BRIEF SUMMARY

The present disclosure is, in one implementation, directed to a system and method to control the temperature of a medium in a container, such as a tank or vessel.

According to a first aspect of the present invention, there is provided a system to control a temperature of a medium by refrigerant vaporization, comprising:

a container having an exterior and an interior;

at least one refrigerant reservoir associated with the container, the at least one refrigerant reservoir having at least one reservoir section configured to hold refrigerant, each at least one reservoir section having a wall with an exterior surface structured to be thermally coupled with a volume of the medium in the container and to provide thermal change to the volume of the medium in the container and thereby provide a volume of medium thermal coverage in the container, the volume of medium thermal coverage having an outside boundary;

a vapor pressure apparatus to provide regulation of refrigerant vapor pressure in the at least one refrigerant reservoir; and

wherein the at least one refrigerant reservoir is configured to form a vapor space in each of the at least one reservoir sections in response to receiving refrigerant and in response to the vapor pressure apparatus regulation of vapor pressure above the refrigerant to enable refrigerant vaporization at or near a selected temperature of the volume of medium thermal coverage for the volume of the medium in the container that is thermally coupled to the respective at least one reservoir section.

There is provided a system and method of controlling temperature of a medium by refrigerant vaporization is provided. the system includes a container, at least one refrigerant reservoir having at least one reservoir section that includes a wall with an exterior surface structured to be thermally coupled with a volume of the medium in the container and to provide a volume of medium thermal coverage in the container, a vapor pressure apparatus to provide regulation of refrigerant vapor pressure in the at least one refrigerant reservoir, whereby the refrigerant reservoir forms a vapor space in

each of the at least one reservoir sections in response to receiving refrigerant and to the vapor pressure apparatus regulation of vapor pressure above the refrigerant to enable refrigerant vaporization at or near a selected temperature of the volume of medium in the container that is thermally coupled to the respective reservoir section.

The at least one reservoir section comprises a plurality of reservoir sections that each have a respective internal reservoir space that is in fluid communication with at least one other internal reservoir space of an adjacent reservoir section, and the plurality of reservoir sections arranged in spaced relationship to adjacent reservoir sections with the respective volumes of medium thermal coverage having the respective boundaries of thermal coverage to be at least contiguous.

The system further includes a refrigerant source in fluid communication with the refrigerant reservoir and the vapor pressure apparatus and configured to provide refrigerant to the refrigerant reservoir in response to a change in vapor pressure in the refrigerant reservoir as regulated by the vapor pressure apparatus.

The plurality of reservoir sections are coupled together in series or in parallel or in a combination of series and parallel arrangements.

Each internal reservoir space is formed by at least one weir in the respective reservoir section, with the at least one weir sized and shaped to divide the reservoir section into a vapor space and a refrigerant space.

The refrigerant reservoir comprises a lattice of reservoir sections.

R3 is a radius of the volume of medium thermal coverage that is determined as follows:

$$R3 = \sqrt{\frac{1}{J * \pi} * (T2 - T1) * \frac{1}{\frac{1}{2 * \pi} * \left(\frac{1}{H1 * R1} + \frac{\ln\left(\frac{R2}{R1}\right)}{K1} + \frac{1}{H2 * R2} \right)} + R2^2}$$

where:

H1 = Refrigerant heat transfer coefficient, including boundary layer effects (W/m^2*K);

H2 = Medium heat transfer coefficient, including boundary layer effects (W/m^2*K);

J = Heat generated by medium per unit volume per unit time (W/m^3);

K1 = Thermal conductivity of refrigerant reservoir wall material of construction (W/m*K);

R1 = Radius from center of reservoir section to interior of reservoir section wall (m);

R2 = Radius from center of reservoir section to exterior of reservoir section wall (m);

R3 = Radius from center of reservoir section to outside boundary of liquid medium thermal coverage (m);

T1 = Temperature of refrigerant at a location of vaporization (K); and

T2 = Temperature of the medium at an outer boundary of thermal coverage (K).

A minimum spacing between a center of adjacent reservoir sections is not less than $\frac{2}{\sqrt{2}} * R3$ and R3 is a radius of the volume of medium thermal coverage.

