

METHOD AND APPARATUS FOR REMOVAL OF HAZARDOUS
GASES FROM ENCLOSED STRUCTURES

This invention relates to a method and apparatus for scrubbing gases, or stripping liquids, containing hazardous materials such as ethylene dichloride and hydrogen sulfide from the enclosed confines of storage tanks or other vessels, and more particularly to such a method and mobile apparatus for rendering these enclosed spaces safe for human entry without extraneous safety equipment while preventing contamination of the environment.

Petroleum products, particularly crude oil, are stored in tanks, many of which are very large, holding as much as 500,000 barrels of crude oil. Such tanks may exceed 250 feet in diameter. Crude oil stored in these tanks deposit sludges which accumulate on the bottom of the tanks, resulting in operational problems and diminished volumetric capacity. Several methods have been devised to agitate or circulate the contents of the tanks, simplify the cleaning of these tanks and the removal of accumulated sludges from the tanks. For example, such methods and equipment are described in U.S. Patents 4,945,933, 4,817,653, 5,091,016, 5,460,331 and 4,407,678. While each of these patents describes successful means for handling the sludges in various ways, another problem has existed with respect to sour crude oil storage that is not addressed by any of the aforementioned art and, yet, creates an extremely hazardous situation for ultimate cleaning of storage tanks, requiring the entry of work people into the tanks. This problem is the accumulation of dangerous hydrogen sulfide gas and for carcinogen benzene vapors in the

tank.

An environmental concern has also developed in connection with soils contaminated with volatile hazardous chlorinated hydrocarbon gases, such as ethylene dichloride. Often the only solution for containment of the solids contaminated with ethylene dichloride in a benign manner is by using an enclosed storage tank as a holding vessel for such contaminated soils. As the soil lies in the tank, the volatile ethylene dichloride permeates the atmosphere within the tank, creating a dangerous situation of proportions equal to that of the hydrogen sulfide invasion of the contained atmosphere of a hydrocarbon storage tank.

Additionally, the entry of a worker into an atmosphere of ethylene dichloride requires care equal to that of the care required in an atmosphere invaded by hydrogen sulfide. Many attempts have been made to avoid the necessity of entry into such tanks which burdens the worker by the necessity of wearing heavy, hot and cumbersome equipment to the extent that efficiency is lost and dangerous, life threatening work situations occur, particularly in the enclosed tank atmosphere during hot periods, such as summer along the Texas and Louisiana Gulf Coast where many such tanks exist.

Because of continued governmental regulations, such as the United States Resource Conservation and Recovery Act (RCRA) and the United States Hazardous and Solid Waste Amendment of 1984 (HSWA), which establish comprehensive "cradle to grave" provisions to regulate hazardous materials, there is an increased need of the efficient

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removal of volatile compounds from solid materials and enclosed environments.

The ethylene dichloride problem is particularly troublesome since it is a material which, when contaminating soil, must be removed but, without adequate means of containment, becomes a complicated environmental problem. Soil contaminated with ethylene dichloride also presents a threat to the water supply. Since benzene, ethylene dichloride and the chlorinated hydrocarbons are somewhat water soluble, they leach from surface soil into progressively deeper areas of soil and ultimately end up in lakes and streams. Therefore, the contamination to be contained must be separated from the possibility of leaching caused by natural circumstances such as rain and weather. However, when so protected by putting it into closed containers, such as large storage tanks, the vapor pressure of VOCs and ethylene dichloride at elevated temperatures increases to the point where the entire atmosphere within such storage vessel is, in short time, permeated with the hazardous gas mixture.

Further, the captivity of such hazardous gases within the vapor atmosphere of such storage tanks creates a hazard in the neighborhood of such tanks because of the expansion and contraction of gases with changes in ambient temperature. A temperature rise causes the gases to exit through vents into the surrounding area and, while attempts are made to contain such exposure to gases, such as hydrogen sulfide and ethylene dichloride, through absorption in carbon canisters on such vents, high concentrations of such materials quickly saturate

the carbon bed and cause breakthroughs into the surrounding area creating hazards of health and fire for even a slightly careless act.

One aspect of this invention is to provide for the removal of hazardous gases from the interior of closed vessels, particularly storage tanks, without requiring the entry of workers into the vessel and without causing atmospheric contamination.

The present invention, therefore, provides a method for capturing hazardous gases having water solubility from containment vessels including the steps of withdrawing hazardous gases from the vessel, introducing the gases into lower regions of a scrubbing zone, contacting the rising gases with sufficient water in counter-current flow to capture such hazardous gases in a water stream and create a gas stream having a substantially reduced content of hazardous gas, recycling the gas stream to the vessel to sweep additional hazardous gases from the vessel, withdrawing the water stream and dissolved hazardous gases from the scrubbing zone, diluting the water stream with additional water to create a recycle stream having a lowered concentration of absorbed hazardous gases and a bottoms stream, returning the recycle stream to the scrubbing zone, and removing the absorbed hazardous gas from the bottoms stream for disposal.

