts over time. Fruit with high rates of ethylene production cannot respond as well to 1-MCP as those fruit with low rates of ethylene production. Typically, varieties that have lower ethylene production rates during the normal harvest window such as Gala, Empire, Delicious and Jonagold respond strongly to 1-MCP. In contrast, varieties with high ethylene production during the normal harvest period respond much less favorably. For example, we find that effects of 1-MCP on Macoun are sometimes limited, as is often the case for McIntosh. Use of ethrel and other pre-harvest factors that induce ethylene production markedly reduce the effectiveness of 1-MCP. (We suspect that NAA used to prevent preharvest drop may also decrease effectiveness of 1-MCP because it can stimulate ethylene production by the fruit, but we do not have conclusive data for NAA). Also, as described below in the section about delays between harvest and 1-MCP treatment, pre- and post-harvest factors are closely linked.

The bottom line is that variety responses to 1-MCP are affected greatly by ethylene production during the harvest period. Different varieties have different ethylene production rates and timing of this production relative to their normal harvest period. Moreover, pre-harvest treatments can affect the timing of autocatalytic ethylene production. The temptation to harvest fruit earlier to improve the response to 1-MCP must be avoided, however, as fruit harvested prematurely will never develop flavor and quality characteristics desired by the consumer.

A further complication in considering varieties and 1-MCP is that ethylene production varies from region to region, not only in the timing of its autocatalytic increase, but also in actual rates of ethylene production. In general, fruit grown in warmer climates have more rapid ethylene production. In varieties such as McIntosh, growers face a constant battle between obtaining sufficient red coloration and avoiding pre-harvest fruit drop, and the relationship between the two factors is affected by region. The best "home" for 1-MCP usage for McIntosh appears to be the Champlain region where good color development usually precedes ethylene production. Therefore, it is possible to harvest high quality fruit and obtain uniform responses to 1-MCP. Elsewhere in the state, the situation is more problematic. Obtaining adequate color development before ethylene increases (often evidenced by preharvest drop) can be difficult, and even worse, affected seasonally. Therefore, 1-MCP is more likely to have inconsistent benefits on texture and other ripening attributes from year to year. In western New York we might have good coloring weather for three years in a row, allowing early harvest of fruit and thus good 1-MCP effects. Those years might be followed by a late coloring year when apples respond poorly to 1-MCP, leaving growers with an inability to provide the market with product that it has come to expect!

The particular variety and when it is harvested provides the base product for 1-MCP treatment. Although maturity guidelines of starch indices and firmness are provided by AgroFresh, the commercial suppliers of 1-MCP, the most reliable guide to responsiveness of fruit to 1-MCP is ethylene production or internal ethylene concentration (IEC). Thus, when one considers the diversity of orchard microclimates and management decisions that exist in the field the process of determining potential effects of 1-MCP remains relatively crude.

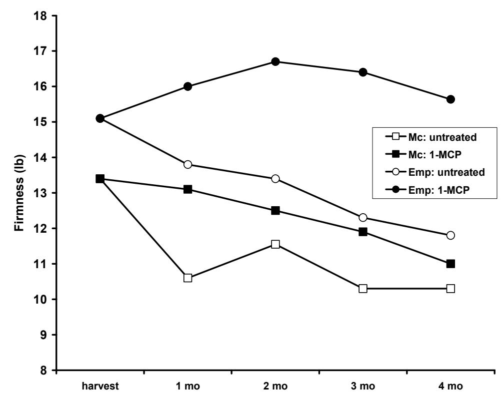


Fig. 1 Firmness (lb) of McIntosh and Empire apples treated with 1 ppm 1-MCP and stored in air for up to 4 months. Fruit were removed from storage at monthly intervals and firmness measured after 7 days at 68°F.

Air compared with CA storage

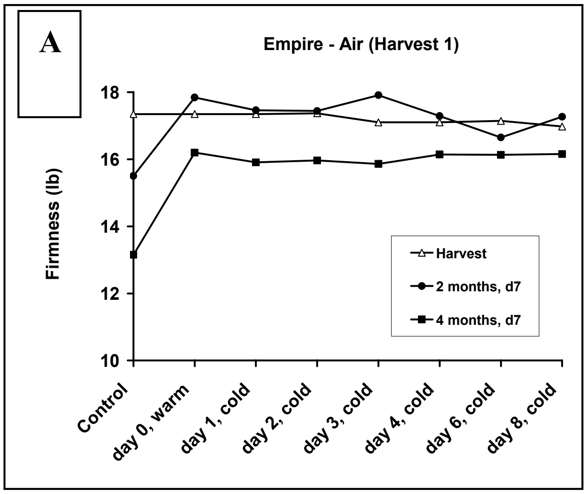
As storage periods increase, we found that 1-MCP and CA are more effective when used in combination. Using both technologies is especially important if fruit from some orchard blocks do not respond to 1-MCP. If not also exposed to CA, quality will be especially poor. Nevertheless, 1-MCP can be an excellent substitute for short-term CA storage, especially to meet the December/January market when quality of air-stored fruit begins to decline. The potential for 1-MCP usage has already been recognized by New York retail operators who lack CA facilities. It is important to realize however, that variety responses to 1-MCP also differ greatly even for shorter term storage periods. Apples such as McIntosh can lose their responses to 1-MCP much more quickly than varieties such as Empire, especially during air storage (Fig 1).

Delays between harvest and 1-MCP treatment

The New York apple industry is diverse, ranging from small retail operations to large volume cooperatives. While the latter type of operation is able to organize fast harvest and rapid CA storage, smaller operations are not always able to do so because of limitations of scale. Commercial guide-lines call for a 7 day maximum period bet-ween harvest and treatment with 1-MCP for most varieties with a maximum 3 days for McIntosh. We have carried out extensive studies with several varieties, and the results of these trials are available in Watkins and Nock (2003). Here, we have selected a few results that illustrate the importance of time between harvest and treatment as a factor in 1-MCP success.

Harvest date interacts with the need to treat fruit with 1-MCP quickly after harvest. Figure 2 A and B shows the effect of 1-MCP applied on the day of harvest (warm) or after being placed in cold air storage for 1, 2, 3, 4, 6 and 8 days for early and late harvested Empire apples. For fruit harvested at the start of the optimum harvest window for CA storage, negligible softening occurred after 2 months plus a 7 day shelf life (Fig. 2 A). There was little difference among 1-MCP treatments, i.e., warm, or cold from 1 to 8 days after harvest. By 4 months of cold storage, fruit had softened about a pound, but there was still no effect of treatment delays. For fruit harvested later, firmness was maintained for 2 months, and again softening occurred by the 4 month evaluation, although to a greater extent than for fruit from the first harvest (Fig. 2 B). Fruit had to be treated within a 4 day time frame to obtain benefits from

Fig 2. Firmness of Empire apples from two harvest dates A. Sept. 28, 2000, when the internal ethylene concentrations were 0.39ppm, and B. October 12, 2000, when the internal ethylene concentrations were 32ppm. Fruit were treated with 1-MCP at harvest (warm) or after 1, 2, 3, 4, 6 or 8 days of cold storage. Fruit were stored in air at 33 °F for 2 or 4 months and assessed after 7 days at 68 °F.



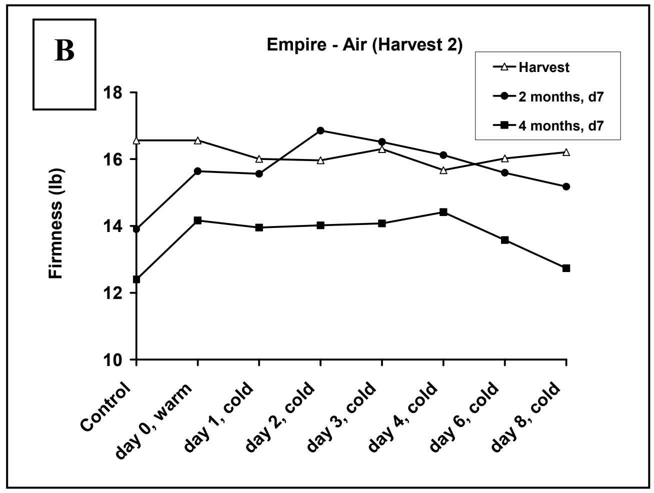


Fig. 3 Firmness (lb) and internal ethylene concentration (ppm) changes that occurred in Jonagold apples over a 21 day period in cold storage (33°F) after harvest.

