CLAIMS

1. A method for controlling a concentration of carbon dioxide in an atmosphere within a closed environment of a transport refrigeration container comprising the steps of:

a. providing a porous mass of a regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342);

b1. removing at least a portion of carbon dioxide in a flow of air by circulating the flow of air from within the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342),

b2. cooling the flow of air by flowing the air through a heat exchanger (28) disposed downstream of the carbon dioxide adsorbent material (42; 42A, 42B), and

b3. circulating the flow of air back into the closed environment;

c1. regenerating the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) by removing adsorbed carbon dioxide from the porous mass of carbon dioxide adsorbent by flowing air from outside the container (10) bypassing the heat exchanger (28) through the carbon dioxide adsorbent material (42; 42A, 42B) while

c2. continuing to flow air from within the closed environment through the heat exchanger (28) bypassing the carbon dioxide adsorbent material (42; 42A, 42B) via a bypass (54) arranged in parallel to the carbon dioxide adsorbent material (42; 42A, 42B); and

d. selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the gaseous atmosphere within the closed environment at a desired level.

2. The method as recited in claim 1 wherein the step of selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the gaseous atmosphere within the closed environment at a desired level comprises selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the atmosphere within the closed environment at a desired level, wherein the step of selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the atmosphere within the closed environment at a desired level in particular comprises maintaining the concentration of carbon dioxide at less than 5 percent by volume.

3. The method as recited in claim 1 further comprising the step of terminating the flow of air from within the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) after a predetermined period of time, after steps b1, b2, and b3 and before the step of regenerating the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342).

4. The method as recited in claim 3 further comprising the step of sensing a concentration of carbon dioxide in the circulating flow of air from the closed environment, wherein the step of terminating the flow of air from within the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises terminating said flow of air in response to the sensed concentration of carbon dioxide, wherein the step of sensing the concentration of carbon dioxide in the circulating flow of air from within the closed environment in particular comprises sensing the concentration of carbon dioxide in the circulating flow of air from within the closed environment at a location upstream of the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342), or at a location downstream of the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342).

5. The method as recited in claim 1 wherein the regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises activated carbon, zeolite or both a carbon dioxide adsorbent and an ethylene adsorbent.

6. The method as recited in claim 1 wherein the step of regenerating the porous mass of regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) by removing adsorbed carbon dioxide from the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises:

directing a flow of air from outside the closed environment through the carbon dioxide

adsorbent material (42; 42A, 42B; 142; 242; 342) to remove at least a portion of the absorbed carbon dioxide from the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342);

terminating the flow of air from outside the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) prior to repeating steps b1, b2, b3.

7. The method as recited in claim 6 further comprising the step of preheating the flow of air from outside the closed environment prior to directing the flow of air through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342), wherein the step of preheating the flow of air in particular comprises one of: passing a flow of ambient air in heat exchange relationship with a refrigerant in a refrigerant heat rejection heat exchanger (24); and passing a flow of ambient air in heat exchange relationship with a flow of exhaust gases from a fuel-fired engine.

8. The method as recited in claim 1 wherein the step of regenerating the porous mass of carbon dioxide adsorbent by removing adsorbed carbon dioxide from the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises heating the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) or establishing a vacuum across the porous mass of carbon dioxide.

9. The method as recited in claim 1 wherein the step of providing a porous mass of a regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises providing a first porous mass of a regenerative carbon dioxide adsorbent material (42A) and a second porous mass of a regenerative carbon dioxide adsorbent material (42B) operatively disposed in parallel relationship with said first porous mass of a regenerative carbon dioxide adsorbent material (42A), in particular further comprising the step of operating one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in an adsorption mode, wherein only steps b1, b2, b3 are performed, and simultaneously operating the other one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in a regeneration mode, wherein only steps c1 and c2 are performed, the method in particular further comprising the step of switching operation of each of the first and second porous masses of a regenerative carbon dioxide adsorption material in coordination between the adsorption mode and the regeneration mode, wherein the step of switching operation of each of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in coordination between the adsorption mode and the regeneration mode in particular occurs after a predetermined period of time, or wherein the step of switching operation of each of the first and second porous masses of a regenerative carbon dioxide

adsorbent material (42A, 42B) in coordination between the adsorption mode and the regeneration mode comprises switching operation in response to a sensed concentration of carbon dioxide in the circulating flow of air from the closed environment.