The present invention is also directed to overcoming the problems set forth above by providing an apparatus for effectively removing undesirable, water soluble compounds from a gas, without requiring the entry of

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workers into a vessel in which the gas is contained. It is also desirable to have such an apparatus that is mobile, and can be moved from site-to-site, as needed, to remove contaminate materials from the enclosed environment of a storage tank. Furthermore, it is desirable to have a mobile apparatus capable of separating water soluble hazardous materials from a gaseous mixture enclosed within a storage tank, and then recirculating the cleaned gases to the tank to sweep additional hazardous materials from the tank.

The present invention is, therefore, also directed to a mobile apparatus for promoting gas/liquid mass transfer, including a mobile frame, a tower containing a packed bed pivotally mounted on said mobile frame for movement between a horizontal transport position to a vertical operating position, said tower having an upper end portion and a lower end portion when disposed at said vertical operating position, means for moving said tower between said horizontal transport position and said vertical operating position, means for maintaining said tower at said vertical operating position, means for receiving and distributing gas upwardly through said tower when the tower is in said vertical operating position, and means for receiving and distributing water downwardly through the packing of said tower when the tower is in said vertical operating position.

Further features and advantages of the invention will become more apparent from the following description taken in conjunction with the accompanying drawings, wherein:

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Fig. 1 is a schematic flow diagram showing in schematic form the preferred embodiment of the method of this invention with gauges, valves and fittings not shown. Also, this drawing shows, within the area defined by broken lines, the principal elements of the mobile apparatus embodying the present invention in which hazardous gases are removed from enclosed structures;

Fig. 2 is a perspective view of a mobile apparatus, defined within the area enclosed by broken lines in Fig. 1, representing a preferred embodiment of the present invention;

Fig. 3 is a side elevation view of the mobile apparatus of the preferred embodiment of the present invention, showing the scrubbing tower in a horizontal traveling position and, in broken lines, in a vertical operating position;

Fig. 4 is a side view of the scrubbing tower and the cradle which support the scrubbing tower;

Fig. 5 is a sectional top view of the tower cradle taken along the line 5-5 in Fig. 4;

Fig. 6 is a cross-sectional view of the scrubbing tower and its supporting cradle taken along the line 6-6 in Fig. 4;

Fig. 7 is a cross-sectional view of the scrubbing tower and the supporting cradle taken along the line 7-7 in Fig. 4;

Fig. 8 is an enlarged detailed sectional view of the tower side support structure, taken from the dashed circle 8 in Fig. 7;

Fig. 9 is an enlarged detailed schematic view of the

cylinder connection portion of the pivot arm used to lift the scrubbing tower, taken from the dashed circle 9 in Fig. 4; and

Fig. 10 is a cross-sectional schematic view of the cylinder connection of the pivot arm taken along the line 10-10 of Fig. 9.

This invention relates primarily to the decontamination of the interior headspace of vessels containing a hazardous gas atmosphere which includes gases which have water solubility, particularly hazardous chlorinated hydrocarbons and, especially benzene, hydrogen sulfide or ethylene dichloride, which permeate the area of inside of storage tanks and, if allowed to invade the atmosphere surrounding such tanks, create a condition hazardous to people in the vicinity of the tank. A number of chlorinated hydrocarbons are volatile and, at the same time, soluble to some extent in water. These gases often find their way into the environment through a spill or leak of one kind or another. Since they have water solubility, they may be transported into an aquifer and subsequently into drinking water. They often are also volatile and, thus, become part of the air pollution problem if they remain unchecked. Consequently, a spill or contamination of soil of this nature must be physically scooped up and placed in a container, often an empty hydrocarbon storage tank. Since the chlorinated hydrocarbon and, especially ethylene dichloride, may be volatile and since tanks are subject to wide ranges of temperatures by virtue of the sun's impact upon their skins, a contaminated atmosphere

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is created inside of the storage vessels or tanks, which atmosphere is dangerous and difficult to abate. Of course, the tank cannot become permanent storage for this contaminated soil. In the broad sense, this invention is a method to clean the atmosphere inside storage tanks to permit entry by workers in order to clean the tank. In a specific sense, the process of this invention is a method to reduce the danger of soil contaminated with chlorinated hydrocarbons, especially ethylene dichloride to allow the proper disposal of such soil in a permitted land fill. To be effective, this method requires that the hazardous gas have water solubility. It does not have to be infinitely water soluble, but the scrubbing is carried out with water and, therefore, to be operable, requires water solubility. For example, the removal of ethylene dichloride, hydrogen sulfide and benzene have sufficient solubility to allow economic operation of the method.

The description of the method of this invention which follows is better understood by reference to the flow diagram shown in Fig. 1 as examples of an embodiment of the invention described herein. The description which follows includes in it the best mode for practicing the invention known to the inventors. It will illustrate both the evacuation of the interior headspace of a vessel using a storage tank as the exemplary structure, either from the vaporization of stored sour crude oil or through the removal of ethylene dichloride from soil.

