

SYSTEM AND METHOD FOR VAPOR SPACE MONITORING AND CONTROL**CROSS-REFERENCE TO RELATED APPLICATIONS**

The present application claims priority to U.S. Provisional Patent Application No. 63/622,803 filed January 19, 2024, titled "System and Method for Vapor Space Monitoring and Control", the disclosure of which is incorporated herein in its entirety.

BACKGROUND**1. Field of Disclosure**

Aspects and embodiments disclosed herein are generally directed to monitoring and control of gaseous mixtures in the vapor space of closed vessels.

2. Discussion of Related Art

Closed-top tanks or closed vessels used in the petroleum and petrochemical industry for wastewater treatment are engineered containers designed to store and process various types of wastewater generated during oil and gas operations. These tanks are often used in conjunction with treatment processes such as flotation, storage, settling, chemical treatment, and separation. The tanks may be used in, e.g., Dissolved Gas Flotation (DGF) systems, American Petroleum Institute (API) oil water separator systems, etc. The closed design is utilized to facilitate prevention of the escape of volatile organic compounds (VOCs) from within the tanks, control odors, and comply with environmental regulations.

Although the tanks are closed to contain emissions, they often include ventilation systems to manage pressure differentials and to safely handle any gases that may be generated within the tank. Additionally, closed tanks may be equipped with monitoring and control systems to optimize the treatment process, track key parameters, and ensure compliance with environmental regulations. In the context of a closed tank, the term "vapor space" typically refers to the region above the liquid level within the tank. At times, combustible organics, hydrogen sulfide (H₂S), and/or oxygen may accumulate in the vapor space, causing the potential for fire, explosion, and/or health hazards. Combustible organic gases and/or inorganic gases such as H₂S can potentially lead to fires and/or explosions when exposed to an ignition source and a certain ratio of oxygen. Mechanical equipment located within the vapor space (such as, e.g., rotating skimmers) could possibly generate a spark or

operate at high temperatures and, thus, may pose a fire and/or explosion risk in the presence of oxygen and combustible gases or vapors.

SUMMARY

5 In accordance with an aspect of the present disclosure, there is provided a method for vapor space monitoring and control, the method including monitoring a concentration of oxygen in a vapor space of a closed vessel, and halting operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

10 In some embodiments, monitoring the concentration of oxygen in the vapor space includes removing gas from the vapor space and exposing the gas to an oxygen concentration sensor outside of the vapor space.

 In some embodiments, the method further includes monitoring a concentration of the combustible gas within the vapor space, halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and the concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas.

15 In some embodiments, the method further includes monitoring a concentration of the combustible gas within the vapor space, and halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and the concentration of the combustible gas in the vapor space being above a lower flammability limit and one of below an upper flammability limit or within a predetermined range above the upper flammability limit for the combustible gas.

20 In some embodiments, monitoring the concentration of oxygen and the concentration of the combustible gas in the vapor space includes removing gas from the vapor space, exposing the gas to an oxygen concentration sensor outside of the vapor space, and exposing the gas to a concentration sensor for the combustible gas outside of the vapor space.

25 In some embodiments, the method further includes monitoring concentrations of multiple combustible gases within the vapor space, calculating a lower flammability limit for a combination of the multiple combustible gases, and halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a

predetermined limit below a limiting oxygen concentration for the combination of the multiple combustible gases within the vapor space and the concentrations of the multiple combustible gases in the vapor space being above a predetermined limit below a lower flammability limit for the combination of the multiple combustible gases.

5 In some embodiments, monitoring the concentration of the combustible gas within the vapor space includes monitoring the concentration of a combustible organic gas within the vapor space.

 In some embodiments, monitoring the concentration of the combustible gas within the vapor space includes monitoring the concentration of a combustible inorganic gas within the
10 vapor space.

 In some embodiments, the method further includes monitoring concentrations of multiple combustible gases within the vapor space, and halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a one of the multiple
15 combustible gases having a lowest lower flammability limit among the multiple combustible gases and the concentration of the one of the multiple combustible gases being above a predetermined limit below the lower flammability limit for the one of the multiple combustible gases.

 In some embodiments, the method includes halting operation of the mechanical
20 equipment in the closed vessel responsive to a trend in the concentration of oxygen predicted to bring the concentration of oxygen above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space within a predetermined period of time.

 In some embodiments, halting the operation of the mechanical equipment in the
25 closed vessel includes halting the operation of a skimmer within the closed vessel.

 In some embodiments, the closed vessel includes a dissolved gas flotation system or an API oil water separator system, and the method further includes halting operation of the dissolved gas flotation system or the API oil water separator system responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen
30 concentration for the combustible gas within the vapor space.