10. A regenerative scrubber system for removing carbon dioxide from an atmosphere within a closed environment of a refrigerated container (10) for transport of perishable produce, comprising:

at least one scrubber apparatus (40; 40A, 40B) housing a porous mass of a carbon dioxide adsorbent material (42; 42A, 42B), the scrubber apparatus (40; 40A, 40B) defining a flow path through the scrubber apparatus (40; 40A, 40B) traversing the porous mass of a carbon dioxide adsorbent material (42; 42A, 42B) and comprising a scrubber system bypass (54) allowing to selectively bypass the porous mass of a carbon dioxide adsorbent material (42; 42A, 42B);

a heat exchanger (28) disposed downstream of the carbon dioxide adsorbent material (42; 42A, 42B); and

a controller (60) configured for

selectively directing a gas from the atmosphere within the closed environment along said flow path and through the heat exchanger (28) during operation in an adsorption mode, and

selectively directing air from outside the closed environment bypassing the heat exchanger (28) along said flow path and directing the gas from the atmosphere within the closed environment through the heat exchanger (28) bypassing the carbon dioxide adsorbent material (42; 42A, 42B) via the scrubber system bypass (54) during operation in a regeneration mode.

11. The regenerative scrubber system as recited in claim 10 wherein the controller (60) is operative for switching operation of said at least one scrubber apparatus between the adsorption mode and the regeneration mode, wherein the controller (60) is in particular operative for switching operation of said at least one scrubber apparatus between the adsorption mode and the regeneration mode at predetermined time intervals, or for switching operation of the at least one scrubber apparatus between the adsorption mode and the regeneration mode in response to a sensed concentration of carbon dioxide in the atmosphere within the closed environment.

12. The regenerative scrubber system as recited in claim 10 wherein: said at least one scrubber apparatus comprises a first scrubber apparatus (40A) and a second scrubber apparatus (40B) operatively disposed in parallel relationship, the first scrubber apparatus (40A) housing a first porous mass of a carbon dioxide adsorbent material (42A) and the second scrubber apparatus (40B) housing a second porous mass of a carbon dioxide adsorbent material (42B); and said controller (60) is configured to operate one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in an adsorption mode and simultaneously operate the other one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in a regeneration mode, wherein the controller (60) is in particular configured to switch operation of the first scrubber apparatus (40A) and the second scrubber apparatus (40B) between the adsorption mode and the regeneration mode after a predetermined period of time, or in response to a sensed concentration of carbon dioxide in the atmosphere within the closed environment.

13. The regenerative scrubber system as recited in clam 10 wherein the scrubber system comprises:

an inner shell (146), an intermediate shell (148) and an outer shell (144) disposed in radially spaced relationship about a central axis;

said inner shell (146) defining a hollow core;

said inner shell (146) and said intermediate shell (148) defining an annular space therebetween, the porous mass of regenerative carbon dioxide adsorbent (142) disposed in the annular space between said inner shell (146) and said intermediate shell (148);

said outer shell (144) and said intermediate shell (148) defining an annular outer flow passage therebetween;

a plurality of flow openings (156) formed in said intermediate shell (148); and

a plurality of flow openings (154) formed in said inner shell (146).

14. The regenerative scrubber apparatus as recited in claim 10 wherein the scrubber apparatus comprises:

an outer shell (244) defining a hollow core; and

a plurality of tubes (246) disposed coaxially and arrayed in spaced parallel arrangement within the core defined by the outer shell (244), the porous mass of regenerative carbon dioxide adsorbent (242) disposed in the core amongst the array of tubes (246) and between the array of tubes (246) and the outer shell (144).

15. The regenerative scrubber apparatus as recited in claim 10 wherein the scrubber apparatus comprises:

an outer shell (344) and an inner shell (346), the outer shell (344) circumscribing and disposed in radially spaced relationship to and coaxially about the inner shell (346), thereby defining an annular outer flow passage about the inner shell (346), the inner shell (346) defining a hollow core in which a porous mass of regenerative carbon dioxide adsorbent material (342) is disposed.

