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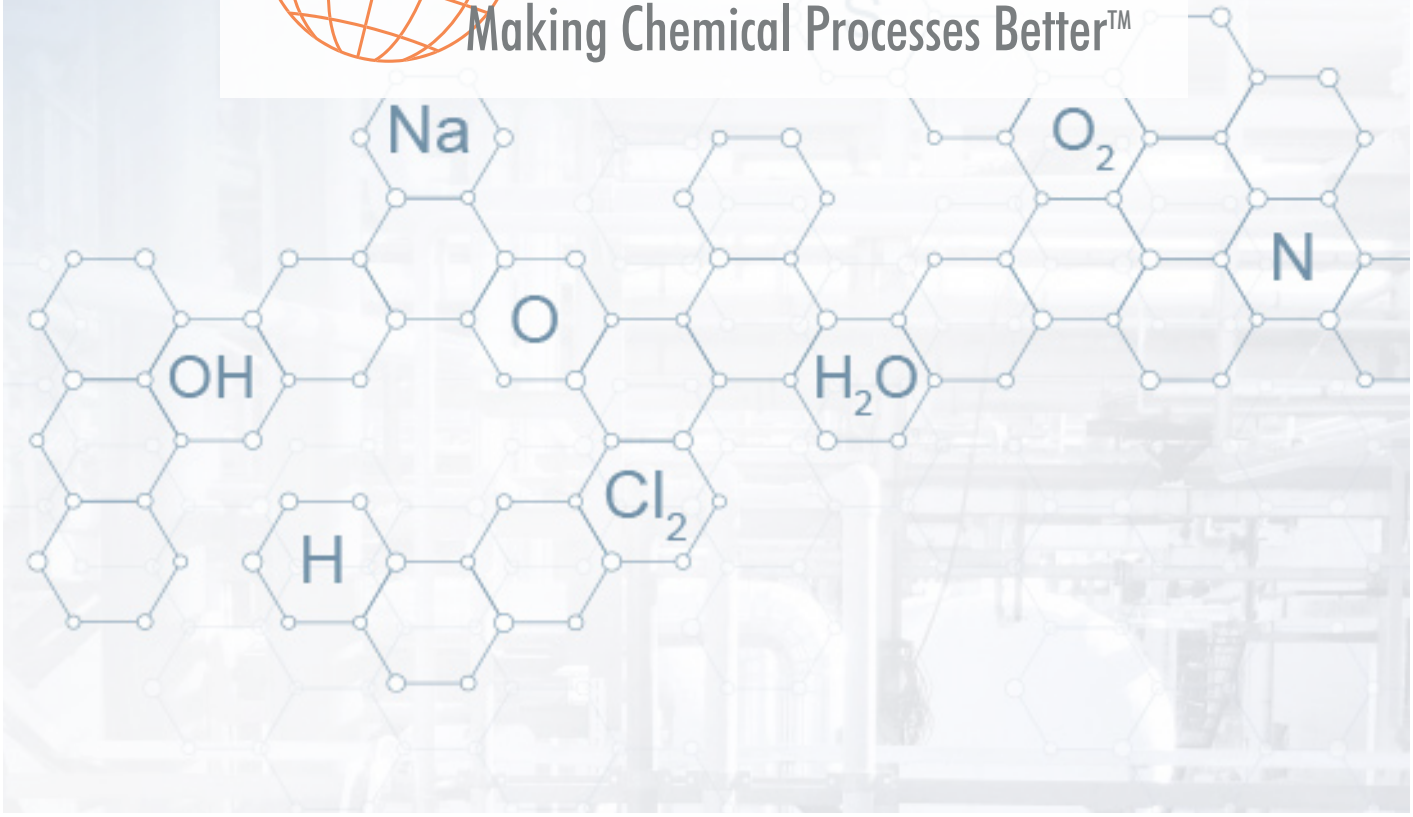

HORIZONTAL PACKED SCRUBBERS

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Chlorine is one of the most useful and economically important of the basic chemicals. Its largest single use is for the manufacture of plastics, mostly polyvinyl chloride (PVC). It also is used for manufacture of pharmaceuticals, aerosol propellants, agricultural chemicals, synthetic rubbers, dyestuffs, and paper pulp. No other material offers the economy of operation, simplicity of control, and safety of operation as chlorine for the treatment of potable water and sewage plant effluent. Other chemicals such as ozone, hydrogen peroxide, and potassium permanganate have been considered but are not widely used or accepted.