 In some embodiments, the method further includes venting the vapor space responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space.

In accordance with another aspect of the present disclosure, a method of retrofitting a closed vessel configured to release a combustible gas into a vent space of the closed vessel is disclosed, the method including installing an oxygen concentration sensor in a location
5 configured to be exposed to gas from the vent space, and programming a control system to monitor the concentration of oxygen in the vapor space with the oxygen sensor and halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

10 In some embodiments, installing the oxygen sensor includes installing the oxygen sensor in a location outside of the vapor space and in fluid communication with the vapor space.

In some embodiments, the method further includes programming the control system to halt the operation of the mechanical equipment responsive to the concentration of oxygen
15 being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and a concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas.

In accordance with another aspect of the present disclosure, a method of retrofitting a
20 group of closed vessels including vent spaces in fluid communication with one another, at least one of the closed vessels configured to release a combustible gas into the vent space of the at least one of the closed vessels is disclosed, the method including fluidically isolating the vent space of the at least one of the closed vessels from vent spaces of any other closed vessels in the group of closed vessels, installing an oxygen concentration sensor in a location
25 configured to be exposed to gas from the vent space of the at least one of the closed vessels, and programming a control system to monitor the concentration of oxygen in the vapor space of the at least one of the closed vessels with the oxygen sensor, and halt operation of mechanical equipment in the at least one of the closed vessels responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a
30 combustible gas within the vapor space of the at least one of the closed vessels.

In some embodiments, the method further includes programming the control system to halt the operation of the mechanical equipment responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the

combustible gas within the vapor space and a concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas.

5 In accordance with another aspect of the present disclosure, a method of facilitating monitoring and control of a vapor space of a closed vessel is disclosed, the method including providing an oxygen concentration sensor and instructions for installing the oxygen concentration sensor in a location in fluid communication with the vapor space of the closed vessel, and providing software for a control system of the closed vessel that when executed by the control system causes the control system to monitor the concentration of oxygen in the
10 vapor space with the oxygen sensor and halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

In accordance with another aspect of the present disclosure, a system is disclosed, the system including a closed vessel configured to house contents which release a combustible
15 gas into a vent space of the closed vessel, an oxygen concentration sensor in fluid communication with gas within the vent space, and a control system configured to monitor the concentration of oxygen in the vapor space with the oxygen sensor and halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for the combustible gas
20 within the vapor space.

Still other aspects, embodiments, and advantages of these example aspects and embodiments, are discussed in detail below. Moreover, it is to be understood that both the foregoing information and the following detailed description are merely illustrative examples of various aspects and embodiments, and are intended to provide an overview or framework
25 for understanding the nature and character of the claimed aspects and embodiments. Embodiments disclosed herein may be combined with other embodiments, and references to “an embodiment,” “an example,” “some embodiments,” “some examples,” “an alternate embodiment,” “various embodiments,” “one embodiment,” “at least one embodiment,” “this and other embodiments,” “certain embodiments,” or the like are not necessarily mutually
30 exclusive and are intended to indicate that a particular feature, structure, or characteristic described may be included in at least one embodiment. The appearances of such terms herein are not necessarily all referring to the same embodiment.

BRIEF DESCRIPTION OF DRAWINGS

Various aspects of at least one embodiment are discussed below with reference to the accompanying figures, which are not intended to be drawn to scale. The figures are included to provide an illustration and a further understanding of the various aspects and embodiments, and are incorporated in and constitute a part of this specification, but are not intended as a definition of the limits of any particular embodiment. The drawings, together with the remainder of the specification, serve to explain principles and operations of the described and claimed aspects and embodiments. In the figures, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every figure. In the figures:

FIG. 1 illustrates one example of a system for vapor space monitoring and control; and

FIG. 2 is a more detailed illustration of some of the components of the system of FIG. 1.

DETAILED DESCRIPTION

Aspects and embodiments disclosed herein pertain to systems and processes to monitor the vapor space of a closed vessel system and control the system accordingly.

More specifically, aspects and embodiments disclosed herein comprise monitoring and controlling operation of moving mechanical equipment within a vapor space of a closed vessel that may include combustible organic gas or gasses and/or combustible inorganic gas or gasses (e.g., H_2S). It may be used in any closed-top tank system or closed vessel system such as, e.g., Dissolved Gas Flotation (DGF) systems, American Petroleum Institute (API) oil water separator systems, etc. Systems and methods disclosed herein may halt, pause, or interlock moving mechanical equipment such as, e.g., a skimmer in a closed vessel if the gas components in the vapor space of the closed vessel are potentially combustible. In some embodiments, the aspects and embodiments disclosed herein utilize both one or more Lower Explosive Limit (LEL) gas monitors in conjunction with one or more oxygen (O_2) sensors.

