APPARATUS AND METHODS FOR CONTROLLING ATMOSPHERIC GAS COMPOSITION WITHIN A CONTAINER

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ABSTRACT

A method of controlling gas composition within a container containing resiping produce is described. The container includes at least one gas outlet and at least one gas inlet and the method includes the steps of: drawing gas from within the container through a selective membrane element under selected control conditions through the at least one gas outlet; introducing ambient air from outside the container into the container through the at least one gas inlet under selected control conditions to control the relative composition of gases inside the container. Apparatus for containing the goods and for controlling the atmosphere in the container according to the method are also described.
1.5 barg FEED/0 barg SWEEP CO₂ scrubbing test KNF pump

duty cycle 15min/15min - Gas levels inside bin

Figure 6
1.5 barg FEED/0.5 barg SWEEP CO₂ scrubbing test KNF pump
duty cycle 15min/15min - Gas levels inside bin

Figure 8
Figure 9

1.5 barg FEED/0.5 barg SWEEP CO₂ scrubbing test KNF pump
duty cycle 15 min/15 min - Gas levels inside bin
1.5 barg FEED/0.5 barg SWEEP CO₂ scrubbing test KNF pump duty cycle 30min/30min - Gas levels inside bin

Figure 10
Cycles 1 bar FEED/0 bar SWEEP 15/300 min - Gas level and pressure inside bin.
APPARATUS AND METHODS FOR CONTROLLING ATMOSPHERIC GAS COMPOSITION WITHIN A CONTAINER

FIELD OF THE INVENTION

[0001] The invention relates generally to a method of and apparatus for controlling atmospheric gas composition within a container, and in particular for extending the life of perishable goods, for example during transport.

BACKGROUND OF INVENTION

[0002] In this specification, where a document, act or item of knowledge is referred to or discussed, this reference or discussion is not an admission that the document, act or item of knowledge or any combination thereof was at the priority date:

[0003] part of common general knowledge; or
[0004] known to be relevant to an attempt to solve any problem with which this specification is concerned.

[0005] In order to prolong the storage life of perishable goods (such as fruit and vegetables) stored in containers during for transportation or storage it is generally important to control atmospheric conditions within the container. This is because atmospheric parameters, for example temperature and atmospheric gas composition within the container, affect the rate of respiration and deterioration of goods after harvest.

[0006] In this respect the conventional method of extending storage life of produce has been to refrigerate the container and to reduce carbon dioxide levels (as carbon dioxide is generated by respiring produce), while maintaining oxygen and nitrogen at desired levels.

[0007] Applicant’s invention described in WO2000/023350 entitled ‘Apparatus for controlled venting of a chamber’ proposed a then-novel approach of a method for adjusting the atmosphere within a chamber containing respiring produce, the method carried out without monitoring the carbon dioxide level in the chamber, involving monitoring the oxygen level in the chamber and admitting ambient air into the chamber when the oxygen level is detected to have fallen below an oxygen setpoint, and removing carbon dioxide from the chamber atmosphere at a predetermined rate byway of a selected quantity of carbon dioxide absorbing material stored within the container, the predetermined rate having been selected before the storage/journey such that the carbon dioxide concentration within the chamber atmosphere does not substantially exceed a predetermined amount.

[0008] Other known methods utilise a permeable membrane within the container which is selective for certain gases. That is, it allows some gases to pass through, whilst excluding certain other gases. The selective membrane is installed in the container as a liner layer which defines a buffer zone which can be opened to the ambient atmosphere outside the container, or manipulated in other ways. Imposing a constant partial pressure difference across the membrane has the effect of selective removal of gases into the buffer zone. Such techniques avoid the need for carbon dioxide absorbing materials.

[0009] However, the use of membrane methods can give rise to partial vacuum conditions inside the container, leading to instability and therefore difficulty in providing desired environmental conditions for the respiring produce. Further, only certain membranes are useful in providing required permeability to some gases over other gases, and the more commonly available gas separation membranes provide relatively poor selectivity to carbon dioxide. For example, commercially available PDMS membrane (such as that supplied by Medarray) presents relatively low CO₂/O₂ and CO₂/N₂ selectivity, meaning that there can be significant loss of oxygen and nitrogen from the container. This has been found to result in the generation of a partial vacuum within the container, and so significant air make-up is required to counter this loss. This leads to control instability, or lack of equilibrium and resulting difficulty in controlling the atmosphere.

[0010] Further complicating the control of atmospheric gases in the container is the phenomenon that, even though the total pressure on the feed side of the membrane is higher than that on the sweep side of the membrane, an oxygen (and/or nitrogen) partial pressure difference can draw oxygen back through the membrane during its extraction operation.

[0011] In view of the above, it has generally been deemed necessary to develop specialised membranes with high carbon dioxide selectivity, such as that described in WO2008/017307 entitled ‘A gas permeable membrane’.

[0012] The present invention seeks to ameliorate one or more of the abovementioned disadvantages, or at least provide a new method of controlling the atmosphere in a container, and/or new container apparatus, and/or apparatus for controlling the atmosphere in the container.