CLAIMS

1. A method for controlling a concentration of carbon dioxide in an atmosphere within a closed environment of a transport refrigeration container (10) comprising the steps of:

a. providing a regenerative scrubber system (38) including a scrubber apparatus (40) housing a porous mass of a regenerative carbon dioxide adsorbent material (42; 42A, 42B);

b1. removing at least a portion of carbon dioxide in a flow of air by circulating the flow of air from within the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B);

b2. passing the flow of air through a heat exchanger (28) of a transport refrigeration unit (20); and

b3. circulating the flow of air back into the closed environment;

c1. regenerating the porous mass of carbon dioxide adsorbent material (42; 42A, 42B) by removing adsorbed carbon dioxide from the porous mass of carbon dioxide adsorbent by passing air from outside the container (10) through the scrubber apparatus (40) while

c2. continuing to flow air from within the closed environment through the heat exchanger (28) while the transport refrigeration unit (20) is in operation bypassing the regenerative scrubber system (38) via a scrubber bypass (54) including a bypass flow control device (56), in particular a bypass flow control damper; and

d. selectively repeating steps b1, b2, b3, c1, and c2 to maintain the concentration of carbon dioxide in the gaseous atmosphere within the closed environment at a desired level.

2. The method as recited in claim 1 wherein the step of selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the gaseous atmosphere within the closed environment at a desired level comprises selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the atmosphere within the closed environment at a desired level, wherein the step of selectively repeating steps b1, b2, b3, c1 and c2 to maintain the concentration of carbon dioxide in the atmosphere within the closed environment at a desired level in particular comprises maintaining the concentration of carbon dioxide at less than 5 percent by volume.

3. The method as recited in claim 1 further comprising the step of terminating the flow of air from within the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) after a predetermined period of time, after steps b1, b2, and b3 and before the step of regenerating the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342).

4. The method as recited in claim 3 further comprising the step of sensing a concentration of carbon dioxide in the circulating flow of air from the closed environment, wherein the step of terminating the flow of air from within the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises terminating said flow of air in response to the sensed concentration of carbon dioxide, wherein the step of sensing the concentration of carbon dioxide in the circulating flow of air from within the closed environment in particular comprises sensing the concentration of carbon dioxide in the circulating flow of air from within the closed environment at a location upstream of the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342), or at a location downstream of the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342).

5. The method as recited in claim 1 wherein the regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises activated carbon, zeolite or both a carbon dioxide adsorbent and an ethylene adsorbent.

6. The method as recited in claim 1 wherein the step of regenerating the porous mass of regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) by removing adsorbed carbon dioxide from the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises:

directing a flow of air from outside the closed environment through the carbon dioxide

adsorbent material (42; 42A, 42B; 142; 242; 342) to remove at least a portion of the absorbed carbon dioxide from the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342);

terminating the flow of air from outside the closed environment through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) prior to repeating steps b1, b2, b3.

7. The method as recited in claim 6 further comprising the step of preheating the flow of air from outside the closed environment prior to directing the flow of air through the carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342), wherein the step of preheating the flow of air in particular comprises one of: passing a flow of ambient air in heat exchange relationship with a refrigerant in a refrigerant heat rejection heat exchanger (24); and passing a flow of ambient air in heat exchange relationship with a flow of exhaust gases from a fuel-fired engine.

8. The method as recited in claim 1 wherein the step of regenerating the porous mass of carbon dioxide adsorbent by removing adsorbed carbon dioxide from the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises heating the porous mass of carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) or establishing a vacuum across the porous mass of carbon dioxide.

9. The method as recited in claim 1 wherein the step of providing a porous mass of a regenerative carbon dioxide adsorbent material (42; 42A, 42B; 142; 242; 342) comprises providing a first porous mass of a regenerative carbon dioxide adsorbent material (42A) and a second porous mass of a regenerative carbon dioxide adsorbent material (42B) operatively disposed in parallel relationship with said first porous mass of a regenerative carbon dioxide adsorbent material (42A), in particular further comprising the step of operating one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in an adsorption mode, wherein only steps b1, b2, b3 are performed, and simultaneously operating the other one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in a regeneration mode, wherein only steps c1 and c2 are performed, the method in particular further comprising the step of switching operation of each of the first and second porous masses of a regenerative carbon dioxide adsorption material in coordination between the adsorption mode and the regeneration mode, wherein the step of switching operation of each of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in coordination between the adsorption mode and the regeneration mode in particular occurs after a predetermined period of time, or wherein the step of switching operation of each of the first and second porous masses of a regenerative carbon dioxide

adsorbent material (42A, 42B) in coordination between the adsorption mode and the regeneration mode comprises switching operation in response to a sensed concentration of carbon dioxide in the circulating flow of air from the closed environment.