Conventionally, LEL gas monitors and/or oxygen sensors are used independently in the vapor space of a closed-top tank or closed vessel to detect potentially unsafe levels of combustible organic and/or inorganic gas or gasses. However, combustible organic and/or inorganic gas or gasses alone do not represent a significant explosion hazard, as a certain ratio

of O₂ must also be present for a spark to ignite the combustible gas or gases and cause a fire and/or explosion.

Accordingly, as described above, aspects and embodiments disclosed herein may utilize both one or more Lower Explosive Limit (LEL) gas monitors in conjunction with one or more oxygen (O₂) sensors to monitor the concentrations or partial pressures of both combustible gases and O₂ in the vapor space of a closed vessel. In particular, aspects and embodiments disclosed herein pertain to a system and process to monitor conditions within the vapor space such that when the LEL gas monitor detects combustible gases / H₂S above a predetermined safety threshold, an algorithm is utilized to commence a check on the O₂ level in the vapor space. If both the combustible gas concentration(s) and the O₂ concentration are above predetermined threshold levels (meaning there is a potentially explosive mixture of combustible gases along with unsafe levels of O₂), a control system of the closed-tank or closed vessel system according to aspects and embodiments disclosed herein is configured to take action to stop (i.e., interlock) all rotating or otherwise potential spark generating equipment (e.g., the skimmer, etc.) in the vapor space under the cover of the closed tank or vessel. With the rotating mechanical equipment interlocked based on this algorithm, creation of a spark from such mechanical equipment can be avoided, thereby avoiding a potential fire and/or explosion.

On the other hand, if it determined that either of the combustible gas concentration(s) or the O₂ concentration are below a predetermined threshold, or otherwise do not present a risk of fire or combustion, the control system of the aspects and embodiments disclosed herein is configured to allow the mechanical equipment to continue operation as normal, thereby avoiding “nuisance tripping” (i.e., unnecessary shutdowns) of the system.

FIG. 1 is a highly schematic diagram of a system 100 in accordance with various aspects and embodiments disclosed herein. The system 100 includes a vessel 110 configured to house liquid 120 for either storage or treatment. The vessel 110 may be one used in the oil and gas industry for wastewater treatment to store and/or process various types of wastewater generated during oil and gas operations or may be a municipal wastewater treatment vessel or a location within a sewer system in which combustible gases such as H₂S may be generated or released. The vessel 110 includes a liquid inlet 130 and a liquid outlet 140 (optional valves and pumps associated with the liquid inlet 130 and liquid outlet 140 are omitted from FIG. 1 for clarity). The vessel 110 may be designed for the separation of solids from liquid 120 within the vessel 100 or for separating liquid or dissolved hydrocarbons such as oil or

gaseous hydrocarbons from an aqueous portion of the liquid 120 within the vessel. The vessel 110 may be equipped with mechanical or pneumatic equipment such as a dissolved air flotation system 150 (illustrated highly schematically in FIG. 1) and /or a skimmer including a motor 160 that drives a plurality of skimmer flights 170 to direct waste from the surface of the liquid 120 in the vessel 110 into, for example, a waste collection chamber 180. The vessel 110 includes an area 190 above the surface of the liquid 120 referred to as a vapor space 190 herein. Combustible organic and/or inorganic gases may evolve from the liquid 120 and enter the vapor space 190. If the vessel 110 is closed the combustible organic and/or inorganic gases may accumulate in the vapor space 190 where they may pose a fire or explosion risk, especially if oxygen is also present in the vapor space 190.

Even if the vessel 110 is not hermetically sealed, or if it has a leak, for the purposes of this disclosure it may still be considered “closed” if it provides for the accumulation of potentially dangerous concentrations of combustible gas or gases and oxygen. In some embodiments, for example, oxygen may enter the vessel through a leak from the external atmosphere but the vessel may still be considered closed.

The vessel 110 may be equipped with vapor space monitoring and control system 200, indicated highly schematically in FIG. 1. The vapor space monitoring and control system 200 may monitor the concentrations of a combustible gas or gasses and/or oxygen in the vapor space 190. The vapor space monitoring and control system 200 may be in communication with a controller 210 that may also be in communication with mechanical or pneumatic equipment such as a dissolved air flotation system 150 and/or a skimmer within the vessel 110 or within the vapor space 190 of the vessel 110. If the vapor space monitoring and control system 200 detects a potentially unsafe concentration of one or more gases in the vapor space 190, it may provide a measurement signal to the controller 210 and the controller may automatically pause or halt operation of potential spark producing equipment within the vessel 100, for example, the skimmer may halt and/or pause operation of equipment within the vessel 100 that may be contributing to increasing the concentration of the one or more gases in the vapor space 190, for example, the dissolved air flotation system 150. The controller 210 may also provide a warning regarding the potentially unsafe concentration of the gas or gases within the vapor space to a user or operator of the system, for example, through a network such as the internet 220.