SUMMARY OF THE INVENTION

[0013] According to one form of the invention there is provided a method of controlling gas composition within a container containing respiring produce, the container including at least one gas outlet and at least one gas inlet, the method including the steps of:

[0014] drawing gas from within the container through a selective membrane element under selected control conditions through the at least one gas outlet;
[0015] introducing ambient air from outside the container into the container through the at least one gas inlet under selected control conditions to control the relative composition of gases inside the container.

[0016] Preferably the selected control conditions under which drawing is conducted are that there is a drawing step when a pump is actuated to draw gas through the membrane element from within the container at a selected range of flowrates and a holding step where the flowrate through the membrane is minimised.

[0017] Preferably the drawing step and the holding step are alternated so that there is generally intermittent drawing of gas.

[0018] Preferably the control conditions are that the drawing step is of one duration and the holding step is of another duration and the two durations are of unequal size.

[0019] Preferably the drawing step is shorter than the holding step to facilitate an equilibrium of gas components and pressures within the container.

[0020] Preferably the drawing step is up to about 20 times shorter in duration than the holding step.

[0021] Preferably the drawing step includes selectively drawing carbon dioxide through the membrane element, so that it is extracted from the container at a higher rate than other gases present within the container.

[0022] Preferably the method includes the step of conducting a container gas tightness test and including the level of leakage, if any, in a control algorithm.

[0023] The method in accordance with any one of claims 1 to 8 wherein the method includes the step of monitoring levels
of one or more gas components inside the container to provide one or more gas component level readings.

[0024] Preferably the method includes the step of monitoring levels of one or more gas components of the gas mixture inside the container to provide one or more gas component level readings. When the method includes the step of monitoring levels of one or more gas components, the introducing step may be in response to the one or more gas component readings. In a preferred embodiment the monitoring step includes monitoring of oxygen.

[0025] Preferably the selected control conditions under which drawing is conducted include changing a rate of drawing of gas from within the container over time. Preferably the selected control conditions under which introducing ambient air is conducted include changing a rate of introduction of ambient air from outside the container over time.

[0026] Preferably the gas drawn from the container is carbon dioxide.

[0027] Preferably the rate of drawing of gas from within the container varies between a maximum rate and a zero rate of drawing, representing respectively a drawing step and a holding step. In some arrangements the selected drawing control conditions are intermittent on-off between the maximum rate of drawing and holding. The control conditions may include a situation where the drawing step and the holding step are of approximately equal time durations. In one embodiment, this time duration may be approximately 15 minutes. Other suitable time durations are include approximately 1 minute, 2 minutes, 5 minutes, 10 minutes, 20 minutes, 30 minutes, 45 minutes, and 1 hour, 2 hours, as well as unequal on-off times, such as 10 minutes on, 20 minutes off, 20 minutes on, and so on.

[0028] It is contemplated that control conditions may include a rate of change of drawing of the gas, or rate of change of introduction of oxygen from a bottle or ambient air may be governed by a sinusoidal pattern, or a sawtooth pattern, or other suitable waveform. The gradient of the sawtooth may be steep between drawing and holding, and flatter between a subsequent holding and drawing, so that there is a longer gap for allowing restoration of equilibrium conditions, or the waveform may be more of a uniform. Furthermore, it is contemplated that the drawing step may be merely reduced in amplitude so that the drawing is brought to a trickle, rather than reducing drawing to a complete holding step. This trickling may have other advantages, such as for example reducing unintentional reverse movements of other gases through the membrane.

[0029] The gas-monitoring step may include the step of monitoring the level of oxygen within the container. The step of measuring the level of oxygen is combined with comparing that level with a desired set point and then introducing the ambient air to the container in accordance with the selected control conditions. Preferably the measurement of the gas is routinely conducted, at selected spaced-apart time intervals, and the amount of introduced gas for that time interval is dependent on the difference between the measured gas level and the selected set point.

[0030] The gas-monitoring step may also include the monitoring of carbon dioxide (CO₂) gas within the container. The method may also include the step of comparing the measured amount of CO₂ gas in the container and then altering the control conditions of selective extraction of CO₂.

[0031] The selected control conditions may be a reduced or zero flow rate at selected times, caused by a throttling step. The throttling step may be caused by a diaphragm being placed across the feed and/or sweep side of the membrane unit, or by some other physical or mechanical interference to increase the pressure and reduce the flow rate through the membrane unit. The throttling may be by a venturi, orifice, partial blockage, choke, variable aperture, sphincter or some porous material such as a sintered block, sponge, or other suitable substance. The throttle may be extended into the feed or sweep streams by a transducer.

[0032] This preferred form of the invention, then, includes controlled modulation of duty flow, through an intermittent operation of the membrane element. A reduced or zero CO₂ extraction flow allows time for the oxygen level within the container to build up, avoiding the risk that continuous drawing of CO₂ through the membrane (which will include significant levels of gases other than CO₂) will lead to instability, as the air inlet introduction operates in response to the monitoring of oxygen level.

