eggs, fruits and vegetables. This gas inhibits the growth of many kinds of bacteria and fungi, the degree of inhibition varying with different organisms, the concentration of the gas and the temperature. The gas also retards the respiration of fruits and vegetables and other chemical changes in stored food materials.

Poultry. Atmospheres containing carbon dioxide improve the storage life of cut-up poultry when stored at refrigerated temperatures above freezing. The effectiveness of the gas increases as the concentration is increased to a maximum of 25 percent. Higher concentrations cause discoloration of the meat. Even 15 to 25 percent causes some loss of bloom if the meat is stored unusually long. The gas is more effective at the lower temperatures.[12,13,14]

Frankfurters. Storage in an atmosphere of 5 to 50 percent carbon dioxide lengthens the storage life of frankfurters. The effectiveness increases with increase in carbon dioxide concentration up to 50 percent and reduction in temperature. The gas has no bad effects on flavor or color. The treatment apparently has a selective action, inhibiting the growth of molds, micrococci and yeasts, but has little or no effect on the lactic acid bacteria. The beneficial effect is due to restriction of the types of microorganisms that cause rapid deterioration and not to reduction of the total microbial population. Packaging frankfurters in wrapping materials that are impermeable to carbon dioxide, such as aluminum foil, MSAT-80 Cellophane, and aluminum foil-pliofilm laminate increases the storage life due to the high concentration of carbon dioxide in the packages. Inclusion of carbon dioxide in the package is beneficial.[13–16]

Beef. The use of atmospheres containing increased quantities of carbon dioxide has made it possible for Australia and New Zealand to ship chilled meat to England in competition with South America. The storage life of meat refrigerated at 28.5 to 29.5 F is ordinarily about 40 days, but in an atmosphere containing 10 to 20 percent of carbon dioxide it remains in saleable condition for 60 to 70 days which is sufficient time for it to reach England in good condition.[17] The gas increases the storage life of meat by inhibiting the development of the microorganisms that cause rapid deterioration.

Spoilage of chilled beef is caused mostly by species of bacteria in the genus *Achromobacter*. These bacteria constitute about 90 to 96 percent of the bacterial flora of beef at 30.2 F and cause development of slime on its moist surfaces.[18,19] Molds cause some spoilage but to a lesser extent than bacteria.[20] Most of the bacteria and molds that are injurious to meat are inhibited satisfactorily at 32 F by a concentration of 20 percent carbon dioxide and are partially retarded by lower concentrations.[20,21,22] Higher concentrations of carbon dioxide cause loss of color and flavor. The lean areas turn brown and the fatty ones pallid because of the change of oxyhaemoglobin, the red pigment of the tissues and blood, to brown methaemoglobin.[23] Higher concentrations also may accelerate the development of species of *Staphylococcus*, bacteria that cause food poisoning.[24] Sanitary precautions in the handling and preparation of meat are essential since the length of successful storage even in a carbon dioxide atmosphere depends to a large degree on the initial bacterial load.[17,19,20]

Pork. Storing pork and bacon in carbon dioxide atmospheres has been reported to prevent rancidity.[25] Fresh pork keeps in perfect condition for over two months in carbon dioxide at 32 F, whereas it spoils in about 17 days in air. Both cured and smoked bacon[26] keep well for eight months in CO_2 at 26 F and for twelve months in carbon dioxide at 14 F.[27]

Fish. Bacteria of the genus *Achromobacter* associated with fresh fish are almost completely inhibited by 20 percent carbon dioxide at 32 F.[28] Carbon dioxide has marked preservative properties for haddock and improves its quality.[29] Whole haddock stored in 25 percent carbon dioxide from the time caught keeps approximately twice as long as when stored in air.

Eggs. About 0.5 to 0.6 percent carbon dioxide in the storage air aids in maintaining the carbon dioxide content of eggs which is an important factor in preserving the quality of the egg white. It also retards development of molds, off odors, and off flavors. A more practical method of preventing loss of carbon dioxide from the eggs is to dip them in light mineral oil. The oil treatment also retards loss of water and development of a large air cell.[30–33]

Apples. Carbon dioxide gas storage with reduced oxygen is used to lengthen the storage life of apples that must be stored at moderate temperatures (36 to 40 F) to prevent low temperature injuries such as brown core, soggy breakdown and soft scald. This method is used extensively in England[34] and it is used in the United States to store northern-grown McIntosh apples.[35] The rooms for gas storage must be gas tight and there must be provision to circulate the air through a washer or scrubber filled with sodium hydroxide solution or other absorbent to remove excess carbon dioxide.[36] The modified atmosphere may be obtained by filling the room with fruit, sealing it and allowing the respiration of the fruit to reduce the oxygen and increase the carbon dioxide until the desired proportions are reached. These proportions are maintained by operation of the scrubber and by ventilation.