FIG. 2 schematically illustrates components of an example of a vapor space monitoring and control system 200 as disclosed herein. The vapor space monitoring and

control system 200 may be mounted on or coupled to a wall of the vessel 110. Components of the vapor space monitoring and control system 200 include a pump 230, for example, a SM5000 Sampling Module available from MSA Safety that pulls gas from the vapor space 190 of the vessel 110 through a supply line 240 in fluid communication with the vapor space 190, and pumps the gas through the sampling loop of the vapor space monitoring and control system 200. The sampling loop of the vapor space monitoring and control system 200 includes an oxygen concentration sensor 250 and a combustible gas concentration sensor 260. In some embodiments, the oxygen concentration sensor 250 may be, for example, the XCELL® Oxygen (O₂) Sensor from MSA Safety. The combustible gas concentration sensor 260 may be sensitive to or specific to the most dangerous combustible gas (e.g., the gas with the lowest flammability limit) expected to be present in the vapor space 190, for example, an organic gas such as methane or propane or an inorganic gas such as H₂S. The gas concentration sensor 260 may alternatively be a sensor capable of detecting or monitoring the concentrations of multiple different gases simultaneously, for example, the ULTIMA® X5000 Gas Monitor from MSA Safety. Gas from the vapor space 190 is pumped by the pump 230 through the oxygen concentration sensor 250 and the combustible gas concentration sensor 260. After passing through the oxygen concentration sensor 250 and the combustible gas concentration sensor 260 the gas flows back into the vapor space 190 through return line 280.

In some embodiments, the vapor space monitoring and control system 200 may further include a condensation knockout system configured to trap and/or remove liquids and/or other foreign materials from the gas stream entering and exiting the pump 230, the oxygen concentration sensor 250, and/or the gas concentration sensor 260. For example, the condensation knockout system may include a first desiccant air dryer/filter 290 fluidly coupled to the supply line 240 upstream of the pump 230, along with a first air separator 310 positioned upstream of the first desiccant air dryer/filter 290. Additionally and/or alternatively, a second desiccant air dryer/filter 300 may be fluidly coupled to the return line 280, along with a second air separator 320 positioned downstream of the second desiccant air dryer/filter 300. These features of the condensation knockout system may act to collect and drain any condensation or other liquid that may be present in the supply line 240 and/or return line 280 of the vapor space monitoring and control system 200.

Each of the oxygen concentration sensor 250 and the gas concentration sensor 260 are in communication (wired or wirelessly) with an electronics module 270. The electronics

module 270 may receive signals from the oxygen concentration sensor 250 and the combustible gas concentration sensor 260 regarding the measured concentrations of oxygen or one or more combustible gases in the vapor space 190. The electronics module 270 may include a controller such as controller 210 of FIG. 1 and may operate to control operation of
5 mechanical equipment within the vessel 110 responsive to measured concentrations of oxygen and/or one or more combustible gases from the oxygen concentration sensor 250 and/or the combustible gas concentration sensor 260. The electronics module 270 may additionally or alternatively include a data transmitter, for example, an X5000 transmitter from MSA Safety that may transmit signals regarding the measured concentrations of
10 oxygen and/or one or more combustible gases to a remotely located controller, for example, through a wireless cellular signal or via a network such as the internet 220 as illustrated in FIG. 1.

The controller may be implemented using one or more computer systems which may be, for example, a general-purpose computer such as those based on an Intel® CORE™-type
15 processor, a Motorola PowerPC® processor, a Hewlett-Packard PA-RISC® processor, a Sun UltraSPARC® processor, or any other type of processor or combination thereof. Alternatively, the computer system may include specially-programmed, special-purpose hardware, for example, an application-specific integrated circuit (ASIC), a programmable logic controller (PLC), or another form of controller intended for water treatment systems.

20 The computer system can include one or more processors typically connected to one or more memory devices, which can comprise, for example, any one or more of a disk drive memory, a flash memory device, a RAM memory device, or other device for storing data. The memory may be used for storing programs and data during operation of the system. For example, the memory may be used for storing historical data relating to the parameters over a
25 period of time, as well as operating data. Software, including programming code that implements embodiments as disclosed herein, can be stored on a computer readable and/or writeable nonvolatile recording medium, and then copied into memory wherein it can then be executed by one or more processors. Such programming code may be written in any of a plurality of programming languages, for example, Java, Visual Basic, C, C#, or C++, Fortran,
30 Pascal, Eiffel, Basic, or any of a variety of combinations thereof.