The gaseous atmosphere being treated in the process of this invention is captive in the headspace of a

containment vessel shown in Figure 1 as storage tank 22. A mobile mass transfer apparatus 20 embodying the apparatus of the invention includes the components enclosed within the dashed line in Fig. 1 will be further described later. In the embodiment where a crude oil storage tank is being decontaminated, the hazardous gas the tank atmosphere would normally be hydrogen sulfide and to a lesser extent, benzene. Where ethylene dichloride contaminated soil is involved, the hazardous gas is ethylene dichloride. The gas within the atmosphere of storage tank 22 is removed through line 24 to a blower 26 which places a suction on tank 22, thus reducing the interior pressure of the tank to below atmospheric pressure. The size and make of the blower 26 is a matter of engineering choice.

In an illustrative embodiment, the blower 26 is a Dresser Industries, Roots Division, Model RGS-JV size 624 driven by a 75 horsepower diesel engine. The blower 26 preferably operates at a variable speed for from about 1100 to about 2100 rpm. Smaller blowers, such as the Model RAIU size 718 blower, are also available and, depending on the desired gas flow rates, also may be used in the present invention. If stripping a hazardous or volatile organic compound from water the inlet of the blower may draw in fresh or ambient air or another gas.

Depending upon the size and capacity of the blower, a vacuum can be drawn on the tank to the extent of several inches of water with the preferred amount being about -1 psig. A preferred range would be from about 0.5 to about 2 psig negative pressure. To affirmatively

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protect the surrounding vicinity of the vessel, a subatmospheric pressure must be maintained. It should be sufficiently below atmospheric pressure to accommodate temperature fluctuations. Of course, a normal storage tank could collapse with the drawing too great of a vacuum on the tank. This negative atmosphere accomplishes the purpose of maintaining a safe atmosphere in the environment surrounding tank 22 to prevent the hazardous gases from exiting through the vent system of the tank (not shown) which occurs when the pressure inside the tank exceeds that of the atmospheric pressure outside tank 22.

The vapors from the atmosphere of tank 22 passing through blower 26 creates a contaminated gas stream which enters line 28 at a superatmospheric pressure of from 3 to about 6 psig, preferably from 4 to 5 psig, and is conducted from there to a scrubber 30 where it is introduced into lower regions of the scrubbing zone 32 at the lower end of scrubbing zone 32 through a means for distributing the gas at the bottom of scrubbers, such as a perforated pipe distributor or sparger 34. The vapors containing the hazardous gas flow upwardly through the scrubber 30, preferably through water-flooded packing P to contact, in counter-current flow, water entering the upper part of scrubber 30 through line 36 and appropriate distributors 38 to uniformly flood packing P. The distributor 38 may be any such structure well known to the skilled engineer, such as, for example, trays, wire boxes or spray nozzles. The gases entering the scrubber 30 are allowed to expand on entering the scrubbing zone

32, thus causing the gases to cool somewhat and increasing the solubility of such gases in the scrubbing water flowing through packing P.

Although a mobile scrubbing tower has been employed in the practice of this invention as a way of keeping the environment around storage tanks clear of hazardous gases and fumes, the scrubber 30 may be designed as a permanent installation connected to a plurality of storage tanks creating subatmospheric pressure in several of them while continually collecting hazardous gases as they are released within the tanks themselves, where the cleanup problem reoccurs with such frequency that a permanent installation is justified.

The solubility of chlorinated hydrocarbons (and other hazardous gases) in water is available in readily available handbooks. Ethylene dichloride has a maximum solubility at 25°C of one part by weight per 128 parts by weight of water (about 8% by weight). This is calculated by the saturation of its water, the ratio of water/gas can be calculated. At lower temperatures, the solubility is greater, resulting in more efficient removal of ethylene dichloride from the gas stream. Thus, the comparable flow rates and residence time can be easily calculated and adjusted by the skilled engineer to provide sufficient contact to remove the ethylene dichloride. In the operation of the method of this invention,, of course the exiting vapors have substantially reduced content of hazardous gas, here ethylene dichloride, but will contain some ethylene dichloride, depending upon the amount of water contact

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and the temperature of the contact. During scrubbing operations the water level in the tower is preferably maintained at a level of from about 10% to about 60% of the scrubber height, preferably from 25% to 50%. In the practice of this invention, it is not necessary to remove all of the ethylene dichloride from the vapor where the vapor is returned to the tank. If not returned, carbon canisters may do the polishing. The flow rate of the water entering scrubber 30 through line 36 is from about 100 to about 300 gallons per minute and, preferably, from about 225 to about 275 gpm. Of course, this will vary with the design size of the scrubber 30 and the loading of the vapors entering the scrubbing zone 32. The water and entering gas stream create an internal pressure within the scrubber from about 1.8 psig to about 5 psig, preferably from about 2 to about 3 psig.

This contact with the scrubbing water removes the hazardous water soluble gases such as ethylene dichloride or hydrogen sulfide from the vapor stream resulting in vapors collecting in the headspace 40 of the scrubber 30, having substantially lowered content, if not substantially free, of hazardous gases. From the headspace 40 the vapors may be vented through a collection device to remove the residual hazardous gas from the vapors such as, for example, carbon canisters, but preferably the vapors are recycled back to tank 22 through line 42. The recycled vapors then sweep more hazardous gases from tank 22 into line 24 and the cycle continues until tank 22 is safe for entry. Where a contaminated soil is the source of atmospheric

contamination the cycle continues until the soil washed in the tank releases no more ethylene dichloride. Fresh outside air could be used to sweep tank 22 and vent the vapors to the atmosphere after complete ethylene dichloride removal through carbon canister but the recycle gas sweep is preferred. Removal of the ethylene dichloride from water using the carbon canister is much more convenient than from a gas stream, primarily due to the size of the canister.