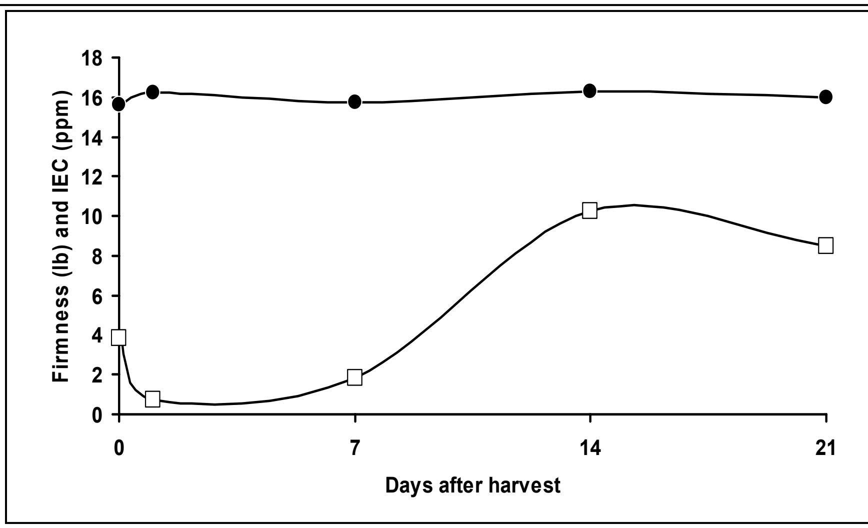
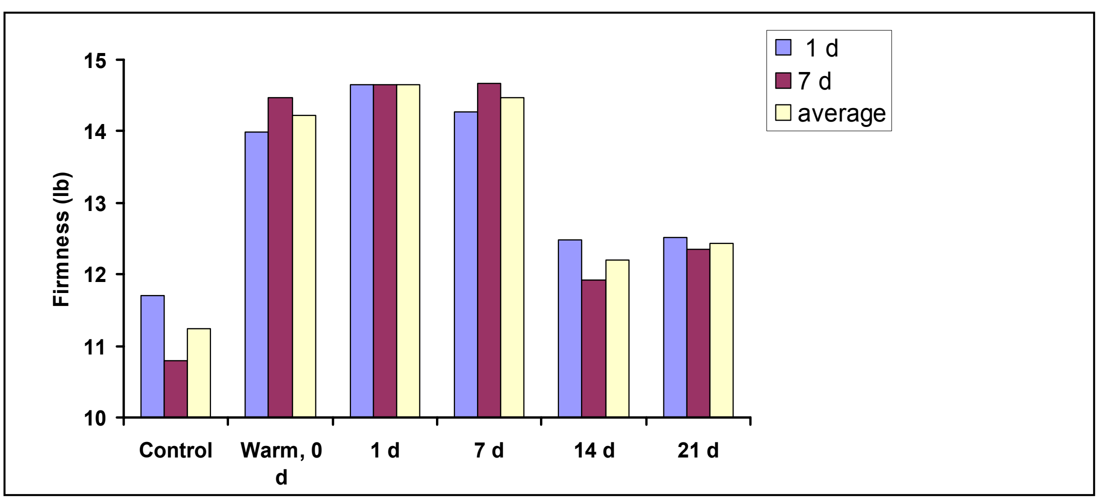


Fig. 4. The firmness of Jonagold apples after storage in CA Conditions for 5 months, when either untreated, or treated with 1-MCP on the day of harvest (warm), or after 1, 7, 14 or 21 days of cold storage.



1-MCP. For fruit from this late harvest, treatment within 3 days was necessary to maintain the firmness of CA-stored fruit for 8 months (results not shown).

We also tested the effect of delays of up to 21 days before application of 1-MCP. Jonagold fruit are used as an example of why the response to 1-MCP is affected by time. After harvest, the IEC of fruit initially declined but started to increase by day 7 (Fig. 3). Our expectation was that this increase would coincide with the declining effectiveness of 1-MCP, and this was illustrated by fruit firmness after 5 months of CA storage (Fig. 4). Fruit treated with 1-MCP either warm, or cold after 1 or 7 days were markedly firmer than fruit that were untreated. However, the effectiveness of 1-MCP declined markedly in fruit that were treated after 14 or 21 days.

These types of data form the basis of current commercial recommendations for maximum delays between harvest and 1-MCP application. It is important to recognize however that there are degrees of response to 1-MCP that are affected by both pre- and post-harvest handling interactions. The times between harvest and 1-MCP treatment to obtain optimum responses may be shorter than the industry recommendations, and a good rule of thumb is that the longer the storage period, the greater the importance of rapid 1-MCP application.

Physiological disorders

1. Carbon dioxide injury

An early concern about 1-MCP was that it appeared to increase fruit susceptibility to external carbon dioxide injury (Fig. 5). The varieties that we were most concerned about were McIntosh, Cortland and Empire. (We have not examined the effects of 1-MCP on internal carbon dioxide injury). Although the mechanism of carbon dioxide injury is not well known, it appears that 1-MCP, by keeping the fruit "younger"

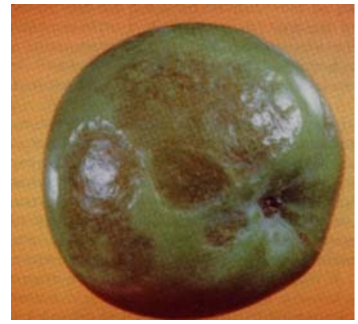


Fig. 5. Severe carbon dioxide injury. In some instances, injury is barely perceptible, especially on Empire apples.

maintains its susceptibility to injury by the gas. In previous research we determined that delays between harvest and exposure to high carbon dioxide levels, or application of diphenylamine (DPA) used for control of superficial scald, decreased or eliminated external carbon dioxide injury. Also, the critical time for exposure of fruit to carbon dioxide was in the first month or so of storage.

We have suggested that there are three possible solutions to avoid carbon dioxide injury (Watkins and Nock, 2003):

1. <u>Apply DPA to all varieties that are susceptible to carbon dioxide injury</u>. No external carbon dioxide injury has been observed in DPA-treated fruit. Therefore, DPA drenching, when it is used according to the label to prevent scald, remains the most straightforward solution to the problem of carbon dioxide injury. However, many storage operators are reluctant to use DPA because of the costs and logistics involved in treatment. Handling costs are much greater, especially for smaller operations that are not able to utilize truck drenching operations that are typically practiced in western New York. Also, some operators have found that decay of fruit in bins is higher when fruit are drenched. Finally, regions such as the Champlain, where the risk of scald is less than elsewhere in the state, do not use DPA for McIntosh and are understandably reluctant to

incorporate its use into their handling operations.

2. Maintain carbon dioxide levels lower than 0.5% for the first 4 to 6 weeks of CA storage. This method has been tested by several operators. Anecdotal evidence has shown that, although carbon dioxide injury may not be completely eliminated using this method, it is usually reduced to minimal levels. However, major losses have been suffered in some storage operations even with low carbon dioxide levels. The reasons why some storages were affected more than others are not known. In addition there are many unknowns related to loading and cooling time and effects of elevated carbon dioxide during this time in relation to injury.

   McIntosh appears less sensitive to carbon dioxide injury but we don't have a recommendation for carbon dioxide levels at this time. Lack of a recommendation for McIntosh only affects the Champlain region as DPA is used on McIntosh in all other New York-growing regions.

   The other consideration about maintaining low carbon dioxide levels in storage is that Empire and McIntosh require high carbon dioxide levels in the storage atmosphere to maintain fruit firmness. Fig. 6 shows that in non-1-MCP treated fruit carbon dioxide levels close to 2.5% are better for maintaining firmness. The firmness benefit of maintaining 2.5% carbon dioxide is reduced in 1-MCP-treated fruit, but Drs. DeEll and Murr in Ontario have found that the absence of carbon dioxide can result in losses of firmness. Therefore, we recommend allowing carbon dioxide levels to increase after the initial low period.