Components of the computer system may be coupled by one or more interconnection mechanisms, which may include one or more busses, e.g., between components that are integrated within a same device, and/or a network, e.g., between components that reside on

separate discrete devices. The interconnection mechanism may enable communications, e.g., data and/or instructions, to be exchanged between components of the system.

The computer system can also include one or more input devices, for example, a keyboard, mouse, trackball, microphone, touch screen, and other man-machine interface
5 devices as well as one or more output devices, for example, a printing device, display screen, or speaker. In addition, the computer system may contain one or more interfaces that can connect the computer system to a communication network, in addition or as an alternative to the network that may be formed by one or more of the components of the system.

According to one or more embodiments, the one or more input devices may include
10 the previously described oxygen concentration sensor 250 and/or combustible gas concentration sensor 260 for measuring concentrations of one or more gases in the vapor space 190 of the vessel 110. Alternatively, the sensors, and/or other components of the system, such as valves and pumps, may all be connected to a communication network that is operatively coupled to the computer system. Any one or more of the above may be coupled
15 to another computer system or component to communicate with the computer system over one or more communication networks. Such a configuration permits any sensor or signal-generating device to be located at a significant distance from the computer system and/or allow any sensor to be located at a significant distance from any subsystem and/or the controller, while still providing data therebetween. Such communication mechanisms may be
20 affected by utilizing any suitable technique including but not limited to those utilizing wireless protocols.

The controller can include one or more computer storage media such as readable and/or writeable nonvolatile recording medium in which signals can be stored that define a program to be executed by one or more processors. The medium may, for example, be a disk
25 or flash memory. In typical operation, the one or more processors can cause data, such as code that implements one or more embodiments of the invention, to be read from the storage medium into a memory that allows for faster access to the information by the one or more processors than does the medium.

Although the computer system is described by way of example as one type of
30 computer system upon which various aspects and embodiments may be practiced, it should be appreciated that the aspects and embodiments disclosed herein are not limited to being implemented in software, or on the computer system as described. Indeed, rather than implemented on, for example, a general-purpose computer system, the controller, or

components or subsections thereof, may alternatively be implemented as a dedicated system or as a dedicated programmable logic controller (PLC) or in a distributed control system.

Further, it should be appreciated that one or more features or aspects may be implemented in software, hardware or firmware, or any combination thereof. For example, one or more
5 segments of an algorithm executable by the controller can be performed in separate computers, which can be in communication with one another through one or more networks.

As described above, a vapor space monitoring and control system as disclosed herein may include at least an oxygen concentration sensor in fluid communication with gas within a vapor space of a closed vessel configured to house contents which release a combustible gas
10 into the vapor space of the closed vessel and a control system (also referred to as a controller herein) configured to monitor the concentration of oxygen in the vapor space with the oxygen sensor and halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for the combustible gas within the vapor space. In some embodiments, the
15 predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space may be about 5%, about 10%, about 15% or less than the limiting oxygen concentration for the combustible gas within the vapor space. In other embodiments, the concentration of oxygen within the vapor space that may cause the control system to generate an alarm or to halt operation of the mechanical equipment in the closed vessel may be set at a
20 fixed minimum concentration, for example, a partial pressure of 1% or greater, 2% or greater, 5% or greater, 10% or greater, or any other concentration suitable based on the expected type(s) of combustible gas or gases expected to be present in the vessel 110.

In some embodiments, it is assumed that the concentration of one or more combustible gases in the vapor space of a vessel will be above a dangerous level at which
25 combustion may occur and control of the mechanical equipment in the vessel may be based on the measured oxygen concentration only. The combustible gas concentration sensor 260 may thus be utilized as a back up or omitted from the vapor space monitoring and control system 200.

In other embodiments, control of the mechanical equipment in the vessel may be
30 based on the measured oxygen concentration in addition to the measured concentration of the one or more combustible gases. In addition to the concentrations of oxygen noted above that may trigger the control system to generate an alarm or to halt operation of the mechanical equipment in the closed vessel, a concentration of the one or more combustible gasses that

may cause the control system to generate an alarm or to halt operation of the mechanical equipment in the closed vessel may be about 5%, about 10%, about 15% or less than the lower flammability limit for the one or more combustible gases. Additionally or alternatively a concentration of the one or more combustible gasses in the vapor space that may cause the control system to generate an alarm or to halt operation of the mechanical equipment in the closed vessel, if measured alone or in combination with the concentrations of oxygen noted above, may be above the lower flammability limit for the one or more combustible gases and less than about 5%, about 10%, about 15%, or more above an upper flammability limit for the one or more combustible gases.

