<u>Maximizing Wet Scrubber Performance on HAP's</u>

Rick Hall
KCH Services, Inc.
144 Industrial Dr.
Forest City, NC 28043
(828) 245-9836

Wet scrubbers are used for abatement of waste gases from semiconductor manufacturing process tools and related equipment. Many wet scrubbers in operation are achieving less than expected emission results and many require frequent shutdown due to problems that can be eliminated or reduced with proper design and operation.

The goal of this paper is to familiarize the owner/engineer/operator of common design and process errors that lead to undesirable conditions, frequent maintenance, and safety hazards. Design, process and operation suggestions will be provided in order to maximize wet scrubber performance and operation.

The following five topics will be addressed: (1) root causes of poor scrubber operation, (2) design of wet packed bed scrubbers to reduce emissions of HAP's to low or non-detectable levels, (3) maximizing design and operation to reduce cost of ownership, (4) developments in liquid distribution design and (5) techniques for reduction or elimination of biological growth.

Root Causes of Poor Scrubber Operation

It is implausible to assume that a scrubber is functioning properly if the pump is on and fan is drawing air. Various items within the scrubber unit and supporting equipment must be checked and maintained after installation and start-up. Even with proper operation and a good checklist, poor design can lead to less than desirable operating conditions and upsets.

Inadequate Sump Fluid Replenishment

For scrubbers using overflow or blowdown to maintain fresh solution, the fresh water make-up rate must be adequate to maintain the concentration gradient between the liquid and gas phase. The concentration gradient for a given unit is dependent upon a number of variables and if not maintained the efficiency of a system can drop quickly and significantly. In some cases, if the gradient is lost, contaminants can be stripped from solution. In these cases, the inlet loading of a particular contaminant can be lower than the tested outlet concentration.

Mentioned earlier, two techniques for sump replenishment are overflow and blowdown with the overflow method being more common and simple to operate with no instrumentation other than a rotometer. Fresh water is added through an adjustable flow meter at a continuous rate while the sump liquid overflows into the scrubber drain at a predetermined location. In the blowdown method, liquid is forced to drain by the recirculation pump. If blowdown is inadequate, the rate of scaling and algae growth will increase. Sedimentation will also increase. Sump level controls and solenoid valves or flow control valves have to be provided in the recirculation piping to allow fluid to be discharged at a determined rate. In either method, the make-up water rate must be greater than the “to drain” rate due evaporation losses which can be from 2 to 4 gpm depending on weather conditions and operating temperatures. This is the key point for keeping the concentration gradient in check.

Pumps

Improper Pump Size

To determine pump size and selection for a given unit it is necessary to perform hydraulic calculations for the recirculation system. Three parameters affect the required design head of a pump: friction losses through piping and fittings, pumping height, and pressure loss of nozzles. If add-in items, such as basket strainers, are not accounted for in the design of a system the pump flow rate will suffer and this, in turn, can effect efficiency.

Pump Logistics

Pumps that are subjected to adverse conditions due to location or water level can lead performance problems. A low sump operating level can create vortexing and the pump will start to suck air, which will quickly deteriorate the volume and pressure of the pump.

Improper Addition of Scrubbing Liquor

Inadequate addition of scrubbing liquid can significantly reduce performance of scrubbers. If ammonia is being scrubbed and sulfuric acid is the neutralizing agent, outlet readings can be higher than inlet readings if pH is not maintained.

Location of pH Probe

A common error with pH control systems is location of the pH probe versus the location of the chemical supply injection. Locating a pH probe within 12 inches from the chemical injection pipe will not give true indication of the pH of the scrubber liquid. The pH controller and on/off switch for chemical injection will continually chase each other.

Velocity Profile

Unfortunately, scrubbers have velocity constraints that play a key role with performance. Once a scrubber is in operation the cross sectional area has forever been established. The likelihood of adding an extra 50 to 75 ft2 is cost prohibitive. If a unit is designed for 10,000 cfm and the fan is exhausting 14,000-cfm, the performance and efficiency decreases while the pressure loss increases. Exceeding the design velocity profile of a unit effects mist eliminator performance, absorption, and evaporation losses.

Channeling Caused by Plugged Spray Nozzles

Spray nozzles can be an operator's nightmare and the cause of frequent and expensive unplanned shutdowns. Plugging should be expected when using scrubbers that incorporate spray nozzles. When a nozzle plugs, the area of packing directly below is not receiving liquid. This will create an area where no absorption is taking place and therefore decreases the efficiency of the scrubber.

Channeling Caused by Poor Air Distribution and Rectangular Housings

In vertical scrubbers, inlets are located 90 degrees from air direction through the packed tower. The incoming air stream must make an abrupt 90-degree turn into the packing. Very few scrubbers are designed to account for this abrupt turn. Air follows the path of least resistance. Air will continue straight through the inlet to the back wall of the vessel where it is disturbed and will spiral and vortex up through the packed bed section. This channeling creates dead spots within the packed bed. The now channeled air streams will pass through the packed bed at higher velocities below the designed retention time.

Air will also follow the same general undisrupted path through rectangular scrubber housings. Dead spaces are common in rectangular vertical and horizontal scrubber housings. Design for these units must also account for air distribution inefficiencies. Theoretical analyses suggest decreases in performance for units without proper design.

Biological Growth

Build-ups of biological growth in packed bed sections and mist eliminators will adversely affect performance of scrubbers. In acid scrubbers, where pH is typically maintained in the 8 to 9 ranges, biological growth is a commonality. Without treatment, the growth can create areas of channeling and increase the pressure drop through the scrubber.