[0033] The drawing step may be considered a forced permeation of gas through the membrane element. In a preferred arrangement, carbon dioxide is drawn through the membrane element at a higher rate than other gases present within the container, in particular, oxygen and nitrogen.

[0034] In that regard, the membrane element preferably has a selectivity which allows carbon dioxide gas to permeate through the membrane element at a higher rate than oxygen and nitrogen, preferably at a ratio of between about 2.5 and about 15. Preferred selectivity ranges for CO₂/N₂ are between about 5 and 50. In a particularly advantageous arrangement which has been shown to be very effective with embodiments of the present invention, the selectivity of a suitable membrane for carbon dioxide over oxygen (CO₂/O₂) is relatively modest or low at between about 4 and 5 and the selectivity for a suitable membrane for carbon dioxide over nitrogen (CO₂/N₂) is similarly modest, at between about 7 and 14. This particular membrane is manufactured from Polydimethylsiloxane (PDMS).

[0035] The invention is implemented without any other means of drawing or extracting carbon dioxide gas.

[0036] Membranes contemplated include an overall permeability for CO₂ of about 3000 Barrer and comprise a thickness of about 35 μm. This is a very high permeability and other materials are contemplated to be useful, including cellulose acetate, which has an overall permeability for CO₂ of 6.3 Barrer. This is a large difference, but it can be mitigated by altering the thickness of the membrane and having a large membrane area.

[0037] Preferred membranes have been shown to be about 3100 Barrers of permeability for CO₂ and 35 μm in thickness. Therefore the permeability per unit thickness for a suitable membrane is about 88 Barrers/μm. One type of suitable membrane for use with preferred embodiments of the present invention is manufactured from Polydimethylsiloxane (PDMS), which has moderate selectivity to CO₂, at about 4 and 5, and a CO₂/N₂ selectivity of between about 10 and 11. Other membranes, including non-silicon membranes, may also be suitable.
[0038] Advantageously, preferred embodiments of the method of the present invention utilise a membrane of moderate CO₂ selectivity, but a membrane which is widely available in the size and format, at a reasonably low cost. The advantage of the preferred embodiments of the present invention are that a membrane with a low selectivity and low cost can be utilised in a control system to provide a stable, controlled, suitable atmosphere for extending the life of respiring goods in transit.

[0039] According to another form of the invention there is provided a container suitable for storing respiring produce, the container including:

[0040] opposed end and side walls, and opposed floor and roof defining a void for storage of the produce;

[0041] at least one gas outlet and a selective membrane unit in fluid communication with the gas outlet so that in use gas within the container may be drawn therethrough, from the container to outside the container;

[0042] a pump in fluid communication with the membrane unit for drawing gas through the membrane unit;

[0043] at least one gas inlet for introducing atmospheric gas from outside the container to the void, and a valve for controlling gas flow through the gas inlet; one or more controllers for selectively controlling operation of the pump and valve.

[0044] Preferably there is provided a sensor for sensing levels of one or more gases within the container. Preferably the sensor is an oxygen sensor. Optionally another sensor is a carbon dioxide sensor.

[0045] Preferably there is provided a second gas outlet for evacuating container gas therethrough. Preferably a valve is provided on the second outlet to control the evacuation of container atmospheric gas therethrough.

[0046] Preferably the container includes a refrigeration unit.

[0047] Optionally there is provided a throttle or choke to increase the pressure and reduce the flow of gases through the feed and sweep portions of the membrane unit.

[0048] Preferably the one or more controllers include a processor, a memory, an input/output device, such that the or each controller is responsive to a program to control the operation of valves and pumps in response to various inputs.

[0049] Preferably each controller also includes a timer for measuring time elapsed in storage for the respiring produce so as to operate a control algorithm which operates the membrane unit based on time elapsed. Preferably the time controller is adapted to receive inputs from such devices as the timer, thermocouples, gas monitors, inputs from operators via the input/output device, including mass and type of produce. The memory and processor may be loaded with tables for calculating run times for various payloads and produce types.

[0050] For one preferred payload of produce, the setpoint for the CO₂ may be about 5%.

[0051] In real-world embodiments, the container will not be wholly sealed from the outside atmosphere. That is, there will be some leakage into the container or from the container, depending on the pressure differential between inside and outside the container. During installation of the system into the container, or beforehand, analysis of gas-tightness may be used to calibrate the system, to ensure leakage will not unaided offset operation of the invention. Preferably the base leakage of the container is less than the respiration rate of the produce in the container.

[0052] It is noted here that the production of CO₂ by respiring produce is, in a typical situation, about 30 ml/kg/hour, and produce in a container is normally of the order of 18 tonnes. So for a useful container, there will be less leakage than the CO₂ gas production by the produce, i.e. less than 540 l/hr.

[0053] The method of preferred embodiments of the present invention is advantageous because CO₂ monitoring equipment is not required, although it can be used if deemed necessary. CO₂ monitoring equipment is costly, both in terms of capital cost and in terms of operation and maintenance.