The desirable amounts of carbon dioxide and of oxygen in the atmosphere vary with different varieties of apples and even with the same variety grown in different localities. In England, 10.5 percent of carbon dioxide and 10.5 percent of oxygen were found to be very satisfactory concentrations for the Bramley Seedling variety, but in New York, 5 percent carbon dioxide and 2.5 to 3 percent oxygen seemed to be best for most of the varieties tested.

Disadvantages of gas storage are the difficulty of making the storage room gas tight, the danger of suffocation to persons entering the room, and the impossibility of entering the room to examine the fruit without losing the desired atmosphere.

Pears. Carbon dioxide gas storage with reduced oxygen delays softening and coloring of pears, inhibits decay and reduces astringency. It is especially useful for extending the normal storage life of Bartlett pears. In experiments in California the normal storage life at 31 F was doubled when an atmosphere containing 5 percent of carbon dioxide and 2.5 percent of oxygen was used. For short storage periods, a temperature of 36 F with carbon dioxide was as good as 31 F in ordinary storage and 45 F with carbon dioxide was as good as 36 F in ordinary storage. An innovation has been the use of sealed plastic film liners for boxes of pears in storage. The concentration of carbon dioxide in these packages builds up to about 5 percent while stored at 31 F. Pears in these films have a fresher appearance, less shriveling, and a 6 to 8 weeks longer storage life than fruit packed without liners. Since permeability of the films to carbon dioxide is not uniform, the liners should be perforated with one or two small holes ($^3/_{16}$ to ¼ in.). If completely sealed there is danger of too much carbon dioxide accumulating in the package which will cause brown core in the fruit.[37,38,39]

Stone fruits. Long time storage of stone fruits in modified atmospheres has not been successful,[40,41] but short time treatment of sweet cherries with carbon dioxide is beneficial and is used commercially in the shipment of that fruit from the West Coast. Dry ice is used as the source of carbon dioxide, enough being placed in the refrigerator car to provide an initial atmosphere with 15 to 30 percent of the gas. The high

CO_2 content lasts only a few days because the cars are not airtight. This gas treatment retards decay and the cherries remain firmer, brighter and fresher in appearance than those held in untreated atmospheres.[42]

In the Pacific Northwest sealed polyethylene liners have been used in the standard 15 lb cherry lug to produce a modified atmosphere within the package while under refrigeration in storage or transit. This reduces stem desiccation, shriveling and decay; it also preserves the bright red color and extends the marketing period. The film liner must be perforated when the lug is removed from refrigeration.[43]

Small fruits. Carbon dioxide storage has been shown to add three or four days to the storage life of strawberries, red raspberries and other small fruits by inhibiting *Botrytis* and *Rhizopus* rots and softening when these fruits are stored in an atmosphere containing 23 percent or more of the gas for short periods at temperatures ranging from 32 to 77 F. Flavor remained normal in tests where the carbon dioxide content of the air was not more than 25 percent for longer than 12 hr and fell to 10 percent within 24 hr. The flavor was likely to be affected by more severe treatments. The gas treatment is useful in inhibiting decay during the first 24 to 36 hr in transit before the fruit has had time to cool.[40,41]

Vegetables. Carbon dioxide is not used commercially in the storage of vegetables although it retards some decays and inhibits respiration processes.[39,40]

Air Purification

Activated coconut shell carbon air filters are used in some commercial apple storages to remove undesirable odors and the volatile fruit emanations that cause scald and promote rapid ripening. There is general agreement that these filters are effective in removing odors but research workers differ as to how effective they are in retarding ripening and the development of scald. Some reports indicate that air purification adds 1 or 2 months to the storage life of the fruit and controls scald about as well as oiled paper wraps.[44,45,46] Still other sources indicate that there is little or no effect on the storage life and that scald is controlled better and more economically by oiled paper wraps.[47–50]