The at least one refrigerant reservoir is located in the interior of the container or, alternatively, the at least one refrigerant reservoir is located on the exterior of the container, or the at least one refrigerant reservoir includes at least two refrigerant reservoirs, with at least one refrigerant reservoir located in the interior of the container and at least one refrigerant reservoir located on the exterior of the container.

In accordance with a second aspect of the present invention, there is provided a method of controlling the temperature of a medium by refrigerant vaporization, the method including:

providing an apparatus for controlling the temperature of a medium by refrigerant vaporization of a refrigerant, the providing including providing:

a container having an exterior and an interior;

at least one refrigerant reservoir associated with the container, the at least one refrigerant reservoir having at least one reservoir section configured to hold refrigerant, each at least one reservoir section having a wall with an exterior surface structured to be thermally coupled with a volume of the medium in the container and to provide thermal change to the volume of the medium in the container and thereby provide a volume of medium thermal coverage in the container, the volume of medium thermal coverage having an outside boundary;

a vapor pressure apparatus to provide regulation of refrigerant vapor pressure in the at least one refrigerant reservoir; and

wherein the at least one refrigerant reservoir is configured to form a vapor space in each of the at least one reservoir sections in response to receiving refrigerant and in response to the vapor pressure apparatus regulation of vapor pressure above the refrigerant to enable refrigerant vaporization at or near a selected temperature

of the volume of medium thermal coverage for the volume of the medium in the container that is thermally coupled to the respective at least one reservoir section;

introducing refrigerant into the at least one refrigerant reservoir to partially occupy the at least one refrigerant section and form a vapor space in the at least one refrigerant section; and

regulating vapor pressure above the refrigerant in the at least one refrigerant reservoir to enable refrigerant vaporization at or near a selected temperature of the volume of medium thermal coverage for the volume of the medium in the container that is thermally coupled to the respective at least one reservoir section.

According to a third aspect of the present invention, there is provided a method of controlling temperature in a medium stored in a container. The method includes the steps of partitioning the medium into localized thermal volumes, and thermally coupling a refrigerant to respective localized thermal volumes to control the temperature of the localized thermal volume to maintain the medium at a selected temperature

Partitioning the medium into localized thermal volumes includes positioning a refrigerant reservoir in physical proximity to the container, with at least one refrigerant reservoir section associated with a respective localized thermal volume.

The thermally coupling includes regulating vapor pressure in a vapor space above the refrigerant in each at least one refrigerant reservoir section to maintain a temperature of the respective localized thermal volume at the selected temperature of the medium.

As will be readily appreciated from the foregoing, the present disclosure provides a system and method for controlling the temperature of a medium by providing localized temperature control of the medium. While representative implementations of the present disclosure are described in the context of fermentation, the system and method of the present disclosure will have application to both heating and cooling of a medium in order to maintain temperature in a wide variety of mediums, and is a novel approach to engineered temperature control that adjusts to both

CLAIMS

1. A system to control a temperature of a medium by refrigerant vaporization, comprising:

a container having an exterior and an interior;

at least one refrigerant reservoir associated with the container, the at least one refrigerant reservoir having at least one reservoir section configured to hold refrigerant, each at least one reservoir section having a wall with an exterior surface structured to be thermally coupled with a volume of the medium in the container and to provide thermal change to the volume of the medium in the container and thereby provide a volume of medium thermal coverage in the container, the volume of medium thermal coverage having an outside boundary;

a vapor pressure apparatus to provide regulation of refrigerant vapor pressure in the at least one refrigerant reservoir; and

wherein the at least one refrigerant reservoir is configured to form a vapor space in each of the at least one reservoir sections in response to receiving refrigerant and in response to the vapor pressure apparatus regulation of vapor pressure above the refrigerant to enable refrigerant vaporization at or near a selected temperature of the volume of medium thermal coverage for the volume of the medium in the container that is thermally coupled to the respective at least one reservoir section.

2. The system of claim 1 wherein the at least one reservoir section comprises a plurality of reservoir sections that each have a respective internal reservoir space that is in fluid communication with at least one other internal reservoir space of an adjacent reservoir section, and the plurality of reservoir sections arranged in spaced relationship to adjacent reservoir sections with the respective volumes of medium thermal coverage having the respective boundaries of thermal coverage to be at least contiguous.

3. The system of claim 2, further comprising a refrigerant source in fluid communication with the refrigerant reservoir and the vapor pressure apparatus and configured to provide refrigerant to the refrigerant reservoir in response to a change in vapor pressure in the refrigerant reservoir as regulated by the vapor pressure apparatus.