Since chlorine is classified as a toxic chemical, special requirements must be followed regarding its shipment and use. It has a distinctive, pungent, and irritating odor which is detectable at a level of even one ppm. This characteristic permits a user to recognize that a leak has occurred and to take corrective action. The Responsible Care (R) program directed by the Chemical Manufacturer's Association provides assistance and guidance to producers and distributors emphasizing the industry's commitment to the safe use of chlorine.

The Chlorine Institute is committed to the Responsible Care program and provides additional support to the industry by aiding in the development of meaningful and useful regulations. Building and Fire Code groups can receive technical support from the Institute in the form of data on the use and handling of chlorine. Publications such as the Chlorine Release and Scrubber pamphlets provide the necessary information regarding the safety and handling of emergency situations. Facilities that offer the potential of releases from areas of production, use, or packaging can obtain the necessary background and supporting data to permit meeting the EPA and OSHA guidelines and the SARA Title 3 requirements.

As most operations involving chlorine now are open to public scrutiny, implementation of adequate precautions to control emergency situations is essential. With all of the information which has been disseminated by the media, the average person is fearful of most chemicals. Even unintentional violations of federal regulations or local ordinances patterned after the Uniform Fire Code can incur large fines or closure of an operation. Thus, installation of an emergency chlorine scrubber that can contain the release of the total contents of a vessel becomes an important step in maintaining good community relations.

This paper will review the characteristics of many of the scrubber types for gaseous contaminants that are in a wide commercial use. The absorption theory applied as the background for the design of a multiple-bed packed scrubber utilizing horizontal gas flow will be given. The arrangement for conducting full scale tests on this scrubber design will be shown. The results of four tests on the discharge from one-ton containers of chlorine at rates exceeding the Uniform Fire Code will be presented. Finally, the basis for the design of the commercial scrubber will be discussed.

Absorption is the usual method used for removal of chlorine from an air stream. Absorption refers to the process for transferring a particular component from the gas phase to the liquid phase. Thus, the gas stream containing chlorine must be brought into intimate contact with a liquid in which the chlorine is at least some what soluble. Removal of chlorine from the gas stream will continue only until the scrubbing liquid becomes saturated with chlorine at the conditions of operation. Since chlorine has a limited solubility in water, another chemical with which the chlorine will react can be added to the water. Sodium hydroxide combines rapidly with dissolved chlorine to produce a solution which has no tendency to release the chlorine. Thus, by use of a caustic solution for scrubbing chlorine from a gas stream, the limitation of the low solubility of chlorine in water has been circumvented.

Various devices have been employed for contacting a gas stream with a scrubbing liquid. The simplest of these devices is a spray tower. This scrubber is an empty shell in which droplets of liquid travel through a gas stream usually in countercurrent flow. Typically, the scrubbing liquid is introduced through spray nozzles located at the top of the tower. The gas stream enters near the bottom of the column and flows upward. Droplet size created by the spray nozzles is limited by entrainment. The efficiency of such scrubbers for pollutant removal is low due to limited liquid surface area and contact time between liquid and gas streams. Such scrubbers primarily are useful where a high degree of pollutant remove (90% or greater) is not required.

The ejector scrubber uses a high-pressure liquid spray to aspirate the gas stream through a Venturi-shaped throat. Absorption of the contaminant takes place in the highly turbulent flow regime in this throat. Typically these devices are used for small gas flow rates since there is no fan needed to move the gas stream. Contaminant removal efficiency is limited by the short contact time between gas and liquid phases in the ejector throat. Power requirements are high due to the large flow of liquid needed to aspirate the gas stream per 1,000 CFM of gas handling capacity.

Venturi scrubbers contact the liquid with the gas stream in the throat section at high gas velocities (150 ft/s or greater). This gas velocity shares the scrubbing liquid into many small droplets which provide a large surface area for absorption. However, the concurrent flow arrangement restricts the absorption driving force to equilibrium between the outlet gas and liquid streams. Also, the very short contact time limits the amount of absorption. These high pressure-drop scrubbers primarily are useful for removing very small size particles from a gas stream. Their removal efficiency is a function of the power input of the Venturi scrubber.