The water circulating through the packing P of the scrubber 30 in the scrubbing zone 32 becomes contaminated with the condensed and absorbed hazardous gases and collects in the bottom 44 of scrubber 30. The contaminated water stream proceeds from the bottom 44 of scrubber through line 46, pump 48 and line 50 to a holding vessel 52 which is, of course, isolated from the atmosphere because of the volatility of the hazardous gases absorbed in scrubber 30. In holding tank 52, a stream of feed water enters holding tank 52 through line 54 to dilute the contaminated water entering through line 50. The dilution reduces the concentration of the hazardous gas in the water stream making it useful to absorb additional hazardous gases in scrubber 30 when used, in the preferred manner, as a recycle stream. The water entering through line 54 into holding tank 52 may be used to adjust the temperature of the water being circulated in the system over the scrubber 30, since lower temperature water will absorb more ethylene dichloride and hydrogen sulfide. Such temperature adjustment depends, of course, upon the overall operation

of the process and the temperature of the source of dilution water. Most often, the temperature of the water and, indeed, the entire system will be dictated by the ambient temperature and, thus, in the summer, in the Northern Hemisphere, of course, the water circulated and the gas treated would be at a higher, nearly ambient temperature. The flow rates would, of course, then be adjusted to accommodate the temperature.

This recycle stream, diluted to approximately 1/4 to 2/3 the concentration of the entering contaminated water stream through line 50 is removed from holding tank 52 as a purge stream through line 56 sent through a second pump 58 at the aforementioned flow-rate and conduit 36 to the scrubber 30. The balance of the diluted water is removed from holding tank 52 through line 60, a third pump 62 and line 64 to carbon cartridge filters (not shown) where the hazardous material, whether ethylene dichloride or hydrogen sulfide is absorbed from the water onto carbon cartridges. Preferred filter cartridges are supplied by Calgon and are well known to those skilled in the art. The sizing of such cartridges, usually installed in parallel in order to allow for replacement when fully charged without shutting down the entire system, is within the ordinary skill of the engineer.

The dilution of the contaminated water stream entering holding tank 52 through line 50 protects the carbon cartridges from being consumed at a rapid rate. Holding tank 52 must be protected against the escape of vapors by the installation of carbon filter 66 on the tank vent to absorb the hazardous gases which may be

released into the vapor phase. One or more carbon filters 66 are placed in series and parallel in order to prevent an accidental contamination to the atmosphere. As a safety precaution to protect against reaching an LEL condition in the vapors of tank 52, nitrogen gas was directed into the tank at a rate of from about 2 to about 6, but preferably, about 4 cubic feet per minute to dilute the ethylene dichloride level. This also extended the life of the carbon canister.

Often the gas contaminating the space of a vessel will be resulting from solids which have collected as residue inside the vessel, particularly in the case of storage tanks, or in the case of containing in such a tank contaminated soil resulting from a spill of a hazardous material. In the embodiment of our invention which involves not only the removal of hazardous gases from the vapor space in a tank, but the cleansing of contaminated solids in the tank, it is important to use some agitation or dilution of the solids in the tank in order to free noxious gases for removal and recovery as part of the tank cleaning. This occurs when there is a storage tank with a heel of heavy hydrocarbons or where the soil is contaminated with chlorinated hydrocarbons, particularly those that are water soluble and much more particularly, ethylene dichloride, specifically.

In the case where tank 22 is an oil storage tank, the sludge can be agitated in ways known to those skilled in the art, for instance, as described in U.S. Patent 4,407,678, which is incorporated herein by reference for all purposes. The tank may be permanently fitted with

dispersion apparatus as described in U.S. Patent 5,460,331, also incorporated herein by reference for all purposes. As shown in Fig. 1, (sludge) soil 66 is mixed and slurried with water which causes the contaminant to be released from the soil into the water to saturate it and from there into the atmosphere in tank 22. Where the contaminated soil has resulted from a spill, there may even be instances where the contaminant is floating on the saturated water thereby creating a maximum concentration in the tank. Additional water must be added to accomplish the removal. Part can be removed by removing the slurry itself. The slurries are removed through line 68, pump 130 to a holding tank 132. There it is agitated by mixers 133 and, thence, the solids are separated by appropriate separation means shown as filter press 134. Of course, other known means for separation of solids and liquids, such as centrifuge and the like, are well known.

Other means of cleaning sludge from storage tanks are known and described in U.S. Patents 4,817,653, 4,945,933 and 5,091,016, for example, all of which are incorporated herein by reference for all purposes.