[0054] As described herein, the method and apparatus of the present invention can utilise, among other steps, the step of monitoring of oxygen and controlled input of atmospheric air to the container from outside, which affects the control and levels of carbon dioxide inside the container.

[0055] According to yet another form of the invention there is provided a computer that is arranged for operation in accordance with a method of controlling atmospheric gas composition within a container suitable for storing respiring produce, the container including at least one gas outlet and at least one gas inlet, the method including the steps of: drawing gas from within the container through a membrane element through the at least one gas outlet under selected control conditions; and introducing atmospheric gases from outside the container into the container through the at least one gas inlet under selected control conditions to control the relative composition of gases inside the container.

[0056] According to a still further aspect of the present invention there is provided a computer program for instructing a computer and arranged so that, when loaded in the computer, the computer operates as a controller for controlling atmospheric gas composition within a container in accordance with methods hereindescibed.

[0057] According to a yet further aspect of the present invention there is provided a computer readable program code embodied therein for causing a computer medium to operate as a controller for controlling atmospheric gas composition within a container in accordance with methods hereindescribed.

[0058] According to an even further aspect of the present invention there is provided a data signal having a computer readable program code embodied therein for causing a computer to operate as a controller for controlling atmospheric gas composition within a container in accordance with methods hereindescribed.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0059] To enable a clearer understanding, the invention will now be further explained and illustrated by reference to the accompanying drawings in which:

[0060] FIG. 1 is a schematic drawing of a container according to one embodiment of the present invention;

[0061] FIG. 2 is a schematic view of a testing arrangement of a scaled-down container generally in accordance with an embodiment of the present invention which has been constructed to show results set out herein;

[0062] FIG. 3 is an end elevation view of a membrane unit used in the testing arrangement of FIG. 2;

[0063] FIG. 4 is a side elevation view of the membrane unit of FIG. 3;

[0064] FIG. 5 is a cutaway isometric view of the membrane unit of FIG. 3;
FIG. 6 is a graph of results which were produced in the testing arrangement of FIG. 2 under selected initial conditions;

FIG. 7 is a graph of results which were produced in the testing arrangement of FIG. 2 under other selected initial conditions;

FIG. 8 is a graph of results which were produced in the testing arrangement of FIG. 2 under further selected initial conditions;

FIG. 9 is a graph of results which were produced in the testing arrangement of FIG. 2 under still further selected initial conditions;

FIG. 10 is a graph of results which were produced in the testing arrangement of FIG. 2;

FIG. 11 is a schematic drawing of a container according to another embodiment of the present invention;

FIG. 12 is a schematic view of a processing system which is part of a controller for use with a preferred embodiment of the present invention;

FIG. 13 is a schematic view of a portion of the architecture of the processing system of FIG. 12;

FIG. 14 is a schematic view of a distributed architecture which may be used as a controller;

FIG. 15 is a graph of results of a test of an improved model of a preferred embodiment of the present invention which shows that there was an intermittency of 15 minutes pumping out of a 300 minute cycle and that stability of gas composition was obtained at suitable levels;

FIG. 16 is a graph of results of another test of the improved setup, with a different intermittency signature of 15.75 minutes, wherein atmospheric air was the starting conditions for the air composition inside the container;

FIG. 17 is another graph of further test results in the improved test setup, with an intermittency of 15/30 minutes, as previously tested,

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIG. 1 there is shown a refrigerated container 10 which includes a refrigeration unit 12 and doors 14. The container 10 in use contains respiring produce 13, and further includes gas outlets 20 and 22 and gas inlet 24.

The container 10 also includes a membrane unit 30 which is in fluid communication with the gas outlet 22. A pump is associated with the membrane unit 30 which draws gas from the container 10 through a membrane (not shown) of a predetermined selectivity so that some gases from the container are drawn through (i.e., permeate through) the membrane at a greater rate than other gases.

The selectivity of the membrane of the embodiment shown is relatively modest or low, at about 4 or 5:1 for CO₂:O₂ and about 10 or 11:1 for CO₂:N₂. Other selectivities for the membrane may be used, including between about 2.5 and 15.

A useful membrane used in tests has been shown to have an absolute permeability for CO₂ of about 3100 Barrer and comprises a thickness of about 35 μm. Therefore the permeability per unit thickness for a suitable membrane is about 88 Barrer per μm. One material useful for the purposes of the test set out herein is Polydimethylsiloxane (PDMS). One of the reasons for this is that it is cost-effective and widely available in a format and size which is useful for extracting gases from shipping containers.

The container further includes a controller 8 which includes a CPU, a memory, a processor, actuators for actuating the pump on the membrane unit 30, actuators for valves 20, 22 and 24, as well as a sensor in the form of an oxygen concentration measurement device. The controller may also receive inputs relating to temperature in the container, pressure in the container, other gas sensors, and the like.