Orifice type scrubbers also use the energy in the gas stream to create interfacial contact area for absorption by the liquid phase. Although conventional trays usually used in fractionation services (bubble cap, sieve, or valve trays) can be applied for absorption, special designs have been developed for use in scrubbers. The gas stream can be passed through a series of perforated horizontal plates fitted with impingement targets located above each orifice. The depth of liquid, which usually flows horizontally across each plate, is controlled by overflow baffles. Although the ratio of liquid flow to gas flow is low, pressure drop in the gas phase for such devices is high since it represents the sum of the pressure losses through the orifices and the liquid head on each plate.

Packed towers fined wide use as scrubbers because tower packings are shaped to provide a large surface area for gas-to-liquid contact while producing minimum resistance to gas flow thus low pressure drop in the gas stream. Since the development of the first random tower packing in 1915, improvements in packing shapes have greatly increased their gas and liquid flow capacities as well as their absorption efficiency. While packing shapes are manufactured from ceramics, metals, and plastics, it is the plastic packings that have found extensive use in scrubbers. Plastics offer a wide range of chemical resistance to attack by acids, alkalies, and many organic chemicals. In addition, plastic packings are light in weight, resistant to mechanical damage, and available at low cost.

Packed scrubbers can be operated in four different flow arrangements as defined by the directions of gas and liquid flows. In a horizontal concurrent flow design, both the gas and liquid flow horizontally into the same end of the packed bed. The gas flow rate must be kept below the liquid reentrainment velocity. Thus, the depth of penetration of liquid into the packing is short so that absorption efficiency is limited.

In a vertical concurrent flow design, both the gas and the liquid flow downward through the packed bed. Very high flow rates can be accommodated since there is no flooding limit for packing; however, pressure drop increases with gas velocity. Absorption is limited to the contaminant concentration in the outlet gas stream which is in equilibrium with that in the liquid effluent since these two streams are in contact at the bottom of the tower.

In a counter flow design the liquid is introduced at the top of the bed and flows downward while the gas stream enters at the bottom of the bed and flows upward. The gas flow rate is restricted by the flooding velocity of the packing due to increasing holdup of liquid in the packed bed with gas velocity. This arrangement produces the maximum driving force for absorption since the outlet gas stream is in contact with liquid containing little or not solute at the top of the tower.

In a cross flow design, the gas stream flows horizontally through a packed bed which is irrigated with downwardly flowing liquid introduced at the top of the bed. Thus, the gas flow direction is perpendicular to the liquid flow direction. Since the cross-sectional area for gas flow is different than the cross sectional area for liquid flow, the ratio of these flows can be varied widely.

Pressure drop through a scrubber is very important as the power required to move the gas stream may be the largest operating cost factor. Packed towers are favored because of their low pressure drop together with their high contaminant removal efficiency. To evaluate the merits of various types of scrubbers, one must understand the mechanism of absorption. The contaminant will diffuse through the gas phase toward the gas liquid interface. At this interface, the contaminant passes through a gas film then a liquid film in series. Finally, the contaminant must diffuse through the liquid phase away from the interface. Once of the functions of tower packing is to promote turbulence in the gas and the liquid so that the main body of each phase is of uniform composition. Therefore, the mass transfer coefficient is determined by the resistance to absorption offered by the gas film and the liquid film in series. The amount of contaminant absorbed per unit of time is the product of the mass transfer coefficient, the interfacial area of contact between gas and liquid phases, and a driving force. The driving force is the difference between the partial pressure of the contaminant in the gas phase and the vapor pressure of the contaminant above the liquid phase. The interfacial area varies with the type and size of the tower packing as well as the gas and liquid flow rates.

Absorptions conveniently are classified as liquid filum controlled or gas film controlled. In liquid film controlled systems either the solute has limited solubility in the liquid (as oxygen absorbed into water) or reacts slowly with the liquid (as carbon dioxide absorbed into water to form carbonic acid). In gas film controlled systems either the solute is very soluble in the liquid (as ammonia absorbed into water) or the solute reacts rapidly with some material in the liquid (as chlorine absorbed into caustic solution). This classification permits determination of the effect of the gas and liquid flow rates on the rate of absorption. In order to simplify calculations, the interfacial area is combined with the mass transfer coefficient to yield an overall mass transfer coefficient for a packing.