Aspects and embodiments of a vapor space monitoring and control system as disclosed herein may be configured to or be programmed to perform a method for vapor space monitoring and control. The method may include monitoring a concentration of oxygen in a vapor space of a closed vessel and halting operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space. As noted above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space may be set at about 5%, about 10%, about 15% or less than the limiting oxygen concentration for the combustible gas within the vapor space.

Monitoring the concentration of oxygen in the vapor space may include removing gas from the vapor space and exposing the gas to an oxygen concentration sensor outside of the vapor space.

The method may further comprise monitoring a concentration of the combustible gas within the vapor space and halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and the concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas. As noted above, predetermined limit for the combustible gas may be about 5%, about 10%, about 15% or less than the lower flammability limit for the combustible gas.

In an alternative embodiment, the method may further comprise halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and the concentration of the combustible gas in the

vapor space being above a lower flammability limit and one of below an upper flammability limit or within a predetermined range above the upper flammability limit for the combustible gas.

Monitoring the concentration of oxygen and the concentration of the combustible gas
5 in the vapor space may include removing gas from the vapor space, exposing the gas to an oxygen concentration sensor outside of the vapor space, and exposing the gas to a concentration sensor for the combustible gas outside of the vapor space.

In some embodiments, the method may comprise monitoring concentrations of multiple combustible gases within the vapor space, calculating a lower flammability limit for
10 a combination of the multiple combustible gases, and halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for the combination of the multiple combustible gases within the vapor space and the concentrations of the multiple combustible gases in the vapor space being above a predetermined limit below a lower
15 flammability limit for the combination of the multiple combustible gases.

In some embodiments, instead of or in addition to monitoring the concentration of the combustible gas with a concentration sensor disposed outside of the vapor space, the concentration of the combustible gas in the vapor space may be monitored with a concentration sensor disposed within the vapor space. Additionally or alternatively, in some
20 embodiments, the concentration of oxygen in the vapor space may be monitored with an oxygen concentration sensor disposed within the vapor space.

The combustible gas may be an organic gas such as a hydrocarbon or an inorganic gas such as H₂S.

The method may further comprise monitoring concentrations of multiple combustible
25 gases within the vapor space and halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a one of the multiple combustible gases having a lowest lower flammability limit among the multiple combustible gases and the concentration of the one of the multiple combustible gases being above a predetermined limit below the lower
30 flammability limit for the one of the multiple combustible gases.

In some embodiments the vapor space monitoring and control system may halt operation of the mechanical equipment prior to the concentration of oxygen and/or combustible gas within the vapor space reaching hazardous levels by monitoring trends in

these gas concentrations and halting operation of the mechanical equipment in the closed vessel responsive to a trend in the concentration of oxygen predicted to bring the concentration of oxygen above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space within a predetermined period of time.

As discussed above, halting the operation of the mechanical equipment in the closed vessel may include halting the operation of a skimmer within the closed vessel, although the mechanical equipment is not limited to being a skimmer but may be any form of equipment, for example, an electric motor, a filter cleaner/scrapper, a moving chain, rotating shaft, etc., that may be capable of generating a spark or causing heat above an auto-ignition temperature that could cause ignition of the combustible gas in the vapor space.

In other embodiments the closed vessel includes a dissolved gas flotation system that may be considered the mechanical equipment and the method may further comprise halting operation of the dissolved gas flotation system responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space. Halting operation of the dissolved gas flotation system may stop or reduce a rate at which combustible gas evolves from the liquid in the vessel and may allow the concentration of the combustible gas in the vapor space to decrease over time to levels considered safer.

In some embodiments, the concentration of combustible gas and/or oxygen in the vapor space may be reduced to safer levels below the predetermined levels discussed above by venting the vapor space responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and/or responsive to the one or more combustible gases being above or within the limits described above.

Aspects and embodiments disclosed herein also contemplate a method of retrofitting a closed vessel configured to release a combustible gas into a vent space of the closed vessel. The method may include installing an oxygen concentration sensor in a location configured to be exposed to gas from the vent space and programming a control system to monitor the concentration of oxygen in the vapor space with the oxygen sensor and halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

The oxygen concentration sensor may be installed in a location outside of the vapor space and in fluid communication with the vapor space.