One function of the controller 8 is to actuate the pump on the membrane unit 30 in accordance with a selected control regime. An effective control regime is to vary the drawing of gas from within the container over time. This control regime, which has been demonstrated, can be used in maintaining an O₂ setpoint of about 5% and a CO₂ setpoint of about 7% in a sealed-down container of 750 L, to draw the gas out of container 10 in an intermittent manner. This means that control varies from a maximum drawing rate for a first prescribed time period, to a zero drawing rate for a second prescribed time period. The maximum drawing rate of CO₂ in the test was about 0.25 SLPM (an overall air-drawing rate through the membrane unit was about 30 Standard Litres Per Minute (SLPM)) and the on-off times (the first and second prescribed time periods) were both 15 minutes.

As will be understood by persons skilled in the art, the pressure drop across the membrane affects the extraction rate of CO₂ because the air flow changes when the pressure drop changes. Therefore the maximum overall air flow rate through the membrane was useful at between, at the drawing step, about 20 and 35 SLPM. This range is a useful range, but it will be appreciated that the drawing can vary between the maximum level and a trickle during the holding step. The rate of drawing of actual CO₂ is far less than the overall flow rate because CO₂ is only a small component of normal atmospheric gas, and when the CO₂ is in the container of respiring produce, it is desired to be only at about 7%.

Again, it will be appreciated that control may vary between said maximum drawing rate for a first prescribed time period and a lower drawing rate for a second prescribed time period. It will also be appreciated that control regimes other than a step function may be used, such as sinusoidal, sawtooth or other waveform between drawing rates. The important common feature is the intermittency of operation of membrane unit 30, so allowing successive periods of time for an equilibrium to be re-established.

The sensor of controller 8 makes measurements of oxygen concentration at selected intervals. If the oxygen concentration varies from a selected value (a ‘setpoint’, which may be preset in accordance with the rate of respiration of produce 13 in the container), controller 8 sends a signal via wires 17 or other communication means to open valves 20 and 24. This introduces air from outside the container 10 through inlet 24 and draws air from container 10 through outlet 20. Outlet 20 may include a fan to force air from the container. A fan may also be provided on inlet 24 to draw air into the container 10.

In one embodiment, the portion of the controller 8 which is responsible for oxygen concentration operates on an 8-minute cycle. That is, every 8 minutes the sensor checks the oxygen concentration level, and compares it with the set point. If the level is within an acceptable range of deviation from the same as the set point, the valves 20 and 24 are not opened. If there is a large difference between the desired set point and the measured level, the valves are opened for most of the 8-minute interval. If there is a small difference, the valves are opened for a small portion of the 8-minute interval.
It is contemplated that the system of one embodiment of the present invention might also operate without the sensor means for measuring oxygen. In place of the oxygen sensor, selected calculations are made, and selected inputs provided to the controller so that the controller can function to maintain selected gas concentrations, in particular, CO₂ and O₂ at selected levels. These calculations and inputs include at least respiration rate of produce, volume/mass of produce, temperature of atmosphere, inside container, gas leakage rate of container (through doors, seals etc) and gas transfer rates through valves 20, 22, 24 and membrane unit 30. Once these inputs have been provided, the controller can calculate the control regime required, for example, the nature of intermittent operation required (first and second prescribed time periods).

FIG. 11 shows a schematic layout of another arrangement of the present invention described above where there is no sensor. The controller includes a timer to operate the valves.

FIG. 12 shows a block diagram of operative components of a controller 1100 which may be the same as the controller 8 shown in FIG. 1. The method of preferred embodiments of the present invention may be executed by such a machine, smartphone or other computer, generally as hereinafter described.

The controller 1100 includes a control device 1101 having a processor 1102. Instructions and data to control operation of the processor 1102 in accordance with preferred embodiments of the present invention are stored in a memory 1103 which is in data communication with the processor 1102.

Typically, the controller 1100 will include both volatile and non-volatile memory and more than one of each type of memory, with such memories being collectively represented by the memory 1103.

FIG. 13 shows a block diagram of the main components of an exemplary memory 1103. The memory 1103 includes RAM 1103A, EPROM 1103B and a mass storage device 1103C. The RAM 1103A typically temporarily holds program files for execution by the Processor 1102 and related data. The EPROM 1103B may be a boot ROM device and/or may contain some system or control-related code. The mass storage device 1103C is typically used to store control programs, the integrity of which may be verified and/or authenticated by the processor 1102 using protected code from the EPROM 1103B or elsewhere.

The controller 1100 has an input/output (I/O) interface 1105 for communicating with an operator interface 1120 of the controller 1100, the operator interface 1120 having several peripheral devices. The input/output interface 1105 and/or the peripheral devices may be intelligent devices with their own memory for storing associated instructions and data for use with the input/output interface or the peripheral devices.

In the example shown in FIG. 12, the peripheral devices that communicate with the control device 1101 comprise one or more displays 1106, a touch screen 1107 and a printer 1109. Additional hardware may be included as part of the controller 1100, or hardware may be omitted as required for the specific implementation.