Design of Wet Packed Bed Scrubbers to Reduce HAP's to Low or Non-Detectable Levels

L/G Ratio – 20 to 40 gpm/1000 cfm or 5 to 10 gpm/ft2

Velocity - 300 to 400 fpm on acids/alkali's and less than 300 fpm for NOx

Configuration – Vertical (Counter Current) Round Vessels

Air Distribution Enhancement – Use Packing Support Beams as turning veins for proper

air distribution

Liquid Distribution – Overflow Weirs with V-Notches (min. 12 drips points/ft2)

Packed Bed Depths – Acids: 8-12 ft, Alkali's: 6-10 ft, NOx: Ratio Dependent

Packing Size – Minimum 40ft2/ft3 of surface area

Mist Eliminator – Chevron Type 99% efficiency greater than 10 micron

Mist Eliminator Velocity – 800 fpm for high efficiency

Material of Construction – Polypropylene (UV inhibitor in sunlight)

Maximizing Design and Operation to Reduce Cost of Ownership

Pumps

Include a redundant pump and ensure control system is capable of automated switchover in case of loss of pump or low flow. Utilize pressure gauges and flow meters on discharge piping. Oversize pumps by 125% to ensure adequate capacity and operation.

pH Control System

It is best to monitor pH away from the chemical injection area. To measure pH as it exits the packed bed section, utilize a catch cup just below the packing to capture liquids falling from above. The catch shall be plumbed to the exterior portion of the unit where liquid will gravity flow through the pH probe and down back into the sump area.

Chemical injection should be as close to the pump suction as possible. Utilize a pipe with small holes to act as a sparging device as chemical is brought into the unit. Chemical should exit the pipe near the pump suction area. The holes in the pipe will allow sump water to mix with the neutralizing chemical prior to entering the recirculation piping. The pump impellers will provide an excellent means of turbulence and mixing to prevent the channeling of liquid through the piping and packed bed.

Instrumentation

Monitor and Alarm the following:
pH
Fresh Water Make-up
Pump Flow Rate
Pump Pressure
Pressure Drop (Scrubber and Mist Eliminator)
Sump Levels
Blowdown
Sump Temperature

Air flow and air temperature should also be monitored in the duct system at a suitable location before the scrubber.

Access Considerations

Design mist eliminators for ease of removal for inspection, cleaning and replacement. Mist eliminator blades should be encapsulated in boxes to prevent potential by-pass and for ease of removal.

Access doors should be provided for an operator to enter the packed bed section, sump area, pump area, and liquid distribution section. The access for the sump area should be above water level to prevent leak points.

View doors should be provided for easy inspection of internals. Borosilicate glass works best as a window. It resists fading unlike clear PVC or Plexiglas and takes the heat of the high intensity lights. Locate widows between the water line and packing bottom, at the packed bed section, and at the liquid distribution section. Utilize slide shades to keep light from entering the scrubber where possible. Locate lights (300 watt minimum) 90 degrees from the inspection windows for operators to adequately inspect internals. At this angle, light back scattering from mist and droplets is minimal. Without the use of lighting, viewing is poor.

Biological Growth

Establish a biological growth treatment program for acid scrubbers prior to start-up.

Developments in Liquid Distribution

Overflow Weir Liquid Distribution System

Overflow weirs are comprised of an inlet header pipe with several smaller size pipe drops, a distribution box with several side spouts, and a series of weir troughs with V shaped notches configured along the sides of the troughs.

The overflow weir system works via gravity flow of the scrubbing liquid through the inlet header pipe. Liquid is evenly distributed through a series of drops as it flows through the header. The distribution box collects the liquid from the header and evenly distributes the liquid through a series of side spouts down to individual weir troughs. The weir troughs fill and overflow the V-notches down into the packed bed section.

Benefits of Overflow Weir Systems

1. Eliminates nozzles that are prone to plugging. Plugging creates dry sections that can lower overall efficiency.

2. Utilization of weirs offers a major reduction of mist versus nozzles. Nozzles work at higher pressures, which emit fine mist that get captured and carried into the mist eliminator. Heavy loading of mist can overload a mist eliminator and liquid can get carried through.
3. Weirs work via gravity flow and are capable of high turndown, whereas, nozzles are designed to operate at a constant pressure range.
4. Weir systems operate with lower energy requirements. Hydraulic design for nozzles includes pumping height, friction losses, and nozzle pressure. Overflow weir design eliminates the design requirement for nozzle pressure, therefore, weir systems typically require 1/3 less total horsepower than nozzle systems.

Design

1. Minimum of 12 drip points per square foot.
2. Utilize in systems over 4' diameter.
3. Maximum velocity of 1200 fpm between the trough sections.
4. The system shall be built in components, not as a single device, to allow field adjustment of each component to ensure proper liquid distribution. Each trough and weir shall be field adjustable as well. The troughs shall include adjustable side plates to calibrate even flow over each V-Notch once the unit is field installed.
5. Design calculations shall verify balancing of liquid flow through each flow point from the header pipe to the V-Notches.
6. Design for deflections due to full liquid systems that can weigh as much as 30 to 60 pounds per square foot.

Techniques for Reduction of Biological Growth

- Acid wash the unit periodically or shock it with sodium hypochlorite (5% solution) to destroy algae and other biological organisms.
- Use a chlorinating or brominating system to destroy algae and other biological organisms.
- Use UV light devices for disinfecting supply and recirculation liquid.
- Segregate VOC exhaust from scrubbed exhaust. Field experience indicates less evidence of growth with non-VOC exhaust.
- Segregate all sources of phosphoric acid or other phosphates that feed algae and scrub them with a strong caustic solution at a pH of 10 to 11.
- Field experiences suggest reduced growth in polypropylene constructed units versus FRP construction. Porosity and pinholes tend to be breeding areas, which are common in FRP units.
- Utilize sliding shades over all clear view doors to prevent light from entering the unit.
- Use other chemicals such as copper sulfate.