The control system may be programmed to halt the operation of the mechanical equipment responsive to the concentration of oxygen being above the predetermined limit
5 below the limiting oxygen concentration for the combustible gas within the vapor space and a concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas.

Aspects and embodiments disclosed herein also contemplate a method of retrofitting a group of closed vessels including vent spaces in fluid communication with one another, at
10 least one of the closed vessels configured to release a combustible gas into the vent space of the at least one of the closed vessels. The method may include fluidically isolating the vent space of the at least one of the closed vessels from vent spaces of any other closed vessels in the group of closed vessels, installing an oxygen concentration sensor in a location configured to be exposed to gas from the vent space of the at least one of the closed vessels,
15 and programming a control system to monitor the concentration of oxygen in the vapor space of the at least one of the closed vessels with the oxygen sensor and halt operation of mechanical equipment in the at least one of the closed vessels responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space of the at least one of the closed vessels.

20 The control system may be further or alternatively programmed to halt the operation of the mechanical equipment responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and a concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas.

25 Aspects and embodiments disclosed herein also contemplate a method of facilitating monitoring and control of a vapor space of a closed vessel. The method may include providing an oxygen concentration sensor and instructions for installing the oxygen concentration sensor in a location in fluid communication with the vapor space of the closed vessel and providing software for a control system of the closed vessel that when executed by
30 the control system causes the control system to monitor the concentration of oxygen in the vapor space with the oxygen sensor and halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

The aspects and embodiments disclosed are not limited in their application to the details of construction and the arrangement of components set forth in the following description or illustrated in the accompanying drawings. These aspects are capable of assuming other embodiments and of being practiced or of being conducted in various ways.

- 5 Examples of specific implementations are provided herein for illustrative purposes only and are not intended to be limiting. In particular, acts, components, elements, and features discussed in connection with any one or more embodiments are not intended to be excluded from a similar role in any other embodiments.

- Also, the phraseology and terminology used herein is for the purpose of description
10 and should not be regarded as limiting. Any references to examples, embodiments, components, elements or acts of the systems and methods herein referred to in the singular may also embrace embodiments including a plurality, and any references in plural to any embodiment, component, element or act herein may also embrace embodiments including only a singularity. References in the singular or plural form are not intended to limit the
15 presently disclosed systems or methods, their components, acts, or elements. The use herein of “including,” “comprising,” “having,” “containing,” “involving,” and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. References to “or” may be construed as inclusive so that any terms described using “or” may indicate any of a single, more than one, and all of the described terms. In addition,
20 in the event of inconsistent usages of terms between this document and documents incorporated herein by reference, the term usage in the incorporated reference is supplementary to that of this document; for irreconcilable inconsistencies, the term usage in this document controls.

- Having thus described several aspects of at least one example, it is to be appreciated
25 that various alterations, modifications, and improvements will readily occur to those skilled in the art. For instance, examples disclosed herein may also be used in other contexts. Such alterations, modifications, and improvements are intended to be part of this disclosure and are intended to be within the scope of the examples discussed herein. Accordingly, the foregoing description and drawings are by way of example only.

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What is claimed is:

CLAIMS

1. A method for vapor space monitoring and control, the method comprising:
monitoring a concentration of oxygen in a vapor space of a closed vessel; and
5 halting operation of mechanical equipment in the closed vessel responsive to the
concentration of oxygen being above a predetermined limit below a limiting oxygen
concentration for a combustible gas within the vapor space.
2. The method of claim 1, wherein monitoring the concentration of oxygen in the vapor
10 space includes removing gas from the vapor space and exposing the gas to an oxygen
concentration sensor outside of the vapor space.
3. The method of claim 1, further comprising:
monitoring a concentration of the combustible gas within the vapor space; and
15 halting operation of the mechanical equipment in the closed vessel responsive to the
concentration of oxygen being above the predetermined limit below the limiting oxygen
concentration for the combustible gas within the vapor space and the concentration of the
combustible gas in the vapor space being above a predetermined limit below a lower
flammability limit for the combustible gas.
20
4. The method of claim 1, further comprising:
monitoring a concentration of the combustible gas within the vapor space; and
halting operation of the mechanical equipment in the closed vessel responsive to the
concentration of oxygen being above the predetermined limit below the limiting oxygen
25 concentration for the combustible gas within the vapor space and the concentration of the
combustible gas in the vapor space being above a lower flammability limit and one of below
an upper flammability limit or within a predetermined range above the upper flammability
limit for the combustible gas.
- 30 5. The method of claim 4, wherein monitoring the concentration of oxygen and the
concentration of the combustible gas in the vapor space includes:
removing gas from the vapor space;
exposing the gas to an oxygen concentration sensor outside of the vapor space; and

exposing the gas to a concentration sensor for the combustible gas outside of the vapor space.