3. Delayed application of CA storage after treatment of fruit with 1-MCP. If fruit respond to 1-MCP, their metabolism is slowed down. Therefore, it should be possible to treat with 1-MCP, but not apply CA storage regimes for a week or two. No commercial testing of this recommendation has been carried out to our knowledge for control of carbon dioxide injury, although treatment of smaller fruit volumes on a daily basis and later closing of rooms is becoming more common. In the 2003 harvest season we tested delays of 7 and 14 days on fruit treated with 1-MCP at harvest. McIntosh from the Champlain (Rogers) and western New York (Marshall), and Empire from the Hudson Valley and western New York, were harvested from three orchard blocks in each region.

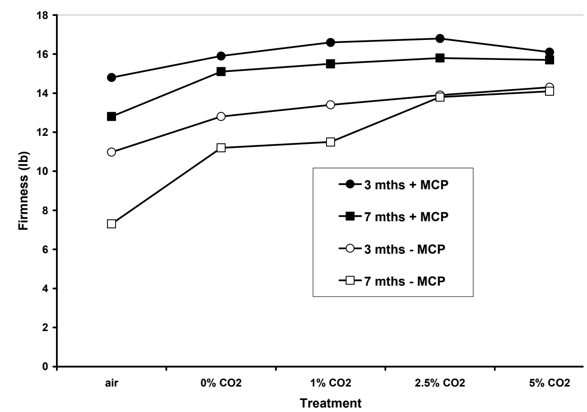


Fig 6. Firmness (lb) of Empire apples either untreated or 1-MCP treated at harvest and stored in air or in 0, 1, 2.5 or 5% carbon dioxide (in 2% oxygen) for 3 and 7 months. The 1-MCP-treated fruit (closed symbols) maintained firmness irrespective of carbon dioxide concentration, whereas the firmness of untreated fruit declined with carbon dioxide of less than 2.5%.

Both McIntosh and Empire fruit responded to 1-MCP in typical fashion (Tables 1 and 2); fruit were firmer than untreated fruit and the softening during the shelf life period at 68°F was reduced or prevented. Treating fruit at the time of harvest, but not applying CA for up to 14 days did not result in softer fruit.

However, the objective of this method was to reduce carbon dioxide injury. For McIntosh, injury was found only on Champlain fruit and for Empire only from western New York-grown fruit. Injury was detected only on 1-MCP-treated fruit from 2 of 3 growers, the maximum being 5% for one grower. A delay of 7 days did not reduce injury, but less than 1% was detected after a 14 day delay. However, in Empire, injury was increased by 1-MCP, but not affected by the 14 day delay.

Other disorders were found in these experiments. In Champlain Mc-Intosh, senescent breakdown in untreated fruit increased with delays before CA storage. Depending on the grower lot, 1-MCP decreased but did not prevent development of breakdown. In Marshall McIntosh, the incidence of breakdown was affected by grower but not by 1-MCP or delays.

For Empire, flesh browning was not affected by 1-MCP in fruit from either region. Core browning and decay in fruit from the Hudson Valley was low and not affected by 1-MCP. However, in the western New York fruit, core browning was usually reduced by 1-MCP. Decay incidence increased with delays between 1-MCP treatment and CA storage, but was affected by grower, and was usually reduced by 1-MCP.

The greatest concern about this technique is that if some fruit in the room are not responsive to 1-MCP, then their quality will be worse than if the room was sealed more rapidly after harvest. Therefore, we do not recommend this method to reduce carbon dioxide injury, especially as susceptibility to other disorders may be enhanced.

2. Superficial scald

Development of superficial scald has not been a problem for storage operators that have relied on 1-MCP instead of DPA. If applied appropriately, 1-MCP will control superficial scald for many varieties, especially Delicious, but under New York conditions control is often incomplete for Cortland. In general, if the effects of 1-MCP are beginning to wear off as indicated by fruit softening, then the risk of scald developing in susceptible varieties will increase dramatically.

3. Chilling injury and internal browning disorders

The 2003 storage season has been a difficult one for the industry, with the appearance of browning type disorders. These have fallen into two types – chilling injury and internal breakdown.

The most common disorder that was noticed by the industry this year is chilling injury symptoms as shown in figure 7. on Empire apples.

Figure 7. Chilling injury on Empire Apples.

Table 1. Firmness (lb) of McIntosh from Champlain and western New York orchards harvested on 24 and 22 September, 2003, (internal ethylene concentrations averaged 15 and 42 ppm) respectively. Fruit were treated with 1ppm 1-MCP after overnight cooling and placed under CA (2% carbon dioxide. 2% oxygen) conditions 2, 7 or 14 days after harvest. Firmness was measured after 6 months of storage plus 1 or 7 days at 68°F.

	Champlain				**Western New York**			
	No 1-MCP		**1-MCP**		**No 1-MCP**		**1-MCP**	
Delay	**1 d**	**7 d**	**1 d**	**7 d**	**1 d**	**7 d**	**1 d**	**7 d**
2 d	14.2	11.7	14.5	14.2	12.6	11.8	13.4	13.1
7 d	12.1	10.3	14.5	13.6	12.2	11.6	13.8	13.9
14 d	11.6	10.5	14.7	13.8	11.7	11.3	13.2	12.9

Table 2. Firmness (lb) of Empire from Hudson Valley and western New York orchards harvested on 6 and 7 October, 2003, (internal ethylene concentrations averaged less than 1 ppm) respectively. Fruit were treated with 1ppm 1-MCP after overnight cooling and placed under CA (2% carbon dioxide. 2% oxygen) conditions 2, 7 or 14 days after harvest. Firmness was measured after 6 months of storage plus 1 or 7 days at 68°F.

	Hudson Valley				**Western New York**			
	No 1-MCP		**1-MCP**		**No 1-MCP**		**1-MCP**	
Delay	**1 d**	**7 d**	**1 d**	**7 d**	**1 d**	**7 d**	**1 d**	**7 d**
2 d	15.3	14.4	15.5	15.5	16.6	16.4	17.1	16.9
7 d	14.6	13.7	15.7	15.7	16.2	15.0	17.3	17.0
14 d	15.1	13.8	15.9	15.5	16.1	14.9	17.1	17.1

This injury first appears as a very slight browning discoloration of the flesh, sometimes, but not always accompanied by core browning. To the untrained eye this discoloration can be barely visible and the fruit marketable as no off-flavors are detectable. However, the disorder progresses quickly to the point where fruit become unmarketable. Empire are know for their susceptibility to chilling injury, and that is the reason why storage temperature recommendations for this variety are 35-36^{o}F, especially if fruit are stored beyond May when the risk increases substantially. Risk is typically higher in years when July and August temperatures are below the 30 year average. In the 2003 harvest season, temperatures were not particularly low, but the weather was cloudier and fruit generally had lower soluble solids contents than normal. Thus the risk was higher than normal and many storage operators responded by increasing storage temperatures. It is uncertain if 1-MCP increases the risk of chilling injury development, especially as there are few examples of the same fruit not being treated with the chemical and being stored under identical conditions.

The second problem has been a breakdown of fruit and attendant softening that has been associated with use of 1-MCP. This has tended to show up in later harvested fruit, but we do not know what the exact causes are. In some cases, as described below, the browning is diffuse and again similar in appearance to chilling injury, but in others, the breakdown is much more extensive.

Our results from previous trials are confusing. In 2002 we harvested fruit from three orchard blocks in the Hudson Valley and western New York and stored untreated and 1-MCP treated fruit under CA conditions at 33 ^{o}F and 38 ^{o}F for 9 months. The disorder results (Table 3) show that:

1. Decay was greater in fruit stored at 38 ^{o}F than at 33 ^{o}F, regardless of region, and there was no effect of 1-MCP.
2. Senescent breakdown occurred only in untreated fruit from the Hudson Valley that were stored at 38 ^{o}F. As we have found elsewhere, senescent disorders were markedly reduced by 1-MCP application.
3. Flesh browning, which was diffuse, and easily confused with chilling injury, was more prevalent in fruit stored at 38 ^{o}F compared with 33 ^{o}F, and was much more so in fruit that were treated with 1-MCP.
4. Core browning was more common at higher storage temperatures but not affected greatly by 1-MCP application.
5. External carbon dioxide injury was not detected in fruit from the Hudson Valley, while in western New York it was worse at 38 ^{o}F than at 33 ^{o}F, but was not affected by 1-MCP application.