10. A regenerative scrubber system (38) for removing carbon dioxide from an atmosphere within a closed environment of a refrigerated container (10) for transport of perishable produce, comprising:

at least one scrubber apparatus (40; 40A, 40B) housing a porous mass of a carbon dioxide adsorbent material (42; 42A, 42B), the scrubber apparatus (40; 40A, 40B) defining a flow path through the scrubber apparatus (40; 40A, 40B) traversing the porous mass of a carbon dioxide adsorbent material (42; 42A, 42B) and comprising a scrubber system bypass (54) including a bypass flow control device (56), in particular a bypass flow control damper, allowing to selectively bypass the regenerative scrubber system (38);

a heat exchanger (28) of a transport refrigeration unit (20); and

a controller (60) which is configured for

selectively directing a gas from the atmosphere within the closed environment along said flow path through the heat exchanger (28) during operation in an adsorption mode, and

selectively directing air from outside the closed environment along said flow path and passing the gas from the atmosphere within the closed environment through the heat exchanger (28) bypassing the regenerative scrubber system (38) via the scrubber system bypass (54) during operation in a regeneration mode, while the transport refrigeration unit (20) is in operation.

11. The regenerative scrubber system as recited in claim 10 wherein the controller (60) is operative for switching operation of said at least one scrubber apparatus between the adsorption mode and the regeneration mode, wherein the controller (60) is in particular operative for switching operation of said at least one scrubber apparatus between the adsorption mode and the regeneration mode at predetermined time intervals, or for switching operation of the at least one scrubber apparatus between the adsorption mode and the regeneration mode in response to a sensed concentration of carbon dioxide in the atmosphere within the closed environment.

12. The regenerative scrubber system as recited in claim 10 wherein: said at least one scrubber apparatus comprises a first scrubber apparatus (40A) and a second scrubber apparatus (40B) operatively disposed in parallel relationship, the first scrubber apparatus (40A) housing a first porous mass of a carbon dioxide adsorbent material (42A) and the second scrubber apparatus (40B) housing a second porous mass of a carbon dioxide adsorbent material (42B); and said controller (60) is configured to operate one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in an adsorption mode and simultaneously operate the other one of the first and second porous masses of a regenerative carbon dioxide adsorbent material (42A, 42B) in a regeneration mode, wherein the controller (60) is in particular configured to switch operation of the first scrubber apparatus (40A) and the second scrubber apparatus (40B) between the adsorption mode and the regeneration mode after a predetermined period of time, or in response to a sensed concentration of carbon dioxide in the atmosphere within the closed environment.

13. The regenerative scrubber system as recited in clam 10 wherein the scrubber system comprises:

an inner shell (146), an intermediate shell (148) and an outer shell (144) disposed in radially spaced relationship about a central axis;

said inner shell (146) defining a hollow core;

said inner shell (146) and said intermediate shell (148) defining an annular space therebetween, the porous mass of regenerative carbon dioxide adsorbent (142) disposed in the annular space between said inner shell (146) and said intermediate shell (148);

said outer shell (144) and said intermediate shell (148) defining an annular outer flow passage therebetween;

a plurality of flow openings (156) formed in said intermediate shell (148); and

a plurality of flow openings (154) formed in said inner shell (146).

14. The regenerative scrubber apparatus as recited in claim 10 wherein the scrubber apparatus comprises:

an outer shell (244) defining a hollow core; and

a plurality of tubes (246) disposed coaxially and arrayed in spaced parallel arrangement within the core defined by the outer shell (244), the porous mass of regenerative carbon dioxide adsorbent (242) disposed in the core amongst the array of tubes (246) and between the array of tubes (246) and the outer shell (144).

15. The regenerative scrubber apparatus as recited in claim 10 wherein the scrubber apparatus comprises:

an outer shell (344) and an inner shell (346), the outer shell (344) circumscribing and disposed in radially spaced relationship to and coaxially about the inner shell (346), thereby defining an annular outer flow passage about the inner shell (346), the inner shell (346) defining a hollow core in which a porous mass of regenerative carbon dioxide adsorbent material (342) is disposed.