6. The method of claim 4, further comprising:
- 5 monitoring concentrations of multiple combustible gases within the vapor space; calculating a lower flammability limit for a combination of the multiple combustible gases; and
- halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen
- 10 concentration for the combination of the multiple combustible gases within the vapor space and the concentrations of the multiple combustible gases in the vapor space being above a predetermined limit below a lower flammability limit for the combination of the multiple combustible gases.
- 15 7. The method of claim 4, wherein monitoring the concentration of the combustible gas within the vapor space includes monitoring the concentration of a combustible organic gas within the vapor space.
8. The method of claim 4, wherein monitoring the concentration of the combustible gas
- 20 within the vapor space includes monitoring the concentration of a combustible inorganic gas within the vapor space.
9. The method of claim 4, further comprising:
- monitoring concentrations of multiple combustible gases within the vapor space; and
- 25 halting operation of the mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a one of the multiple combustible gases having a lowest lower flammability limit among the multiple combustible gases and the concentration of the one of the multiple combustible gases being above a predetermined limit below the lower flammability limit for
- 30 the one of the multiple combustible gases.
10. The method of claim 1, further comprising halting operation of the mechanical equipment in the closed vessel responsive to a trend in the concentration of oxygen predicted

to bring the concentration of oxygen above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space within a predetermined period of time.

5 11. The method of claim 1, wherein halting the operation of the mechanical equipment in the closed vessel includes halting the operation of a skimmer within the closed vessel.

12. The method of claim 1, wherein the closed vessel includes a dissolved gas flotation system or an API oil water separator system, and the method further comprises halting
10 operation of the dissolved gas flotation system or the API oil water separator system responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space.

13. The method of claim 1, further comprising venting the vapor space responsive to the
15 concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space.

14. A method of retrofitting a closed vessel configured to release a combustible gas into a vent space of the closed vessel, the method comprising:
20 installing an oxygen concentration sensor in a location configured to be exposed to gas from the vent space; and
programming a control system to:
monitor the concentration of oxygen in the vapor space with the oxygen
sensor; and
25 halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

15. The method of claim 14, wherein installing the oxygen sensor includes installing the
30 oxygen sensor in a location outside of the vapor space and in fluid communication with the vapor space.

16. The method of claim 14, further comprising programming the control system to halt the operation of the mechanical equipment responsive to the concentration of oxygen being above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and a concentration of the combustible gas in the vapor space
5 being above a predetermined limit below a lower flammability limit for the combustible gas.

17. A method of retrofitting a group of closed vessels including vent spaces in fluid communication with one another, at least one of the closed vessels configured to release a combustible gas into the vent space of the at least one of the closed vessels, the method
10 comprising:
fluidically isolating the vent space of the at least one of the closed vessels from vent spaces of any other closed vessels in the group of closed vessels;
installing an oxygen concentration sensor in a location configured to be exposed to gas from the vent space of the at least one of the closed vessels; and
15 programming a control system to:
monitor the concentration of oxygen in the vapor space of the at least one of the closed vessels with the oxygen sensor; and
halt operation of mechanical equipment in the at least one of the closed vessels responsive to the concentration of oxygen being above a predetermined limit below a
20 limiting oxygen concentration for a combustible gas within the vapor space of the at least one of the closed vessels.

18. The method of claim 17, further comprising programming the control system to halt the operation of the mechanical equipment responsive to the concentration of oxygen being
25 above the predetermined limit below the limiting oxygen concentration for the combustible gas within the vapor space and a concentration of the combustible gas in the vapor space being above a predetermined limit below a lower flammability limit for the combustible gas.

19. A method of facilitating monitoring and control of a vapor space of a closed vessel,
30 the method comprising:
providing an oxygen concentration sensor and instructions for installing the oxygen concentration sensor in a location in fluid communication with the vapor space of the closed vessel; and

providing software for a control system of the closed vessel that when executed by the control system causes the control system to:

monitor the concentration of oxygen in the vapor space with the oxygen sensor; and

5 halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for a combustible gas within the vapor space.

20. A system comprising:

10 a closed vessel configured to house contents which release a combustible gas into a vent space of the closed vessel;

 an oxygen concentration sensor in fluid communication with gas within the vent space; and

 a control system configured to:

15 monitor the concentration of oxygen in the vapor space with the oxygen sensor; and

 halt operation of mechanical equipment in the closed vessel responsive to the concentration of oxygen being above a predetermined limit below a limiting oxygen concentration for the combustible gas within the vapor space.

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