4. The system of claim 2 wherein the plurality of reservoir sections are coupled together in series or in parallel or in a combination of series and parallel arrangements.

5. The system of claim 2 wherein each internal reservoir space is formed by at least one weir in the respective reservoir section, with the at least one weir sized and shaped to divide the reservoir section into a vapor space and a refrigerant space.

6. The system of claim 2 wherein the refrigerant reservoir comprises a lattice of reservoir sections.

7. The system of claim 2, in which R3 is a radius of the volume of medium thermal coverage that is determined as follows:

$$R3 = \sqrt{\frac{1}{J * \pi} * (T2 - T1) * \frac{1}{\frac{1}{2 * \pi} * \left(\frac{1}{H1 * R1} + \frac{\ln\left(\frac{R2}{R1}\right)}{K1} + \frac{1}{H2 * R2} \right)} + R2^2}$$

where:

H1 = Refrigerant heat transfer coefficient, including boundary layer effects (W/m^2*K);

H2 = Medium heat transfer coefficient, including boundary layer effects (W/m^2*K);

J = Heat generated by medium per unit volume per unit time (W/m^3);

K1 = Thermal conductivity of refrigerant reservoir wall material of construction (W/m*K);

R1 = Radius from center of reservoir section to interior of reservoir section wall (m);

R2 = Radius from center of reservoir section to exterior of reservoir section wall (m);

R3 = Radius from center of reservoir section to outside boundary of medium thermal coverage (m);

T1 = Temperature of refrigerant at a location of vaporization (K); and

T2 = Temperature of the medium at an outer boundary of thermal coverage (K).

8. The system of claim 7 wherein a minimum spacing between a center of adjacent reservoir sections is not less than $\frac{2}{\sqrt{2}} * R3$ and in which R3 is a radius of the volume of medium thermal coverage.

9. The system of claim 1 wherein the at least one refrigerant reservoir is located in the interior of the container.

10. The system of claim 1 wherein the at least one refrigerant reservoir is located on the exterior of the container.

11. A method of controlling a temperature of a medium by refrigerant vaporization, the method comprising:

providing an apparatus for controlling the temperature of the medium by refrigerant vaporization of a refrigerant, the providing including providing:

a container having an exterior and an interior;

at least one a refrigerant reservoir associated with the container, the at least one refrigerant reservoir having at least one reservoir section configured to hold refrigerant, each at least one reservoir section having a wall with an exterior surface structured to be thermally coupled with a volume of the medium in the

container and to provide thermal change to the volume of the medium in the container and thereby provide a volume of medium thermal coverage in the container, the volume of medium thermal coverage having an outside boundary;

a vapor pressure apparatus to provide regulation of refrigerant vapor pressure in the at least one refrigerant reservoir; and

wherein the at least one refrigerant reservoir is configured to form a vapor space in each of the at least one reservoir sections in response to receiving refrigerant and in response to the vapor pressure apparatus regulation of vapor pressure above the refrigerant to enable refrigerant vaporization at or near a selected temperature of the volume of medium thermal coverage for the volume of the medium in the container that is thermally coupled to the respective at least one reservoir section;

introducing refrigerant into the at least one refrigerant reservoir to partially occupy the at least one refrigerant section and form a vapor space in the at least one refrigerant section; and

regulating vapor pressure above the refrigerant in the at least one refrigerant reservoir to enable refrigerant vaporization at or near a selected temperature of the volume of medium thermal coverage for the volume of the medium in the container that is thermally coupled to the respective at least one reservoir section.

12. A method of controlling temperature in a medium stored in a container, the method comprising:

partitioning the medium into localized thermal volumes; and

thermally coupling a refrigerant to respective localized thermal volumes to control a temperature of the localized thermal volume to maintain the medium at a selected temperature,

wherein partitioning the medium into localized thermal volumes comprises positioning a refrigerant reservoir in physical proximity to the container, with at least one refrigerant reservoir section associated with a respective localized thermal volume.

13. The method of claim 12 wherein the thermally coupling comprises regulating vapor pressure in a vapor space above the refrigerant in each at least one refrigerant reservoir section to maintain a temperature of the respective localized thermal volume at the selected temperature of the medium.