If tank 22 contains a soil contaminated with ethylene dichloride to be cleaned to allow disposal, then water is introduced through line 65 to an agitation means 67, the operation of which is more specifically disclosed and described in U.S. Patents 4,945,933 and 5,091,016, which are incorporated herein by reference for all purposes. In this instance, the use of the agitation means 67 causes the ethylene dichloride contamination on

the soil to be freed from the soil into the water and then to permeate the atmosphere within the tank 22 with ethylene dichloride or to become dissolved in the water up to the level of solubility at the given temperature. Thus, the soil becomes substantially cleaned and then withdrawn in the form of a slurry having 2 to 3 parts by volume of water per part of solids in the slurry. It is withdrawn through line 68, pump 130 and, thence, into holding tank 132, where agitation is maintained with stirrers 133. Evaporation again occurs in an appropriate solids liquid separation device with the vapors being trapped and conveyed back into tank 22 directly or into the system heretofore described. The solids are now sufficiently free of any ethylene dichloride to be removed to the environment for disposal as a solid waste in a permitted site. The liquid having minor ethylene dichloride contamination remaining is either polished by passing through a carbon canister, not shown, or transmitted to the holding tank 132 for mingling with other contaminated water streams resulting from the practice of this invention.

In Fig. 2 the blower 26, first pump 48 and second pump 58 are shown in their preferred embodiments as mounted on the mobile frame shown as a flatbed trailer 70 it being understood, however, that one or more of these pieces may be separately mounted and transported to the area wherein the scrubbing apparatus of this invention is used. The determination of which, if any of this equipment is mounted on the mobile frame, is an option but the preferred embodiment shown in Fig 2 carries the

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entire apparatus as a distinct unit. Desirably, a removable suction filter 25 is located on the inlet side of the blower 26. The suction filter 25 is used during operations as a stripping tower but is not generally required during closed loop circulation, and therefore may be removed during such operation and the inlet line 24 coupled directly to the inlet port of the blower 26.

EXAMPLE

A fixed-roof crude oil storage tank 22, having a diameter of 110 ft. was used in this example. The tank 22 had an accumulation of about 1 1/2 feet of soil and water contaminated with ethylene dichloride in the bottom. The atmosphere within the tank 22 was contaminated with well over 1,000 parts per million of ethylene dichloride. The mobile scrubbing apparatus 20 embodying one aspect of the present invention was placed adjacent the tank 22 and the lines 24 and 42 were connected with the interior of the tank 22. The scrubbing zone 32 of the scrubbing tower 30 was packed with 3 1/2 inch diameter hollow spherically shaped packing made of injected molded plastic (JAEGER TRI-PACS, Jaeger Products, Inc., Spring, Texas) to a depth of 19.7 feet. Tanks 52 and 132 were covered portable tanks normally used to contain oil well fracturing materials, frac tanks, fitted with carbon pack absorption units to clean any vapors escaping from such portable tanks. The water level in the storage tank 22, containing the soil, was raised from 1 ft. 8 in. to 3 ft., with the water entering through the supply line 65 and the agitator 67, thereby causing intermixing of the water and the ethylene

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dichloride soil and causing the ethylene dichloride to be released from the soil and dissolved in the water. Water circulation was started at a rate of about 240 gpm in the loop through the scrubber using pumps 58 and 48. The liquid level in the scrubbing tower 30 was maintained at about one half the height of the scrubber. The vapor blower 26 was started and the contaminated gas atmosphere in the storage tank 22 was withdrawn and delivered to the sparger 34 in the lower end portion 44 of the scrubbing tower 30. The blower 26 raised the pressure of the gas stream delivered to the scrubbing tower 30 to about 4.5 psig. The operating pressure within the scrubbing tower 30 was about 3.5 psig. It was a hot day on the Gulf Coast with the ambient temperature being about 95°F. The compressed gas exited the blower 26 at temperature of about 124°F. The temperature of the contaminated water removed from the bottom of the scrubbing tower 30 was about 97°F. The water exiting the scrubbing tower 30, through the drain line 46 contained from about 2,000 ppm to about 2,700 ppm ethylene dichloride over a recorded 12 day operation period. The scrubbing tower effluent was diluted to about 1,000 ppm ethylene dichloride in the portable holding tank 52 with feed water taken from an uncontaminated source at about 200 gpm. The stream from the holding tank 52 was split, with 240 gpm being recirculated over the scrubbing zone 32 in the tower 30, and 200 gpm drawn from the tank 52 through the line 60 by the pump 62, and pumped through carbon canister filters to remove ethylene dichloride. The ethylene dichloride concentration of the withdrawn stream was approximately

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1,100 ppm, having been diluted from the higher concentration of the stream withdrawn from the scrubbing tower 30 by the uncontaminated water added through the supply line 54. The recycle stream pumped to the distributor 38 in the top of the scrubber 30 also contained about 1,100 ppm ethylene dichloride. While passing down through the packing in the scrubbing zone 32, more ethylene dichloride was absorbed and the cycle thus continued. The contaminated stream from the bottom of the scrubber 30 was diluted to moderate the rate at which the carbon canister pack, through which the withdrawn stream was processed, was loaded with ethylene dichloride.