The diameter for a countercurrently operated packed tower is chosen to produce a certain pressure drop by fixing the gas velocity. For this cross sectional area the liquid flow used must be sufficient to wet adequately the packing surfaces and not so great as to flood the packed bed. The degree of contaminant absorption required determines the packed height. When high removal efficiency is needed, such towers can become quite tall. Thus, it usually is not practical to install such scrubbers inside buildings. The foundations

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and supporting steel for a tall tower can be expensive due to the wind loading as well as seismic considerations. Also, maintenance can be costly.

The gas flow area for a cross flow scrubber is the product of the width and the height of the packed bed. This area also is chosen to produce a certain pressure drop by fixing the gas velocity. The liquid flow area is the product of the width and the length of the packed bed. Once the gas flow area is fixed, the packed length needed is a function of the degree of contaminant removal required. The liquid flow rate much be sufficient to wet adequately the packing surfaces. In order to reduce the overall length of such a scrubber, multiple gas passes operating in series can be used by increasing the scrubber width. The overall dimensions of this scrubber arrangement can be varied so as to provide a compact unit. Such designs can be short enough for installation inside of buildings. The width of the scrubber can be varied to meet clearance requirements. Thus, such a scrubber can require only a minimal foundation.

In the last half of 1992, a project was initiated to design an emergency scrubber for the absorption of chlorine that would meet the existing requirements of the Uniform Fire Code for the storage of one ton containers of liquid chlorine. Such containers usually are stored in a separate building having a concrete floor. The storage room must be kept at a negative pressure relative to the surrounding environment and vented through a treatment system. Article 80 of the 1994 Code requires that the treatment system be capable of handling the release of the entire contents of the storage vessel in 30 minutes. For an overfilled one ton container, this is equivalent to a release of 78.3 lb/min of chlorine. Discharge from this treatment system shall not exceed one half the concentration of contaminant immediately dangerous to life and health (IDLH).

A flow rate of 3,000 ACFM was selected for ventilating the storage building. Based on the specified chlorine release rate, the inlet gas stream could contain a maximum of 140,000 ppm by vol of chlorine assuming complete vaporization of the spilled liquid. At that time, the IDLH value was 30 ppm by vol for chlorine so that the scrubber design was based on a discharge concentration of 15 ppm. At 20 wt% sodium hydroxide solution was chosen for use as the absorbent liquid. An overfilled on ton container of chlorine would consume 2,650 lb of pure sodium hydroxide if reacted completely. In order to provide a 50% excess over the theoretical caustic requirement, a sump which had a capacity of at least 2,000 gallons of caustic solution was incorporated into the bottom of the scrubber.

Scrubbers using packings are the most commonly applied devices for air pollution control applications. (“Handbook, Control Technologies for Hazardous Air Pollutants”, United States EPA). Tower packings provide a large wetted surface area for absorption with all the geometric surface area of the packing available as long as the minimum liquid flow needed is applied uniformly to be packed bed. The mass transfer efficiency of packed bed can be scaled up reliably from technology developed over more than 50 years. Further, packed scrubbers have low power requirements and are readily adaptable to corrosion resistant construction. A modern plastic tower packing, Intalox (R) Snowflake packing, was selected for the design as this packing provides a high absorption efficiency along with a very low pressure drop. The packing permits use of a design gas velocity of over 6 ft/sec. This packing utilities intersticial contact surface area to enhance mass transfer. It was calculated that a conventional vertical packed scrubber containing this packing and equipped with a separate caustic tank would have an overall height of about 30 ft. A cross flow scrubber utilizing the same gas flow area was evaluated to determine whether such a design would provide a more compact unit.

For the cross flow scrubber, the gas stream enters each square foot of the packed bed at a uniform velocity and contaminant concentration. Also, the absorbent liquid is distributed onto the top of the packed bed at a uniform composition and rate per square foot. The partial pressure of chlorine in the entering gas stream is the same for each square foot of inlet gas flow area. As the liquid descends through the packing, the amount of absorbed contaminant increases. So long as an excess of caustic is present in the liquid phase, there will negligible vapor pressure of chlorine above the liquid. With sufficient liquid flow, the pressure driving force for absorption is the same at the top and bottom of the packed bed and the liquid flow rate changes only slightly due to the contaminant absorbed, the mass transfer coefficient and interfacial area are practically the same at the top and bottom of the bed. Thus, the amount of chlorine absorbed per foot of packed bed length will be the same for the entire gas flow area. Therefore, the gas stream entering the second foot of packed bed length will be of uniform composition. The amount of contaminant absorbed in the second foot of bed length primarily will depend on the average partial pressure of chlorine in the gas stream.