In addition, the controller 1100 may include a communications interface, for example a network card 1112. The network card may, for example, send status information or other information to a central controller, server or database and receive data or commands from the central controller, server or database.

It is also possible for the operative components of the controller 1100 to be distributed, for example input/output devices 1106, 1107, 1108, 1109, 1110, 1111 may be provided remotely from the atmosphere controller 1101.

FIG. 14 shows a control system 200 in accordance with an alternative embodiment. The control system 200 includes a network 201, which for example may be an Ethernet network, a LAN or a WAN. In this example, three banks 203 of two control machines 202 are connected to the network 201. The control systems 202 provide a control interface and may be the same as the controller 8 shown in FIG. 1, or may have simplified functionality depending on the requirements for implementing control, such as controlling a bank of containers at once. While banks 203 of two controllers are illustrated in FIG. 14, banks of one, three or more controllers are also envisaged.

One or more displays 204 may also be connected to the network 201. The displays 204 may, for example, be associated with one or more banks 203 of controllers. The displays 204 may be used to display representations associated with control situations on the control machines 202, and/or used to display other representations.

In a thick client embodiment, a control server 205 implements part of the control system using a control system 202 and the control system 202 implements part of the control algorithm. With this embodiment, as both the control server 205 and the control system 202 implement part of the control, they collectively provide a controlled atmosphere controller. A database management server 206 may manage storage of algorithms and associated data for downloading or access by the control devices 202 in a database 206A.

In a variation of the above thick client embodiment, the control machine 202 may implement the control, with the control server 205 functioning merely to serve data indicative of a control algorithm or method to a control machine 202 for implementation.

With this implementation, a data signal containing a computer program usable by the client terminal to implement the control method may be transferred from the control server to the client terminal, for example in response to a request by the client terminal.

In a thin client embodiment, the control server 205 implements most or all of the method by an operator using a control machine 202 and the control machine 202 essentially provides only the operator interface. With this embodiment, the control server 205 provides the method controller. The control machine will receive instructions, and pass the instructions to the control server which will process them and return settings and other outcomes to the control machine and display them. In a thin client embodiment, the control machines could be computer terminals, e.g. PC's running software that provides a user interface operable using standard computer input and output components.

The control system 200 may communicate with other control systems, other local networks such as a corporate network, and/or a wide area network such as the Internet, for example through a firewall 211.

Example 1

A test set up has been constructed to demonstrate the effectiveness of a preferred embodiment of the invention, in
accordance with FIG. 2. It will be understood by persons skilled in the art that the test set up includes features which would not be required for the invention to function in a commercial embodiment, since certain measurements and functionalities useful for tests are not required in the commercial embodiment.

[0105] In this example, features like those described above are denoted with like numerals.

[0106] The test included a container 110 of 750 L volume, and a 153.1 kg load of bananas 113 disposed in the container 110. The container 110 was refrigerated at about 11°C. The container 110 was disposed in a test laboratory set at about 22°C.

[0107] A controller was provided at 108. The controller 108 was operatively connected to valves 120 and 122 and 124 in the walls of the container, and to a membrane unit 130. Fans 121 and 123 are also provided to force air from the container and to draw at into the container from outside the container through the valves 120 and 124. The membrane unit 130 was a PDMS membrane unit, which has a moderate selectivity to CO₂, i.e., preferentially selecting CO₂ over O₂ and N₂ when drawing gases from the container 110.

[0108] The membrane unit 130 is shown in FIGS. 3-5, in which a generally cylindrical module housing 198 houses a plurality of hollow membrane (PDMS) fibres 197. The housing 198 includes side or feed ports 196 which are in fluid communication with an inside of the hollow PDMS membrane fibres. In the vest, side port 194 functioned as an inlet port and side port 193 functioned as an outlet or retentate port in fluid communication with inlet valve 146.

[0109] The housing 198 further includes shell side ports or outlet ports 191, 189 and 188 which are in fluid communication with the outside of the hollow PDMS membrane fibres 197. That is, these ports include permeate which is extracted from the container and is directed to ambient air outside the container 110.

[0110] In operation, container atmospheric gas is pumped from outlet 122 into side port 194. A portion of that gas permeated through the membrane 197 and into the outlet ports 191, 189 and 188 and a portion returned to the container 110 via side port 193 and valve 146.

[0111] A flushing valve 140 was provided in the wall of the container 110, as well as a purging valve 142, only to provide selected initial conditions.

[0112] Further, the membrane unit has an extraction port 122 and a re-introduction port 146, both in the wall of the container 110. Gas permeate (mostly CO₂, but with smaller amounts of other gases including O₂ and N₂) leaves the extraction port 122, and retentate can be returned to the container through the re-introduction port 146.

[0113] Pumps 150, 152 were provided to drive the membrane unit 130. The pumps 150, 152 are powered by 24V DC power supply 154. Filters 156 and 158 were provided to filter pump air inputs.

[0114] Additional ports were provided in the container to facilitate selected set points from which to commence testing.