We are also re-examining disorder results from other trials. One for example, was described above where we treated Empire fruit with 1-MCP at harvest or after delays of up to 8 days. In the experiment where we stored fruit for 4 and 8 months under CA conditions there was 27% flesh browning in fruit from the first harvest, but 83% in fruit from the second harvest. The fruit from the second harvest also had high incidences of core browning and water-soaked areas. However, 1-MCP did not affect the amounts of any of these disorders relative to the untreated controls.

We have suggested previously that one way to avoid chilling-type disorders would be to use higher storage temperatures, especially as 1-MCP use should mean that ripening is controlled and therefore the requirement to minimum storage temperatures should be reduced. This recommendation is tempered by the observations that other problems may be much more severe at the higher temperature of 38 ^{o}F. Understanding how this problem can be solved is a priority for research. In the meantime, the industry should assume that there are limits to the usefulness of 1-MCP for extending CA storage periods for Empire. Anecdotal evidence is that most problems are associated with extended storage beyond May/June.

Conclusions

1. The vast majority of apple varieties respond well to 1-MCP, but most can also have poor responses, especially if ethylene production at harvest is high.
2. 1-MCP can maintain quality of fruit in air for several months, but its effectiveness is affected by variety. Best responses of fruit to 1-MCP occur in combination with CA, and we believe that 1-MCP is unlikely to be a substitute for long term CA storage. For some varieties, 1-MCP has the potential to greatly improve quality of air-stored fruit marketed during December and January, especially where it is not feasible to hold that fruit in short-term CA storage.
3. Even for responsive varieties 'degrees of response' to 1-MCP occur. Response to 1-MCP depends on harvest maturity, storage type, length of storage, handling protocols prior to 1-MCP application, and interactions among all of these factors. These interactions are most likely associated with ethylene production of the fruit at harvest and the effectiveness of postharvest handling treatments on slowing down ethylene production by the fruit.
4. Fruit must not be harvested too early to get better responses to 1-MCP however, as these fruit may never develop marketable quality characteristics.
5. Minimizing the time between harvest and 1-MCP treatment becomes increasingly important as the storage period desired increases.
6. 1-MCP can increase risk of carbon dioxide injuries, but strategies that can reduce this risk have been identified.
7. 1-MCP can reduce the risk of superficial scald developing, and for many, but not all varieties, can eliminate the requirement for DPA drenching.
8. 1-MCP may increase the risk of chilling injury development, but solutions to the problem have not been identified.

Publications

Watkins, C.B., Nock, J.F. 2000. MCP: Facts, speculation, and how could it affect the NY apple industry? New York Fruit Quarterly 8 (3): 5-9.

Watkins, C.B., Nock, J.F. 2003. 1-Methylcyclopropene (1-MCP) – New York update and recommendations. p18-55. In: Apple handling and Storage, Proceedings Storage Workshop 2003, Dept Hort. Publ. 22. [The proceedings are available for purchase for $15 (postage included) from Max Welcome, Department of Horticulture, Cornell University; phone 607 255 5439].

Table 3. Storage disorders of Empire apples harvested from the Hudson Valley (Oct.3, 2002) and western New York (Oct. 4, 2002), treated with 1ppm 1-MCP and stored at 33 or 38°F in CA (2% carbon dioxide/2% oxygen) for 9 months and assessed after 7 days at 68 °F. Means are the average of fruit from three orchard blocks.

Growing region	Temperature (°F)	1-MCP	Decay (%)	Senescent breakdown (%)	Flesh browning (%)	Core browning (%)	Ext. CO_2 injury (%)
Hudson Valley	33	-	10	0	6	4	0
		+	10	0	2	14	0
	38	-	38	30	0	26	0
		+	38	0	54	21	0
Western NY	33	-	5	0	12	12	1
		+	6	0	14	16	0
	38	-	20	0	21	29	6
		+	21	0	41	35	4

Current Empire Storage Recommendations

(summary table by Mike Fargione)

CA storage of fruit NOT TREATED with SmartFresh:

Oxygen 2-3%
- computerized monitoring – run closer to 2%
- manual monitoring – run closer to 2.5%

Carbon Dioxide
- without DPA – less than or equal to 2% for first 4-6 weeks, then 2-3%
- with DPA – 2-3%

Temperature 35-36°F
- 36 °F for long-term
- lower temperatures possible if not storing until May (less concern about chilling injury)

CA storage of fruit TREATED with SmartFresh:

If using DPA:

Oxygen 2-3%
- computerized monitoring – run closer to 2%
- manual monitoring – run closer to 2.5%

Carbon Dioxide – 2-3%

Temperature 35-36°F
- 36 °F for long-term

If not using DPA:

Oxygen 2-3%
- computerized monitoring – run closer to 2%
- manual monitoring – run closer to 2.5%

Carbon Dioxide – 0.5% for first 8 weeks,
- especially for rapid CA, then 2-3%

Temperature 35-36°F
- 35 °F for long-term

Carbon Dioxide Control using Hydrated Lime

James A. Bartsch, PE

Freshly hydrated, high calcium lime (Ca $(OH)_2$) may be utilized to remove carbon dioxide from CA storage rooms. Bags of hydrated lime placed inside the room will supplement existing scrubbing methods or a dedicated lime scrubber may be used for CO_2 regulation during the storage period.

The amount of lime needed will depend on the length of the storage period, the apple variety, storage temperature, atmosphere composition and use of nitrogen generators, etc. In the past, lime use was based on a half pound of lime per bushel of apples for a three-month storage period. This works out to be 10 fifty-pound bags per 1,000 bushels of fruit. The exact amount needed for a specific set of storage conditions will need to be determined from experience.

Either "chemical" or "agricultural" hydrated lime can be used. Each type is suitable if it is fresh, high in calcium, and of adequate fineness. Particle size is indicated on the bag; at least 95% should pass a 100-mesh sieve. Chemical grade is usually finer and more expensive than agricultural grade.

"High calcium" hydrate is more reactive than lime containing large amounts of magnesium. The calcium and magnesium content is stated on the bag in terms of percent calcium oxide (CaO) and magnesium oxide (MgO) contained in the original limestone. For efficient CO_2 removal, the assay should show “70% to 75% CaO" and "less than 2% MgO."

Only fresh hydrated lime is effective in removing carbon dioxide, and lime will gradually loose its freshness over time because it continuously absorbs CO_2 from the air. The 50-pound bags of hydrated lime will weigh approximately 68 pounds when they have absorbed the maximum quantity of carbon dioxide. If the new bags of hydrated lime weigh more than 55 pounds at the time of delivery, reject the shipment and order new lime. The bags may have plastic liners that must be punctured before the lime is effective for rapid CO_2 uptake. A board with several nails driven through it can be used to punch a number of holes in the side and ends of each bag as it sits on a shipping pallet.

If hydrated lime is used to supplement other scrubbing methods, it may be placed directly in the CA room under the evaporator, inside the door, or on a pallet on top of a stack of bins where it does not disrupt the atmosphere circulation in the room. Some heat will be given off as the lime absorbs carbon dioxide, so locate the lime in an area with good air movement away from the room thermometer and refrigeration thermostat sensors.

If lime is used as the only method to remove CO_2, it is usually placed in an airtight box or “scrubber” outside the CA room, adjacent to the wall where the evaporator is located (Figure 1). The lime box may be constructed of plywood or metal, fitted with an airtight door and insulated with urethane foam. Size the scrubber to hold 10 bags of lime per 1,000 bushels of fruit and allow approximately 3.5 cubic feet of internal volume for each 50 pounds of lime. Make sure the box is large enough to provide clearance space for atmosphere circulation around and across bags stacked on a shipping pallet. The lime box door should be large enough to permit loading and removal of pallets of lime with a forklift.