Ozone

Ozone as a supplement to refrigeration is used in some storages to prevent mold on eggs. Mold is a serious problem in the storage of eggs because of the high humidities that are necessary to prevent loss of moisture and enlargement of the air cell. A continuous concentration of 1.5 ppm in the aisles assures 0.6 ppm of ozone in the center of the pile which is adequate to prevent mold growth in egg rooms at 31 F and 90 percent rh if the eggs, cases and liners are clean when stored. Concentrations as high as 3.5 ppm for several[51] months do not cause injury[51] but 10 ppm for 5 months causes off flavors.[52]

Ozone is used to some extent in meat rooms to prevent mold on the dressed meat. A concentration of 2.5 to 3 ppm for 2 hours twice each day is said to be effective for initially clean meat stored at 34 to 37 F and 90 percent rh.[51] Higher concentrations oxidize the fats and cause rancidity and bad flavor.[52]

Ozone has been recommended for use in the storage of apples and small fruits.[53,54] When it was used, growth of surface molds, the mold spore count in the air, germination of spores and infection of the fruit were reduced and offensive odors were destroyed. A concentration of 1 to 2 ppm for a few hours a day was effective and not injurious to the fruit.[54] Decay of apples that were already infected was not reduced by ozone. Concentrations of 3.25 ppm seemed to increase decay, caused pitting, and also caused a musty flavor to develop in apples of some varieties.[55]

ULTRAVIOLET LIGHT

Ultraviolet lamps are used in some refrigerated storages for the control of bacteria and molds. It is said that they are particularly beneficial in preventing development of bacterial slime and molds on meat that is being ripened by the high temperature rapid tenderization process in which the meat is kept at 68 F and a high relative humidity for one or two days.

Although there is no doubt about the lethal effect of ultraviolet light on bacteria and fungi that are exposed to the direct rays, there is some question about the effectiveness of the lamps under storage conditions. The ultraviolet rays have poor penetrating power and, therefore, only the bacteria and fungi on the surface of colonies are killed. Also there is very little if any bactericidal effect of reflected light on microorganisms on the dark sides of meat or other food products, or on surfaces shaded by shelves or other obstructions. The beneficial effect of ultraviolet lights on the side not exposed to direct rays is probably due to the ozone that is synthesized by some lamps. Ultraviolet light has not been found effective in reducing decay of fruits and vegetables.[57,58,59]

In addition to not giving complete control of fungi and bacteria, ultraviolet light has been reported to cause discoloration, rancidity and development of a tallowy odor of the fat if too close to beef, pork and lamb; darkening of cheese and lettuce and rancidity of butter, cream, and lard.[60] These defects appear to result from the combined effect of the ultraviolet rays and the ozone produced by the lamps.

FUMIGATION

Sulfur Dioxide

Fumigation of grapes with sulfur dioxide to reduce decay, retard respiration, and preserve the color of the stem and capstems has been a standard practice in California for many years. The grapes are fumigated for 20 min with a 1 percent concentration of sulfur dioxide as soon as possible after they are packed. This may be done in the regular storage room, in a special fumigation room or in the refrigerator car. Further treatments of grapes in storage are made at about 10 day intervals with ½ percent concentrations of the gas.

Liquefied sulfur dioxide in cylinders is easily procured. For fumigation the cylinder is attached to a copper tube leading into the room or car, placed in a container of hot water and then the valve is opened. The heat from the hot water causes the sulfur dioxide to vaporize rapidly and the gas is discharged under high pressure through nozzles in the room or car. Fans should be used in the fumigation chamber to circulate the gas quickly and thoroughly. In storage houses used only for grapes, the gas is sometimes discharged into the air ducts. If the storage uses a brine spray system, a bypass should be installed around the spray chamber so that the gas will not be absorbed by the spray and corrode the metal surfaces. After fumigating for the required time, the room should be cleared of the gas by ventilation.

The amount of sulfur dioxide needed may be calculated by the formula:

$$W = \frac{Q \times S}{5.5}$$

where

W = SO_2 required, pounds.
Q = free space in storage, cubic feet.
S = SO_2 required, percent.

The cubic feet of free space is determined by calculating the