[0115] Analysis chambers were provided at 164, 166 and 168 for gas component monitoring inside the container and for monitoring of gas components at input and output of a membrane unit 130. Flowmeters 190 and 192 are provided to measure flow into and from membrane unit 130. A thermometer 195 was provided to monitor temperature in the container.

[0116] A datalogger was provided at 175 and various A/D converters from various items such as thermometer, flowmeters, gas analysis devices, were provided to input to that datalogger at 180. Various of the elements were powered by power supply 199.

[0117] In operation the test setup was commenced at various given setpoints of O₂ concentration. FIG. 3 shows a test run where a control algorithm set by controller 8 was such that the membrane unit 130 was run for 15 minutes on maximum draw rate for CO₂ followed by a 15 minute period of a zero draw rate (holding).

[0118] While the 15 on/15 off control algorithm for the membrane unit was running, the controller 108 was monitoring the O₂ levels in the container via the oxygen sensor unit on an 8-minute cycle. The controller 108 opened the valves 120 and 124 as required on this 8-minute cycle (for the full 8 minutes if the oxygen level was far from the set point; less time open if the oxygen level was nearer the set-point), which had the effect of changing the concentration of Oxygen and CO₂ as well. The results can be seen in FIGS. 6-9.

[0119] FIGS. 6 and 7 show one set of test results with the 15 on/15 off algorithm (for the membrane unit) with a feed/ sweep pressure differential being 1.5 barg/0 barg. FIG. 6 shows the gas levels inside the banana bin during a test run where the membrane unit 130 commenced operations while the oxygen level was above a suitable set point (5%). Gas concentration trace 201 is carbon dioxide while trace 202 is oxygen. It can be seen that the oxygen levels stabilised at about 5% while the carbon dioxide levels stabilised at about 7%. FIG. 7 shows the flow rate of carbon dioxide gas through the membrane unit 130 during the test, showing a stabilising of the rate when the membrane unit 130 was scrubbing.
taught that use of such a technique would not result in an equilibrium, for reasons discussed above.

[0125] Though finding the right algorithm can be complex, the method and apparatus show that a control of the CO₂ levels inside a container can be made with introduction of atmospheric air and selective extraction of CO₂ on a simple, tuned basis. Some embodiments do not require O₂ measurement; others require it. This was also a surprise to the inventors.

[0126] The commercially available PDMS membrane used in this case, supplied by Medarray, presents only a moderate CO₂/O₂ and CO₂/N₂ selectivity, meaning that there is significant loss of oxygen and nitrogen from the container when operating the membrane. Despite this, and to the surprise of the inventors, this did not result in a loss of stability of the controlled atmosphere system.

Example 2

[0127] The above test rig was improved by including a more rigid board to inhibit reduction in volume when a reduction in internal container pressure was experienced.

[0128] The sealing of the test rig was improved so that there was slightly lower leakage. Similar produce at similar stages of ripening were used—green bananas.

[0129] The results of various test runs are shown in FIGS. 15, 16, and 17. In FIG. 17 the earlier test runs were repeated and the results were shown to be repeatable, however, the CO₂ level was reduced a lot further than was necessary, so other intermittency runs were conducted—15/75, 15/300 and the like, all shown in the Figures.

[0130] It should be stressed that although there are simple on-off runs made, this was only for convenience and the pump associated with the membrane unit could easily be run with a variac controller or the like which causes the pump to run at any level of pressure that any of the user needs. Furthermore, the membrane constants were input, being selectivity, permeability, and the like. An inlet of atmospheric air was included in the model, of a certain flowrate.

Example 3

[0131] The examples above have been scaled up and the results repeated for a mathematical model of a standard 40-foot container. The initial conditions were modelled to be a container volume of 67.4 cubic metres; volume of respiration goods 22.5 m³; mass of respiration goods 30 tonnes, selected leakage and respiration rates, and a temperature of 10 degrees Celsius. Further, the membrane constants were input, being selectivity, permeability, and the like. An inlet of atmospheric air was included in the model, of a certain flowrate.

[0132] On one run of the model, the membrane permeability constant was 3250 Barrer for CO₂, thickness was 35 μm, membrane permeability constant for Nitrogen was 280 Barrer, membrane permeability constant for Oxygen was 600 Barrer, and for Water vapour it was 360000Barrer.

[0133] The results of the mathematical modelling showed that the system stabilised at generally the same gas composition for the tested model 750 L container when the same respiration rates, temperature, and membrane data were used, when the oxygen set points were sought by the oxygen controller by a variable but intermittent introduction of oxygen contained in atmospheric ambient air, and the intermittent operation of the membrane unit was effected.

[0134] Modelling also showed that alteration of the pressure through the membrane unit, affecting the flowrate during the holding step, by a mechanical interference such as a blockage or other porous item, is useful for causing a holding step and controlling the flow through the membrane unit to facilitate equilibrium conditions.