Replace the lime when the CO_2 level in the room can no longer be held to the desired level. Spent lime (calcium carbonate, $CaCO_3$) will be a solid lump, but still good for soil application if it is broken up and spread on fields.

Use a 4-6" diameter PVC pipe to connect the lime box to the CA room as shown in Figure 1. Connect a similar size pipe to the base of the lime box and extend it overhead and through the wall of the CA room in the vicinity of the evaporator fan intake. The low pressure developed by the evaporator fans are usually sufficient to draw the room atmosphere into the top of the lime box, downward through the stacks of lime where CO_2 is removed, and back into the storeroom. If circulation is not adequate or if smaller diameter scrubber lines are used, install a small externally controlled centrifugal blower inside the lime room to assist with circulation. Gate valves in the scrubber lines are necessary to regulate scrubbing action or isolate the lime box when lime is changed. If the lime room is located outdoors, it may be necessary to insulate the lines or place the vertical pipe inside the CA room to prevent condensation or ice buildup inside the pipe in winter. The lime box should be leak tested each time the CA room is leak tested.

References:

Bartsch, J. A. and G. D. Blanpied. 1990. Refrigeration and CA Storage for Horticultural Crops. NRAES-222. Northeast Regional Agricultural Engineering Service-Cornell Cooperative Extension, Ithaca NY. PP31-32.

Bishop, David. 1996. Controlled Atmosphere Storage A Practical Guide. ISBN O 9529187 0 6. David Bishop Consultants, E. Sussex, UK. Pg 28.

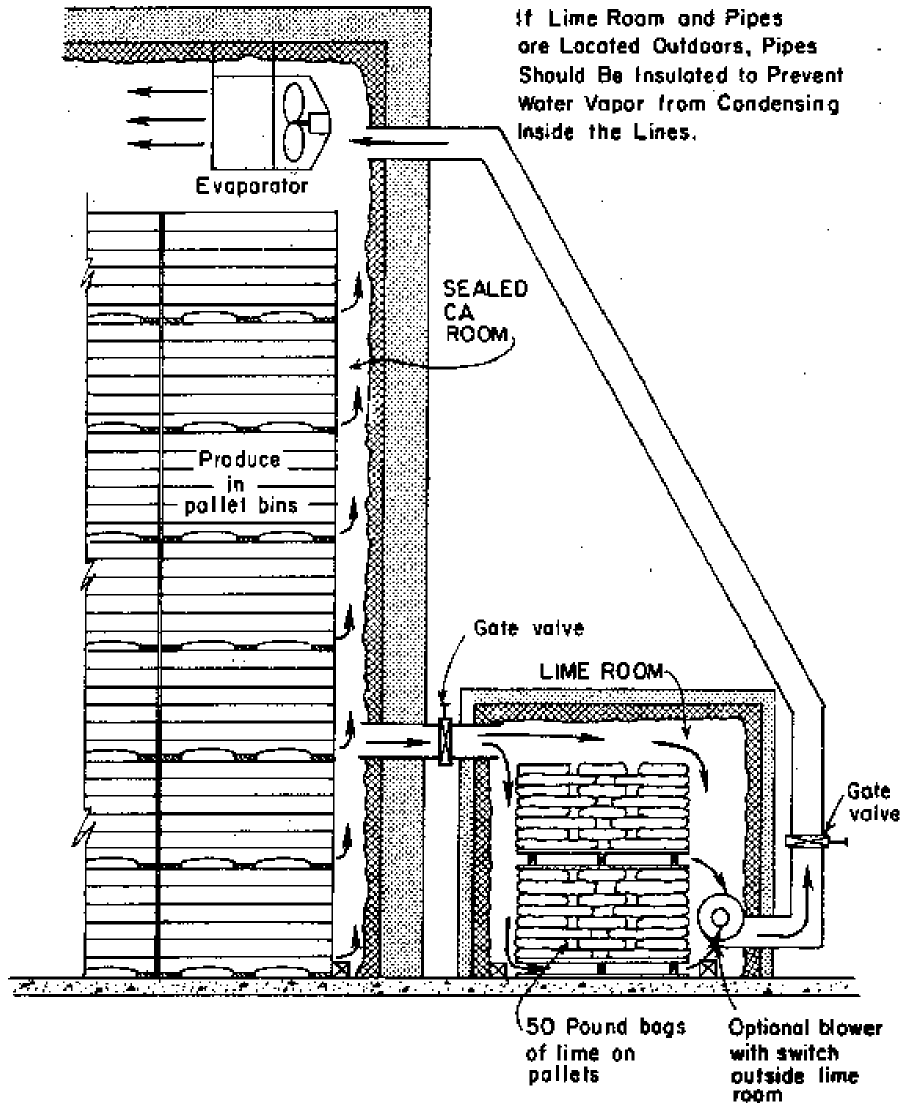


Figure 1. Lime Box Schematic.

CA Room Testing

James A. Bartsch

Background

The gas tightness of a CA room is determined by performing a test that monitors the rate of change of pressure over time in an empty, sealed room. The gas tightness value is expressed as the number of minutes it takes for the room pressure to decrease by 50%. If the pressure change occurs in an unacceptably short period of time, the room is not sufficiently gas tight to efficiently maintain the desired storage atmosphere. If the pressure change takes longer than a specified number of minutes, the room is considered to be "tight" and there should be no problems maintaining the desired storage atmosphere.

Over the years there has been considerable evolution in the materials and construction of CA rooms and also in the atmosphere generation and control equipment. When fruit respiration was relied upon totally for atmosphere establishment and maintenance, rooms had to be tight enough to permit establishment of an atmosphere in the "legal" time period and tight enough to hold the desired O_2 level throughout the storage period. A "tight" room was one where air needed to be added daily to prevent low O_2 injury to the fruit. In the early days of commercial CA, the combination of brine-spray evaporators, water scrubbing of CO_2, and galvanized sheet metal gas seals meant the rooms needed to be tested annually to locate rust damage and loose caulking which caused leaks in the sheet metal liners.

When sprayed in place urethane construction, on site generated nitrogen and automatic atmosphere controllers became commonplace, gas-tightness of CA rooms seemed less important than before. Nitrogen purging rapidly established the atmosphere, and N_2 assisted CO_2 scrubbers added no air to the rooms. If the O_2 level increased for any reason, N_2 was available to correct the atmosphere, and the correction was often made automatically by the atmosphere controller.

With all this technology and automation, why do we even care about the room tightness when everything seems to be operating exactly the way we programmed it to operate? The answer is cost and performance. Just because things may appear to be working as intended, the system may in fact be using far more N_2 then it should. Making N_2 requires electricity, and the N_2 is dry, so excessive purging means excessive moisture loss from the CA room and water loss from the fruit. The postharvest effectiveness of expensive materials like 1- MCP requires a tight room to ensure the concentration and time retention requirements of the material are being met.

CA Room Tightness Recommendations

The tightness recommendations are expressed as the time for 50% pressure loss to occur in the empty sealed CA room. This method is accurate and it works for both negative and positive pressures. It is possible to quickly determine the “tightness” of very leaky rooms with this technique because only three or four data points are necessary to establish the pressure-time line for the room.

The tightness value needed for successful CA storage depends on the CO_2 scrubbing method, the quantity of produce per unit volume of the room, and the O_2 level to be maintained in the room. A partially filled or loosely stacked room will need to be tighter than a densely filled room to achieve the same level of CA performance. The standards recommended below are based on tight stacking of pallet bins resulting in a loading factor of 20-21 pounds of fruit per each cubic foot of empty storage volume

The graph shown in Figure 1 indicates three standards of room tightness, the "12 minute", "20 minute" and the "30 minute" room. Each room looses half of its pressure in the indicated time of 12, 20 and 30 minutes respectively. This method of specifying CA room tightness is very convenient because when you plot the pressure-time data from the test on the graph you obtain a straight line. Using this 'best fit line' you can determine the number of minutes it takes for a 50% reduction in pressure, and this value can easily be compared to one of the three "standard" lines shown on the graph.