This analysis indicates that the cross flow design and the countercurrent design behave in a similar manner for the absorption of chlorine into an excess of caustic solution. Through each foot of packed bed traversed by the gas, the pressure driving force for absorption si the average of the partial pressures of chlorine in the entering and leaving gas streams. In a gas film controlled absorption, the mass transfer coefficient varies as about the 0.75 power of the gas rate and about the 0.30 power of the liquid rate. Thus, the mass transfer coefficient primarily is a function of the average of the entering and leaving gas flow rates. The small change in liquid flow rates due to absorption has only a minor effect. Therefore, the overall design of a cross flow scrubber for this absorption can be approached in the same manner as for a countercurrent scrubber.

Several types of liquid distribution systems were considered. Low discharge velocity orifice pipe type distributors were selected; however, there was insufficient design data available regarding their flow capacities at low pressure drops. Therefore, distributors of this type were fabricated and the flow rates experimentally determined for various sizes of orifices at pressure drops below 5 psi using increments of 0.5 psi pressure drop.

A full size scrubber was constructed and installed on a concrete pad located outdoors about 20 ft away from a sheet metal building with a concrete floor. One end of this building contained two horizontal one ton containers of chlorine mounted on scales. The other end of the building constituted a sealed flash room 10 ft. wide by 15 ft. long by 10 ft. high. The flash room contained a steel pan 96 in square supported 24 in above the floor on scale. Liquid chlorine was fed into this pan from the adjacent room through four tubes. Make up air entered the flash room through a vent and flowed across the pan into an 18 in duct leading to the scrubber inlet. The flash room was maintained at a negative pressure of 0.3 in of water by a centrifugal fan installed on the outlet of the scrubber. The speed of the fan could be varied by use of an adjustable belt drive. Caustic solution was recirculated from the sump to the liquid distributor by means of a centrifugal pump.

Full scale testing was conducted on August 11th and 12th in 1993. Sample collection and analysis was performed under the direction of Dr. John R. Richards, P.E. of Entropy, Inc. Entropy is a nationally known emission testing firm. Dr. Richards has more than 25 years of experience in emission testing of scrubbers and other air pollution control systems. Gas flow rates to and from the scrubber and were measured in accordance with EPA Methods 1-4. Chlorine concentrations in the scrubber inlet gas stream were determined using EPA Reference Method SW 846-0050. The chlorine concentrations in the scrubber effluent gas stream were measured using EPA Reference Method 26. These two EPA references were selected since they provide the most accurate chlorine measurements for the concentrations that existed at the inlet and outlet of the scrubber.

Additional data readings were recorded by two data loggers. The following other items were measured:

1. Weight of the chlorine container and contents.
2. Weight of the flash pan and contents.
3. Temperature of liquid chlorine in the flash pan.
4. Pressure reduction from atmospheric in flash room.
5. Air temperature in flash room.
6. Temperature of gas stream entering the scrubber.
7. Temperature of gas stream leaving the scrubber.
8. Temperature of liquid in the scrubber sump.
9. Total pressure drop across the packed beds.
10. Pressure drop across the mist eliminator.

Each test was divided into two distinct parts. Since the pressure in the chlorine container would fall as it was emptied, an air padding system was installed. Thus, the pressure in the container could be maintained so as to give a constant rate of discharge of liquid chlorine. During the first part of the test, the chlorine discharge rate would be maintained above the 78.3 lb/min flow required by the Code. The second part of the test started after the chlorine container had been emptied when the liquid chlorine in the pan was allowed to vaporize with the scrubber operating. Initially, the liquid chlorine fed to the pan at ambient temperature would flash down to its atmospheric boiling temperature of about -30°F. Subsequent chlorine vaporization would be limited to a rate determined by the rate of heat transfer into the pan from its surroundings.