[0135] Advantageously, the preferred embodiments of the method and apparatus of the present invention utilise a membrane of only moderate CO₂ selectivity, relative to N₂ and O₂ but it is a membrane which is widely available in the size and format required for the purpose of controlling container atmosphere, at a reasonably low cost. The advantage of the preferred embodiments of the present invention are that a membrane unit with a low selectivity and low cost can be utilised in a control system utilising controlled introduction of atmospheric air to provide a stable, controlled, suitable atmosphere for reducing respiration of, and extending the life of, respiring goods in transit.

[0136] The word ‘comprising’ and forms of the word ‘comprising’ as used in this description and claims does not limit the invention claimed to exclude any variants or additions.

[0137] Modifications and improvements to the invention will be readily apparent to those skilled in the art. Such modifications and improvements are intended to be within the scope of this invention.

1. A method of controlling gas composition within a container containing respiring produce, the container including at least one gas outlet and at least one gas inlet, the method including the steps of:
   - drawing gas from within the container at predetermined time intervals to outside the container through a selective membrane element through the at least one gas outlet; and
   - introducing ambient air from outside the container into the container through the at least one gas inlet under selected control conditions to control the relative composition of gases inside the container.

2. The method in accordance with claim 1 wherein the predetermined time drawing intervals are such that there is a drawing step when a pump is actuated to draw gas through the membrane element from within the container at a selected range of flowrates and a holding step where the flowrate through the membrane is minimised.

3. The method in accordance with claim 2 wherein the drawing step and the holding step are alternated so that there is generally intermittent drawing of gas.

4. The method in accordance with claim 1 wherein the control conditions are that the drawing step is of one duration and a holding step is of another duration and the two durations are of unequal size.

5. The method in accordance with claim 4 wherein the drawing step is shorter than the holding step to facilitate an equilibrium of gas components and pressures within the container.

6. (canceled)

7. The method in accordance with claim 1 wherein the drawing step includes selectively drawing carbon dioxide through the membrane element, so that it is extracted from the container at a higher rate than other gases present within the container.

8. (canceled)

9. The method in accordance with claim 1 wherein the method includes the step of monitoring levels of one or more gas components inside the container to provide one or more oxygen or carbon dioxide or nitrogen level readings and the
introducing step is conducted by a controller in response to the one or more oxygen or carbon dioxide or nitrogen readings.

10. (canceled)

11. (canceled)

12. The method in accordance with claim 1 wherein the selected control conditions under which introducing ambient air is conducted are that a rate of introduction of ambient air from outside the container changes over a selected time.

13. The method in accordance with claim 1 wherein the selected control conditions under which introducing ambient air is conducted are that there is an introduction of ambient air from outside the container based on the difference between the monitored level of oxygen and a desired oxygen set point.

14. A container suitable for storing respiring produce, the container including:

- opposed end and side walls, and opposed floor and roof;
- at least one gas outlet and a selective membrane unit in fluid communication with the gas outlet so that in use gas within the container may be drawn therethrough, from the container to outside the container;
- a pump in fluid communication with the membrane unit for drawing gas through the membrane unit;
- at least one gas inlet for introducing atmospheric gas from outside the container and a valve for controlling gas flow through the gas inlet; and
- one or more controllers set for intermittent operation of the pump and valve at predetermined timed intervals.

15. The container in accordance with claim 14 wherein the one or more controllers include a processor, a memory, an input/output device, such that the or each controller is responsive to a program to operate the operation of valves and pumps in response to various inputs.

16. The container in accordance with claim 14 wherein the or each controller also includes a timer for measuring time elapsed in storage for the respiring produce so as to operate a control algorithm which operates the pump in fluid communication with the membrane unit based on time elapsed.

17. The container in accordance with claim 14 wherein the or each controller is adapted to receive inputs from devices selected from the group consisting of: a timer; thermocouple; gas concentration monitor; operator input device.

18. The container in accordance with claim 14 wherein the memory and processor is adapted to be loaded with tables for calculating pump and valve run times for various payloads and produce types.

19. The container in accordance with claim 14 wherein the membrane element includes a selectivity which allows carbon dioxide gas to permeate through the membrane element at a higher rate than oxygen and nitrogen.

20. (canceled)

21. The container in accordance with claim 14 wherein the container includes an oxygen, carbon dioxide or nitrogen sensor.

22. (canceled)

23. The container in accordance with claim 14 wherein the container includes a second gas outlet for evacuating container gas therethrough.

24. The container in accordance with claim 23 wherein a valve is provided on the second outlet to control the evacuation of container atmospheric gas therethrough.

25. The container in accordance with claim 14 wherein the container includes a refrigeration unit.

26. A computer that is arranged for operation in accordance with a method of controlling atmospheric gas composition within a container suitable for storing respiring produce, the container including at least one gas outlet and at least one gas inlet, the method including the steps of: drawing gas from within the container through a membrane element through the at least one gas outlet at predetermined timed intervals; and introducing atmospheric gases from outside the container into the container through the at least one gas inlet under selected control conditions to control the relative composition of gases inside the container.

27. (canceled)

28. (canceled)

29. (canceled)

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