The "30 minute" standard was originally proposed for CA systems using activated carbon CO_2 scrubbers without an on site nitrogen supply for room purging. This tightness value meant that fruit respiration alone was adequate to maintain the oxygen concentration at 1.25%. Although the "30 minute" standard exceeds the current recommendations for CA room tightness, this level of gas tightness is routinely exceeded in modern state-of-the art CA construction where tightness values in excess of 120 minutes for a 50% drop in initial pressure are attained. "Thirty minute" rooms were recommended when water scrubbers were used and on-site N_2 was not available.

The “20 minute” standard is acceptable for all rooms operated at 3.0% O_2 regardless of the means of CO_2 removal used. Commercial experience indicates that a 20 minute room is also adequate for fruit storage at 1.25% O_2 if N_2 purging or hydrated lime is used to maintain the desired CO_2 levels. (The 20 minute" standard is also recommended in the UK for O_2 levels down to 2.5%--Bishop-2003)

The "12 minute" standard is proposed for current systems utilizing on site nitrogen and automatic control systems for atmosphere establishment and regulation. This recommendation is based in large part on the data and practices in the UK, and on the earlier work in New York by Bartsch and Blanpied, 1990.

Pressure Test Procedures

The urethane contractor should guarantee the tightness of new and re-sprayed CA rooms. The pressure test in new CA rooms should be performed before the fire barrier is applied to the urethane. The fire barrier makes it very difficult to locate leaks that were present and unnoticed during construction. The most accurate pressure tests are made when weather conditions, temperature, and barometric pressure are stable, and winds are calm. The room should be empty and at ambient temperature with all refrigeration turned off. Also turn off all lights and fans in the room, close all known openings in the room and seal all known leaks. Complete the following checklist before running a test.

Check List --Preparation for a CA Room Pressure Test

— CA door sealed?
— Access window sealed?
— Porthole closed?
— Scrubber lines capped or isolation valves closed?

- — Breather bag connections capped?
- — Pressure relief valves filled with water?
- — Defrost line water traps filled with water?
- — All penetrating members sealed in place?
- — Electrical conduits and boxes caulked inside with silicone?

Connect a sensitive manometer or pressure gauge to the gas sample line at the room to read the pressure difference between the inside and outside of the room. The manometer or gauge should be capable of resolving pressure differences as small as 0.1" of water column pressure. Make sure the gage or manometer reads "zero" before the room is pressurized.

Next, carefully and slowly pressurize the room with a shop vacuum, air fan, or scrubber blower to a desired pressure level and quickly close valve from the pressure source. **Use extreme caution in pressurizing the room: never exceed one inch of water column pressure** because structural damage may result. Record the both pressure and elapsed time values until the room pressure drops to 0.1". Plot the time-pressure data on the graph in Figure 1 and draw a straight line that fits best through the plotted points. Select a convenient pressure value on the line and determine the length of time it takes for the pressure to drop by 50%. Compare the tightness value for the tested room with the recommended standards already plotted on the graph.

Discussion

Seal any obvious leaks because it may not even be possible to obtain the initial level of pressure needed for a reliable test. Have two people enter the room with repair materials such as silicone or butyl caulking and urethane foam sealer to patch the leaks. A pair of portable two-way radios makes communication easier for the crews inside and outside the CA room. Use ladders, scaffolding, or an electric forklift to reach potential leaks high above the floor. Never use internal combustion equipment in a closed room. Never use N_2 enriched gas to leak test a CA room.

After the workers enter the room, pressurize it again so they can find and patch the large leaks. After all leaks have been found and patched, retest the room to certify final gas tightness. Final certification should be done twice, using both positive and negative pressure. When the final tests is are made, have all CA equipment—N_2 generators, scrubbers, breather bags, etc.—connected to the room to make sure that no leaks exist in the plumbing or valves leading to this equipment. Keep a copy of the room test data for future reference.

Locating Leaks

Leaks in new rooms are usually due to improperly sealed doors, gaps in the urethane foam insulation, poorly caulked electrical conduit boxes, or unsealed penetrations. Check all the items on the checklist again, seal them as necessary, and retest the room.

Random leaks can usually be found by listening in the room for the sound of infiltrating air. Leak detection generally is easiest when the room is placed under 0.75" of negative pressure (vacuum), which will cause air to be drawn in through the leaks. Very small leaks that produce no noise can sometimes be found with water and detergent, applied with a paintbrush to an area of suspected leakage. Any visible cracks in the concrete floor should be checked the same way. The room must be under a vacuum so that bubbles form on the leaking surface.

The surface appearance of the urethane foam sometimes indicates where small leaks are likely to be located. Check areas with uneven application, rough surface texture, and joints between structural members and flat surfaces first. "Smoke" from ventilation smoke tubes may help in locating several small leaks or single large leaks that produce no noise. Persons inside the room watch for disruptions in stagnant puffs or streams of smoke, which indicate that air is being drawn into the room. If the room is tested under positive pressure with smoke, then smoke can be seen exiting the leaks. As with other techniques, use smoke in areas of high probability of failure such as around doors, at penetrations, and at the floor-wall junction.

Ventilation smoke “candles” can be used in empty CA rooms pressurized to 0.75” of water gauge. These candles completely fill the volume with nontoxic smoke in 3 to 5 minutes. This smoke can then be seen emerging from the leaks. The exact location of the leak may still be difficult to find because the smoke may emerge from an opening some distance from the surface leak inside the room. When smoke candles are used, use enough to produce a volume of smoke 15 to 20 times greater than the empty storeroom volume and keep everyone out of the room. Be extremely careful when using true smoke generators because of the combustible nature of many of the materials frequently found around the CA storage site.

If the floor or the floor-wall joint has a suspected leak, but it cannot be located, cover the floor with an inch of water and retest the room. An improvement in the pressure test will indicate that leaks were stopped by the water. If water cannot be seen flowing out of the leak, sprinkle sawdust on the surface of the water. When the water has drained out through the leak, the pattern of sawdust left behind on the floor may indicate the direction of flow and area of the hole(s). If the room leaks only when it is loaded with produce, unload a center aisle, then flood the floor and sprinkle the sawdust in the aisle and let the water drain before unloading the rest of the room. When the water has drained out, observe the flow patterns left by the sawdust. It may be necessary to replace the floor in this situation.

The flooding technique may not be practical in large rooms because of the large quantity of water needed to cover the floor to the depth of one inch. There is also some danger of softening or eroding the sub grade if a large quantity of water leaks through the floor. It is also possible to flood interior areas of the storage if the caulking under the CA door fails during this test. Over 60 gallons of water are used to cover each ten by ten foot area of floor to a depth of one inch.

References

Bartsch, J. A. and G. D. Blanpied, 1990 Refrigeration and controlled atmosphere storage for horticultural crops. NRAES publication 22. 45 pages.

Bishop, David, 2003 Personal communication.