The operating pressure within the scrubbing tower 30 ranged from about 2 to about 5 psig, with the preferred range being between about 2.1 and 2.5 psig. The blower 26, in removing the hazardous gases from the tank 22, drew a steady negative pressure of 1 psig on the tank 22. The vapors passing through the scrubbing tower 30 exited the top headspace 40 of the tower 30 with an ethylene dichloride content of about 925 ppm. The exiting vapors were reintroduced into the tank 22, through return line 42, where they picked up more ethylene dichloride from the vapors in the tank 22, and were recycled again through the tower 30. With this injection of vapors, outside air drawn through tank vents and removal of vapors, the tank is maintained under a subatmospheric pressure of about -1 psig and, therefore, escape of ethylene dichloride bearing vapors through the vent system of the tank into the operating area around the

tank is eliminated. It was noted by operating personnel in the vicinity of tank 22 that, prior to the scrubbing operation, there had been continuing detection of ethylene dichloride in the area. After beginning of operation, this no longer occurred. Thus, in carrying out the above illustrative example, the scrubbing apparatus 20 embodying the present invention was also useful in cleaning the atmospheric environs in the vicinity of the storage tank 22.

After sufficient agitation using apparatus described in U.S. Patent 5,091,016, the soils were removed from tank 22 in the form of a slurry having about 60% solids to fill a covered tank 132 fitted with mixer 133. This water with suspended solids was filtered to separate the ethylene dichloride solution from the soil through a filter press 134 so that the soil could be disposed of in an environmentally safe manner. The water, still containing some ethylene dichloride was routed through carbon canister filters to remove the ethylene dichloride. The carbon filters are obtainable from Calgon Carbon Corporation of Pittsburgh, Pennsylvania. Thus, the soil has been removed from tank 22 for safe disposal without requiring any exposure of work personnel to the hazardous ethylene dichloride atmosphere existing in the tank. Neither have workmen been required to don cumbersome protective equipment in order to accomplish the cleaning result. Since the slurry in this particular instance was moved from tank 22 through line 68 to interim tanks 132 agitated by mixers 133 faster than the separation could be accomplished through the filter press

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or other liquid solid separation means, the agitation through apparatus 67 would be suspended. Additional water would be introduced in the tank through line 65 during the slurring activity until the soil was removed from the tank. In the example described above, the slurring, pumping and filtering operations continued for eleven days.

At the end of such time it was still evident that tank 22 was still contaminated with ethylene dichloride preventing entry of work persons to complete the cleaning of the tank. The above described evacuation, scrubbing, and circulation of vapors through the tank continued for an additional fifteen days. During this period of time of operation the water circulation was reduced to 100 gallons per minute at a pump 58 outlet pressure of 30 psig.

Turning again to the description of the apparatus 20 embodying one aspect of the present invention, water enters the scrubbing tower 30 through the distributor nozzles 38 located near the top of the tower 30 and is released as mentioned above. The distributor 38 evenly spreads the waste water over the entire top surface of packing which fills the scrubbing zone 32 of the tower 30. The packing may be either random or structured. The scrubbed gases are collected in the chamber, or headspace 40 at the top of the tower 30 above the distributor 38. A mist eliminator 68, preferably made of a stainless steel mesh, prevents water droplets from being carried from the scrubbing tower 30 into the atmosphere of the storage tank 22.

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In the preferred embodiment of the present invention, the packing disposed in the scrubbing zone 32 of the scrubbing tower 30 are the above-described 3 1/2 inch diameter hollow, spherical-shaped packing made of injection molded plastic. The spherical packing balls may be made from any suitable injection moldable plastic such as polypropylene, polyethylene, polypropylene glass-filled, "NORYL" (a registered trademark of General Electric Company), "TEFLON" (a registered trademark of E.I. Dupont de Nemours & Company, Inc.) or any other suitable materials. Spherical packing for the present invention may range from about 5/8 inch to about 4 inches in diameter. Other useful packing materials include metal packing (including carbon and alloy steels, aluminum, copper, and others), ceramic packing, and chemical porcelain packing. However, since the weight of mobile units for highway travel is important, the lighter, less dense materials are preferred, if not necessary. The tower 30 internal structure is also preferably formed of plastic materials to reduce the weight of the apparatus and thereby enhance the transportability of the apparatus. The internal structure of the tower 30 may be made of any other suitable material, including metal, however.

Spherical polyethylene balls having a diameter of about 3 1/2 inch are the preferred packing material because of weight and mass transfer efficiency. The 3 1/2 inch plastic spheres have a geometric surface area of about 38 square feet per cubic feet and have a packing density in the scrubbing zone 32 of from about 2.9 to

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about 3.7 pounds per cubic feet, preferably 3.3 pounds per cubic foot. With the above illustrative examples and detailed description, the skilled engineer will be able to design a scrubber 30 within the size (length and diameter), weight, and capacity requirements of this invention.