On August 11th 2,012 lb of liquid chlorine was discharged from a one ton container into the flash pan at an average rate of 88.4 lb/min. The initial release rate was 120 lb/min which decreased to the minimum rate of 81 lb/min after 7.5 minutes. Thereafter, air padding was employed to maintain the average release rate. The liquid chlorine temperature in the pan quickly decreased from 79°F to -27°F. After 5 minutes, the rate of chlorine vaporization became constant. The measured inlet gas flow to the scrubber was 3,094 ACFM at a temperature of 80.5°F and 29.6 in Hg barometric pressure. The scrubber sump contained 1,800 gal of 22 wt% sodium hydroxide solution which was recycled to the liquid distributor at a rate of 394 gpm. The temperature of the solution in the sump rose from 86 to 100.5°F during the test.

Analysis by EPA methods indicated that the inlet gas stream contained 56,991 ppm by vol chlorine. Due to the low concentration of chlorine in the gas vented from the fan, duplicate samples were taken. This gas stream contained an average of 3.63 ppm by vol chlorine. The outlet gas flow at a temperature of 97°F was calculated to be 3,050 ACFM after correction for moisture content. These measured number indicated that chlorine entered at a rate of 26.54 lb mol/h and left at a rate of 0.00162 lb mol/h. Thus, the scrubber was absorbing 99.994% of the entering chlorine.

The effective gas flow area was taken as the bed width multiplied by the bed height minus the average height occluded by some baffles. This area was multiplied by the total packed length to obtain the effective packed volume for calculation of the mass transfer coefficient developed. The driving force for absorption was the logarithmic average of the partial pressures of chlorine in the inlet and outlet gas streams. The overall mass transfer coefficient for this test was calculated to be 25.44 lb mol/h ft^3 atm.

After all the liquid chlorine had been discharged from this container, the residual liquid in the flash pan was allowed to vaporize. The measured inlet gas flow to the scrubber was 3,113 ACFM at a temperature of 80.5°F. Analysis indicated that the inlet gas stream contained 8,100 ppm by vol chlorine

and the outlet gas contained an average of only 0.36 ppm by vol chlorine. The outlet gas flow rate at 97°F was calculated to be 3,233 ACFM. Thus, the inlet gas stream contained 3.795 lb mol/h of chlorine and the outlet gas stream only 0.000170 lb mol/h of chlorine. The scrubber was absorbing 99.996% of the entering chlorine. The overall mass transfer coefficient was calculated to be 26.55 lb mol/h ft^3 atm for the second part of this test.

On August 12th, 1,744 lb of liquid chlorine was discharged from another one ton container into the flash pan at an average rate of 90.8 lb/min. The initial release rate of 140 lb/min declined to a minimum rate of 82 lb/min. After 7 minutes, the average chlorine discharge rate had been attained by air padding. The measured inlet gas flow to the scrubber was 3,024 ACFM at a temperature of 85°F and 29.7 in Hg barometric pressure. The scrubber sump contained 1,800 gal of 22.5 wt% sodium hydroxide solution which was recycled to the liquid distributor at a rate of 393 gpm. The temperature of the solution in the sump rose from 91 to 103°F during the test.

Analysis indicated that the inlet gas stream contained 53,420 ppm by vol chlorine and the outlet gas stream contained an average of 5.08 ppm by vol chlorine. At a temperature of 95°F, the outlet gas flow was calculated to be 2,920 ACFM. The inlet gas stream contained 24.19 lb mol/h of chlorine and the outlet gas stream contained 0.00218 lb mol/h of chlorine. Thus, the scrubber was absorbing 99.991% of the entering chlorine. The overall mass transfer coefficient was calculated to be 23.64 lb mol/h ft^3 atm for this test.

After all the liquid chlorine in this container had been discharged, the liquid in the flash pan again was allowed to vaporize. The measured inlet gas flow to the scrubber was 3,024 ACFM at a temperature of 85°F. Analysis indicated that the inlet gas stream contained 7,724 ppm by vol chlorine and the outlet gas stream contained an average of only 0.35 ppm by vol chlorine. The outlet gas flow rate at 96°F was calculated to be 3,078 ACFM. The inlet gas stream contained 3.498 lb mol/h of chlorine and the outlet gas stream contained only 0.000158 lb mol/h of chlorine. The scrubber was absorbing 99.995% of the entering chlorine. The overall mass transfer coefficient for the second part was found to be 25.53 lb mol/h ft^3 atm.