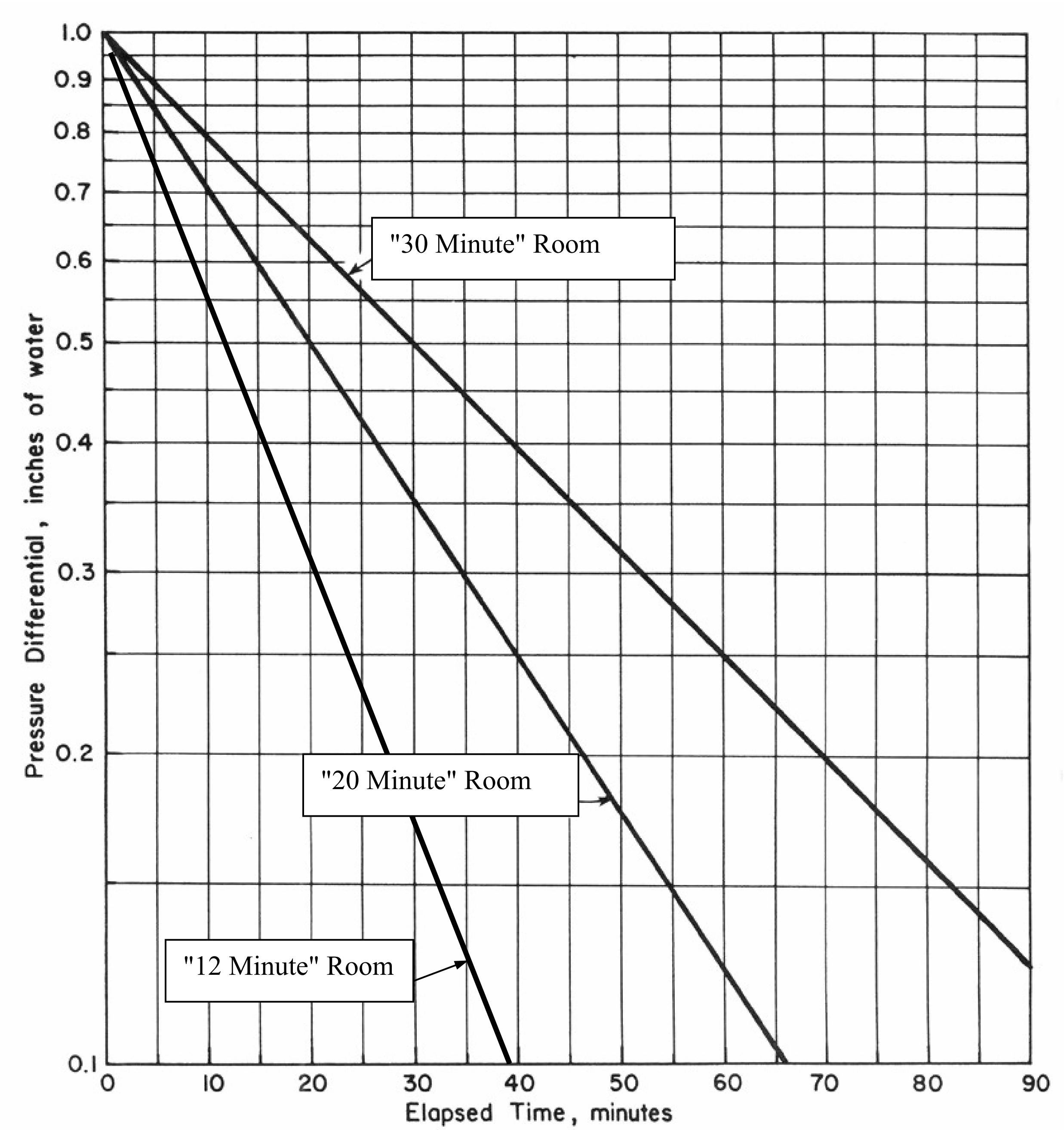
Sources of Room Test Equipment

Ventilation Smoke Tube Kit:
Part Number 458481 Aspirator bulb with 6 one time use plastic smoke tubes
Part Number 458480 Smoke tubes-12 one time use plastic smoke tubes

Mine Safety Appliances Company
P.O. Box 428 - Pittsburgh, PA 15230-0428

Contact Name: Evan K. Erickson
Telephone Number: (724)733-9274
Fax Number: (724)733-8573
E-mail Address:
evan.erickson@MSANet.com
Web Site URL: http://www.msanet.com

Manometers and sensitive pressure gauges:
Mark II-25 air gage (approximately $30.00)
Dwyer Instruments Inc.
Michigan City IN 800-872-9141
Regional sales: 219-879-8000
Web Site URL: http://www.dwyer-inst.com



Room Number:__________________ Date of Test:____________________

Notes & Comments:____

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Figure 1. Pressure-Time graph for CA Room Tightness Tests. Tightness standards of 12, 20 and 30 minutes are shown. The tightness standards indicate the number of minutes for the pressure in the sealed room to decrease by 50%.

New Fungicides for Postharvest Use

David A. Rosenberger

Two new fungicides have recently received EPA labels that allow postharvest applications to apples. Neither of these fungicides are currently labeled in New York State, but state registrations are expected in the near future.

Penbotec contains the active ingredient pyrimethanil. Scholar contains the active ingredient fludioxonil. Both products can be used in postharvest drenches, in line sprays on packing lines, or in combinations with fruit waxes. In postharvest apple trials that I have conducted during the past three years, both products were very effective for controlling blue mold caused by *Penicillium expansum* and also gray mold caused by *Botrytis cinerea*. Both products will control strains of *P. expansum* and *B. cinerea* that are resistant to thiabendazole (Mertect 340F). Both products can be combined with diphenylamine (DPA).

The really good news about these new fungicides is that both of them represent entirely new chemistries for postharvest application. Postharvest pathogens will eventually develop resistance to these products, just as they developed resistance to thiabendazole. However, by having two different chemistries registered at the same time, we now have options for alternating fungicide treatments so as to slow selection for fungicide-resistant pathogens. By combining good fungicide-resistance management with good packinghouse sanitation, we may be able to delay fungicide resistance problems for many years.

If fruit require DPA treatment after harvest, then including one of these new fungicides in the postharvest drench solution in fall of 2005 will prevent infection of wounds in the treated fruit. Using one of these fungicides in a postharvest drench should virtually eliminate problems with postharvest decays during storage. However, these products will be expensive in the quantities needed for high-volume drenching. Therefore, these fungicides may prove cost-effective in postharvest drenches only for decay-susceptible varieties (such as Empire) that will be held for more than 6 months in CA storage.

Applying Penbotec or Scholar in line sprays or mixed with wax that is applied to apples could help to reduce the incidence of decay that develops in packed fruit. Retail store surveys have shown that fruit sold in polyethylene bags sometimes develop an unacceptable incidence of decays after packing. Incorporating line sprays of Penbotec or Scholar should help to eliminate this problem.

These new fungicides have not yet been approved in some apple-importing countries. Before applying these fungicides to apples destined for export, packing house operators should verify that the importing country has an approved MRL (maximum residue level) for the fungicide in question. A database of approved MRLs for various commodities and countries can be found at the following web-site: http://mrldatabase.com .

Maintaining Biocide Levels in Water Flumes in Packing Houses

David A. Rosenberger and Anne L. Rugh

Any time that fruit is handled in recirculating water, the water should be treated to prevent microbial contaminants from building up in the water and contaminating fruit. Most food safety guidelines require that a biocide be included in water flumes. Sodium hypochlorite is probably the most common and cost-effective biocide for treating water dumps and water flumes in apple packing houses, but alternatives include calcium hypochlorite, ozone, chlorine dioxide, and peroxides (e.g., dihydrogen dioxide, the active ingredient in StorOx). This article will focus on how hypochlorite works and how hypochlorite concentrations in water flumes can be monitored.

Why bother sanitizing flume water? Packing house operators should recognize that apples are often eaten without removing the peel and apples should therefore be handled as a ready-to-eat snack food. If flume water in apple packing lines is not clean enough to rinse salad greens before you put them on your plate, then perhaps improved sanitation of water flumes is needed. In packing houses that handle large volumes of fruit, just chlorinating water by itself may not be enough to ensure that water flumes remain clean. Filtration systems may be needed to remove debris and particulate matter from the water flumes because chlorine (or any of the other biocides, for that matter) will be ineffective in water that contains an abundance of organic debris.

Apples are not very likely to carry food-borne human pathogens. However, even a single low-probability event involving human pathogens on fresh apples could have a huge negative impact on the apple industry. Therefore, maintaining effective biocide levels in packing house water flumes provides common-sense "insurance" against a potentially catastrophic event that could affect the entire industry.

University and government food safety publications have recommended the use of biocides in water flumes for many years, and treatment of flume water is now considered standard operating practice for meeting food safety guidelines. If fresh apples were ever to be implicated as a potential source for an outbreak of food-borne illnesses, records showing that water flumes contained a biocide might be essential as evidence that the packing house involved was using good sanitation practices in handling fruit.

How does chlorination kill microbes in flume water? Chlorination of water flumes is usually accomplished by adding sodium hypochlorite (NaOCl) to the flume water. Sodium hypochlorite is the active ingredient in household bleach. Household bleach contains 5.25-6.25% sodium hypochlorite. Other formulations containing 12.5% active ingredient are available for treating swimming pool water or for sanitizing water flumes in packing houses and other food handling facilities.