The preferred embodiment of the apparatus of the present invention is shown in Fig. 2, a perspective view of the mobile scrubbing apparatus 20 in which the elements encompassed within the broken line area of Fig. 2 are mounted on a mobile frame, such as flatbed trailer 70, with wheels 72. Alternatively, the mobile frame 70 may be truck mounted or skid mounted for transport to a decontamination site. The mobile frame 70 may also be mounted on a self propelled frame such as a truck. The scrubbing tower 30 is supported by a tower cradle 74 which can be lowered to a horizontal position A for transport on a cradle rest 76.

Referring now to Fig. 3, a hydraulic tilt cylinder 78 provides a means to move the scrubbing tower 30 between the horizontal transport position A and a vertical operating position B. The scrubbing tower 30 is also supported and stably maintained in the vertical operating position B by the tower cradle 74. As shown in Figs. 3 and 4, the tower cradle 74 preferably has two longitudinal tower supports 80, six side supports 82, and two tower-end side supports 84 which cooperate to hold the scrubbing tower 30 in place in both the horizontal and vertical positions, A,B. As shown in Fig. 5, the scrubbing tower 30 is supported on its bottom side by

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three tower bottom supports 86, the tower-end side supports 84, and the two longitudinal tower supports 80.

The tower cradle 74 in the preferred embodiment also consists of two long frame supports 88 which are attached to the two longitudinal tower supports 80 by six frame side supports 90. The tower cradle support system 74 also has three frame bottom supports 92, as best seen in Fig. 7. As shown in Fig. 3, a diagonal brace 94 is provided between the long frame support 88 and the long tower support 80.

Fig. 6 shows a cross section of the scrubbing tower 30 and the tower cradle 74 near the bottom end of the stripping tower 30. This cross-sectional view shows the tower 30 cradled between the two longitudinal tower supports 80, the two tower-end side supports 84, and a split tower-end bottom support 96.

Fig. 7 shows a similar cross-section near the middle of the scrubbing tower 30, through the tower cradle system 74. Here, the tower 30 is cradled by the longitudinal tower supports 80, along with the two long frame supports 88, two of the frame side supports 90, and one of the frame bottom supports 92. A triangle stiffener 98 is provided for additional strength near the junction of the tower bottom support 86 and the long tower support 80.

Referring now to Fig. 8, a detailed view of the scrubbing tower 30 within the hatched circle in Fig. 7 is shown. A collar assembly 100 supports the tower 30 in conjunction with the cradle 74. An internal collar 102 is welded to the body of the scrubbing tower 30. An

external collar 104, which is attached to the tower side support 82, loosely yet securely, encloses the internal collar 102 in a slidable relationship, thus holding the tower 30 within the tower cradle system 74. The internal collar 102 may move within the external collar 104 to allow for thermal expansion contraction while holding the scrubbing tower 30 securely in the vertical position.

Referring again to Figs. 3 and 4, a pivot arm 106 is connected at one end to the hydraulic tilt cylinder 78 which is secured at the other end to the trailer 70 itself to provide a means for raising and lowering the scrubbing tower 30. The controls for operating the hydraulic tilt cylinder 78 are well known and not shown or described herein. At its other end, the pivot arm 106 is attached to the longitudinal tower support 80 at a pivot arm connection 108. At an intermediate position between the two ends, the pivot arm 106 is pivotally attached to the longitudinal frame support 88 at a pivot point 110. A cylinder connection 112 is shown at the other end of the pivot arm 106, which is the aforementioned connection with the hydraulic tilt cylinder 78.

Fig. 9 is a detailed view of the cylinder connection 112. A cheek 114 is attached to the pivot arm 106 through a hole 116 drilled through the cheek 114 and the underlying pivot arm 106. Fig. 10 shows a cross-sectional schematic view of the cylinder connection 112 of the pivot arm 106 taken along the line 10-10 of Fig. 9. A rod end 118 of the hydraulic cylinder 78 is attached to the pivot arm 106 by a bolt 120 and a nut

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122. The bolt 120 crosses through the cheek 114 and the pivot arm 106 through the hole 112.

Prior to operation, the scrubbing tower 30 is moved to the vertical operating position B as shown in Fig. 3, by use of the hydraulic tilt cylinder 78 mounted to the trailer 70. A plumb line, bubble leveling device, or machinist's level, or the like, informs the operator that the scrubbing tower 26 is in the desired vertical operating position B necessary to provide uniform distribution of water through the scrubbing zone 32. Stabilizing arms and pads 124 with hydraulic operators are used to insure that the scrubbing tower 30 is properly oriented and stabilized. At the completion of the gas decontamination process, the hydraulic tilt cylinder 78 is advantageously used to reposition the scrubbing tower 30 in a horizontal transport position A.

Although the present invention is described in terms of the above preferred embodiments as a scrubbing tower, those skilled in the art will recognize that changes in the apparatus may be made without departing from the spirit of the invention, including such changes necessary to operate the apparatus as a stripper column. Such changes are intended to fall within the scope of the following claims.