These test data demonstrate that this scrubber will consistently absorb over 99.99% of the chlorine in the entering gas steam. This efficiency is maintained even when the chlorine spill rate is as much as 66% greater than that specified by the Uniform Fire Code. This percentage removal is the same over a seven fold change in the amount of chlorine entering the scrubber. There a variation from the overall mass transfer coefficients of +5.0% to -6.5% from the average value. The number of lb mols of chlorine absorbed is not responsible for the variation. The interfacial area for mass transfer does not change. This variation must be due to the partial pressure driving force used in the calculations. A logarithmic average uses a ratio of the inlet to outlet concentrations of chlorine in the gas streams. A small error in the outlet concentration can cause a large change in this ratio.

Mass transfer theory can be applied to adjust the value of the mass transfer coefficient for various gas and liquid flow rates as has been described previously. Thus, the values obtained from these tests can be converted to a basic value for absorption of chlorine into a caustic soda solution at a standard gas and liquid flow rate. These bas values then can be used in the application of this scrubber design to other specified operating conditions. When the NIOSH specification for the IDLH was changed to 10 ppm of chlorine in 1994, only an increase in the liquid recycle flow rate was required to achieve an outlet concentration of 5 ppm chlorine.

The commercial scrubber design incorporates an extension of the liquid sump beyond the end of the packed scrubbing section. This modification permits installation of the fan on top of the sump extension. Also, a sump pump can be used to recycle the scrubbing liquid which eliminates liquid suction piping. The total pressure drop through this scrubber is less than 6 in of water. The large orifices used in the liquid distributor not only eliminate plugging problems, but require a pressure of only 5 psig at the pump discharge. There is no hazard as occurs by the use of high pressure caustic piping. The sump utilizes a composite, insulated, double wall fiber glass construction to safeguard against caustic spillage or solution freezing. The entire system has been designed to use materials resistant to corrosion by the operating environment.

Thus, a compact scrubber which meets the requirements of Section 80 of the Uniform Fire Code now is available for control of emergency chlorine discharges. The efficiency of this unit will equal or exceed that of custom designed vertical packed tower scrubbers. Using EPA test methods, it has been demonstrated capable of absorbing over 99.99% of the entering chlorine by full scale testing. This scrubber can be installed outside on a simple concrete foundation to meet a 100 mph wind loading and seismic IV specifications. No large foundations and expensive steel support structures are required. Its low profile (8 ft wide by 8 ft high by 15 ft overall length) allows it to be installed indoors in buildings of normal ceiling height if desired. The scrubber ready for connection to the compressed gas storage room can be shipped by truck. Its aesthetically simple appearance minimizes community concerns. The low 12.5 hp total power requirements for the fan and pump combined permit installation of a smaller emergency electric generator. There are not exposed metal surfaces which need costly maintenance.

This unique scrubber design has been granted a U.S. patent. The standard scrubber easily can be modified to

handle gas flows up to 8,500 ACFM without exceeding a pressure drop of 6 in of water. Also, it can be operated so as to meet other specified inlet or outlet concentrations for chlorine absorption. This design of horizontal packed bed scrubber also can be employed for control of emergency discharges of other compressed gases. By use of the ratio of the base value for absorption of chlorine to the base value for the absorption of another gas into a caustic soda solution, this scrubber can be applied for the removal of such other containment from a gas stream with high efficiency.

A full scale test already has been conducted on this scrubber absorbing sulfur dioxide released from a one ton container using a 19 wt% caustic soda solution as the scrubbing liquid. Again EPA specified methods were employed for testing and analyses. At an average discharge rate of 103.8 lb/min of liquid SO_2 from the container, the concentration of SO_2 in the inlet gas to the scrubber was 38.631 ppm by vol while the concentration in the discharge from the fan never exceeded 2.8 ppm by vol. This concentration is well below the 50 ppm which represents on half the IDLH for sulfur dioxide. On average, the scrubber was absorbing 99.997% of the entering SO_2 from the 2,936 ACFM inlet gas stream at 84°F.

With minor modifications, this scrubber can be applied to absorb contaminants such as sulfur dioxide, hydrogen sulfide, hydrogen chlorine, or hydrogen fluoride using a caustic soda or similar scrubbing solution. It has been proposed to apply this scrubber for absorbing ammonia from a gas stream. In this case, the scrubbing liquid used would be a dilute solution of sulfuric acid. Thus, this scrubber design can be applied to obtain high removal efficiency by absorption of any contaminant which reacts rapidly with the scrubbing liquid to produce a solution that exhibits a negligible vapor pressure of the contaminant.

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