In aqueous solutions, sodium hypochlorite breaks down into a mixture of hypochlorous acid (HOCl) and hypochlorite (OCl_2). Hypochlorous acid is a strong oxidizer and kills microbes by "stealing" electrons from the microbial surfaces in a process that essentially "burns up" the organism. Unfortunately, oxidizers that can kill microbes will also "steal" electrons from exposed iron in the process known as "rusting". Microbes are killed rather quickly (in a matter of seconds) whereas rusting is a slower process. Nevertheless, because oxidizers are now considered essential for sanitation of water flumes, new water flumes in packing houses should be constructed from stainless steel. Similarly, wooden bins should gradually be replaced with plastic bins both to reduce problems with rusting and loosening of nails and because the nonporous surfaces of plastic bins can be sanitized more easily than porous surfaces of wooden bins.

The biocidal effectiveness of chlorinated water is highly dependent on pH. As noted earlier, hypochlorous acid (NaOCl) is a strong oxidizer, but hypochlorite (OCl_2) is only a weak oxidizer. If the solution pH rises above 7.5, much of the free chlorine in the solution will be tied up in the hypochlorite form and oxidizing potential of the solution will be reduced. If the pH drops below 6.5, the solution becomes more corrosive and some of the free chlorine will form chlorine gas (Cl_2). Chlorine gas causes the typical "swimming pool" smell and is irritating to workers. If chlorinated water flumes produce a detectable chlorine odor within the packing house, then the pH of the solution probably needs adjusting.

The recommended concentration of free chlorine for water flumes in apple packing houses is 100 ppm with pH maintained between 6.5 and 7.5. A 100 ppm concentration of free chlorine can be achieved by mixing 3 quarts of a 12.5% sodium hypochlorite solution into 1,000 gallons of clean water. However, the oxidizing capacity of this solution can disappear rapidly as organic matter is introduced into the water flume. When hypochlorous acid reacts with organic matter, the hypochlorous acid is "used up" in the reactive process. As a result, sodium hypochlorite must be added to water flumes at regular intervals so as to maintain an effective level of biocide in the water flume.

Actually, a concentration of only 25-40 ppm free chlorine would be adequate for sanitizing water in packing houses if those levels could be consistently maintained. However, it is almost impossible to maintain such low concentrations because the organic debris introduced into the water flume with the fruit would quickly deplete the free chlorine in a solution containing less than 75 – 100 ppm of free chlorine. By periodically adjusting free chlorine concentrations to 100 ppm, there is less chance that the oxidizing potential of the solution will drop below effective levels before the solution can be recharged.

<u>Measuring oxidation potential in water flumes</u>: One method for estimating oxidation potential (= sanitizer effectiveness) and determining when flume water must be recharged involves measuring free chlorine in the water flume. As noted above, most of the free chlorine will be present in the form of highly reactive hypochlorous acid if the solution pH is between 6.5 and 7.5. Colorimetric test kits are available for testing chlorine levels in swimming pools, but these generally are effective only for chlorine concentrations between 0 and 4 ppm. Since water flumes used for apples should have 100 ppm free chlorine, water collected from a water flume must be diluted 1:24 (i.e., one fluid ounce of water from the flume with 24 fl oz of non-chlorinated well-water or distilled water) before the colorimetric tests can be used. Test kits that measure total chorine (as opposed free chlorine) are not useful for testing water in flumes because measures of total chlorine will include chlorine that has already reacted with organic matter, thereby making it unavailable for further oxidation reactions.

A more effective approach for measuring oxidation potential is to use an ORP meter. "ORP" stands for oxidation-reduction potential. ORP meters actually measure the oxidizing potential (in millivolts: mv) on a scale from 0 to 2000. The relationship between ppm of free chlorine and oxidizing potential as measured with an ORP meter is not linear. However, a minimum reading of 650 mv is usually considered essential for water sanitation, and a solution containing 100 ppm free chlorine will produce an ORP of 750-850 mv if the pH is between 6.5 and 7.5. ORP's are affected by pH because, as noted above, the oxidizing potential of chlorinated water goes down as pH increases above 7.5 We have also found that ORP's can vary with water quality. Adding sodium hypochlorite at the rate required to produce 100 ppm free chlorine to pH-adjusted distilled water results in an ORP of approximately 1,000 mv whereas the same amount of sodium hypochlorite added to hard water may result in an ORP of only 750 mv. Presumably the minerals in hard water can react with some of the chlorine and make it unavailable, thereby reducing the ORP as soon as the sodium hypochlorite is added to the water. Water temperature does not affect the ORP readings.

Many different brands of ORP meters are available. We are not recommending the one that we purchased to the exclusion of others, but we are providing information on our unit as an indication of product pricing and capabilities. We were looking for an ORP meter that would be portable and rugged with a probe on a flexible wire that would allow the probe to be placed into dump tank water without danger of wetting the body of the instrument. We purchased a digital ORP meter (the IQ150), an ORP probe, and a carrying case from IQ Scientific Instruments for about $500. (Company address: 2075-E Corte del Nogal, Carlsbad, CA 92009; website at http://www.phmeters.com/) This same unit can also be fitted with a probe to measure pH, but the ORP and pH probes cannot be connected to the meter at the same time. An excellent pH probe for this meter is the stainless steel pH probe with the ISFET silicon chip pH sensor (a dry pH probe), but the price for that pH probe alone is $269. Because cheaper wet-bulb pH probes are often difficult to maintain and calibrate, it may be more cost-effective to use pH paper rather than the ORP meter for measuring pH of flume water.

We have found that the ORP probe may need to be submersed in flume water for up to five minutes before the read-out stabilizes, especially if water in the flume is swirling past the probe. Therefore, it may be more convenient to put some flume water into a small jar for testing so that the test can be conducted on a work bench away from the water flume. In practice, one would need to test both the pH and the ORP of flume water at the same time. If the pH is out of the 6.5-7.5 range, then the pH of the entire water flume should be adjusted with a buffer before the ORP sample is collected. Whenever the ORP drops below 650-750 mv, the flume should be recharged with additional sodium hypochlorite. After several days of testing at hourly intervals, a pattern should emerge that will allow routine recharging with less frequent ORP testing. Nevertheless, the ORP of the water flumes should be measured and recorded at least once per day.

For prices starting around $3500, one can purchase an ORP meter that is coupled to an automated feed system for maintaining preset ORP levels in water flumes. The automated system reads the ORP at regular intervals and then automatically turns on a pump to inject chlorine solution and pH buffer into the water flume until the ORP reading reaches the desired level. Some of the systems also include a recording chart that can be used to maintain a continuous record of the fluctuations in the ORP of flume water. This system obviously provides the best method for maintaining and documenting chlorine levels in water flumes if one can afford the initial investment. These automated systems are commonly used in citrus packing houses in California where maintaining effective chlorine levels is essential for avoiding catastrophic losses to postharvest decays.

Summary: Chlorination is an effective way of eliminating microbial contaminants and postharvest pathogens from flume water on apple packing lines. However, regular monitoring of both solution pH and either free chlorine or ORP is necessary because organic debris introduced into the flume water with apples can quickly destroy the oxidizing potential of chlorinated water. Regular monitoring, recharging, and record keeping are recommended to ensure that microbial contaminants in flume waters will be eliminated as soon as they are introduced.

Useful web-links:

Lowry, R.W. and Dickman, D. 2005. The ABC's of ORP: Clearing up some of the mystery of oxidation-reduction potential. http://www.rhtubs.com/ORP.htm

Ritenour, M.A., Sargent, S.A., and Bartz, J.A. 2002. Chlorine use in produce packing lines. Publication HS-761, Hort. Sci. Dept., Florida Coop. Ext. Serv., Inst. Food and Agric. Sciences, Univ. Florida. http://edis.ifas.ufl.edu/pdffiles/CH/CH16000.pdf

Suslow, T.V. 2004. Using oxidation reduction potential (ORP). Univ. Calif. Good Agric. Practices web-site. http://groups.ucanr.org/UC_GAPs/Using_Oxidation_Reduction_Potential_(ORP)/