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CLAIMS

1. Method for capturing hazardous, gases having water solubility from containment vessels including the steps of withdrawing hazardous gases, from the vessel, introducing the gases into lower regions of a scrubbing zone, contacting the rising gases with sufficient water in counter-current flow to capture such hazardous gases in a water stream and create a gas stream having a substantially reduced content of hazardous gas, recycling the gas stream to the vessel to sweep additional hazardous gases from the vessel, withdrawing the water stream and dissolved hazardous gases from the scrubbing zone, diluting the water stream with additional water to create a recycle stream having a lowered concentration of absorbed hazardous gases and a bottoms stream, returning the recycle stream to the scrubbing zone, and removing the absorbed hazardous gas from the bottoms stream for disposal.

2. The method of Claim 1, wherein the hazardous gas is ethylene dichloride or hydrogen sulfide.

3. Method for removing ethylene dichloride from contaminated soil contained in a closed vessel which includes the steps of forming a slurry by mixing the contaminated soil with water, agitating the slurry to free ethylene dichloride from the soil and from a contaminated atmosphere in the vessel, withdrawing the vessel atmosphere contaminated with ethylene dichloride from the vessel such that the pressure within the vessel is below atmospheric pressure and the withdrawn atmosphere forms a gas stream at a greater than



atmospheric pressure, discharging the gas stream contaminated with ethylene dichloride into a scrubbing zone, contacting the gas stream with a sufficient amount of stream water in the scrubbing zone in counter-current flow to absorb the ethylene dichloride into the water and create a vapor stream having a substantially lowered ethylene dichloride content, and returning the vapor stream having lowered ethylene dichloride content from the scrubbing zone to the vessel to sweep additional ethylene dichloride from the atmosphere of the vessel.

4. The method of Claim 3, including the steps of removing the bottoms water stream contaminated with ethylene dichloride from the scrubbing zone, diluting the water stream to lower the concentration of ethylene dichloride contamination and produce a recycle stream and purge stream, both contaminated with lowered amounts of ethylene dichloride, returning the recycle stream to the scrubbing zone to absorb additional ethylene dichloride, and passing the purge stream through carbon canister filters to trap the ethylene dichloride for benign disposal.

5. The method of Claim 5, wherein the contaminated soil in the vessel, suspended in water contaminated with ethylene dichloride, is removed from the vessel as a slurry, said method including the steps of filtering the slurry to separate soil from the ethylene dichloride contaminated water, and passing the contaminated water through carbon filters to capture the ethylene dichloride for benign disposal.

6. Mobile apparatus for promoting gas/liquid mass



transfer, including a mobile frame, a tower containing a packed bed pivotally mounted on said mobile frame for movement between a horizontal transport position to a vertical operating position, said tower having an upper end portion and a lower end portion when disposed at said vertical operating position, means for moving said tower between said horizontal transport position and said vertical operating position, means for maintaining said tower at said vertical operating position, means for receiving and distributing gas upwardly through said tower when the tower is in said vertical operating position, and means for receiving and distributing water downwardly through the packing of said tower when the tower is in said vertical operating position.

7. The apparatus of Claim 6, wherein said means for moving said tower between said horizontal transport position and said vertical operating position includes an extendable hydraulic cylinder having a first end connected to said mobile frame, and a second end attached to a pivot arm attached to said means for maintaining said tower at said vertical operating position.

8. The apparatus of Claim 7, wherein said means for maintaining said tower at said vertical operating position includes a cradle structure supporting said tower, said cradle structure being stabilized by the pivot arm attached at one end said cradle structure and at the other end to the hydraulic cylinder attached to said mobile frame.

9. The apparatus of Claim 6, 7 or 8 configured as a scrubbing tower for removing hazardous gases from an



enclosed vessel and which further includes a blower having a discharge port in fluid communication with said means for distributing gas upwardly through the tower, and an inlet port adapted to receive a first conduit that is connectable with an enclosed vessel containing a hazardous gas mixture, a second conduit in fluid communication with a chamber disposed at an upper end portion of said scrubbing tower and adapted for connection with the enclosed vessel containing a hazardous gas mixture, a first pump having an inlet port in fluid communication with a bottom portion of said scrubbing tower, and a second pump having an inlet port adapted for connection with a source of water and a discharge port in fluid communication with said means for distributing water downwardly through said tower.

10. The apparatus of Claim 9, wherein said blower is mounted on said mobile frame.

11. The apparatus of Claim 9, wherein said first and second pumps are mounted on said mobile frame.

12. The apparatus of Claim 9, wherein said means for distributing gas upwardly through said scrubbing tower when the tower is in said vertical position includes a sparger disposed in said lower end portion of the scrubbing tower, said sparger being connected to said blower in fluid communication with hazardous gases in said enclosed structure.

13. The apparatus of Claim 9, wherein said means for distributing water downwardly through said scrubbing tower when the tower is in said vertical operating position includes a water distributor positioned adjacent



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the upper end portion of said scrubbing tower, said water distributor being in fluid communication with said second pump connected to a source of water.

14. The apparatus of Claim 9, wherein said scrubbing tower includes a scrubbing zone disposed between said means for distributing gas upwardly through said scrubbing tower and said means for distributing water downwardly through said tower, said scrubbing zone having a plurality spherical balls disposed therein.

15. The apparatus of Claim 14, wherein said spherical balls are formed of a plastic material and have a diameter of from about 5 inch to about 4 inches.