Re-engineering a Dry-Scrubbing Odor Control System: Implications on Cost and Performance

Abstract

Dry-scrubbing (or gas-phase) air filtration media are used in many odor control systems. Dry-scrubbing media can vary from adsorptive media such as activated carbon to chemisorptive media such as impregnated alumina, carbon, or zeolite. These media remove odorous gases by both physical and chemical means, and can provide air that is essentially odor-free.

Re-engineering such an odor control system is currently being considered. The ability to increase the face velocity of the system can reduce the overall size of the odor scrubber, thus reducing system footprint and potentially installed cost. Other parameters affected by the face velocity are the contaminant mass transfer zone (MTZ) in the bed and the operational costs. The MTZ describes that portion of the media bed in which active adsorption and/or chemisorption is occurring. The leading edge of the MTZ sees odorous gases at 100% of their inlet concentration, while the back edge of this zone contains essentially 0% of the inlet concentration. Operational costs here would be the energy costs of powering the system and cost for replacement of the media. An investigation of the MTZ in dry-scrubbing media systems has been performed at an elevated velocity, which would allow for a reduction in the overall size of the scrubber. The impact on installed costs and operational costs are investigated as well. These results are presented.

Introduction

Engineered dry-scrubbing media has been used for years to remove the inherent odors of the wastewater industry. The design of such scrubbers has been generally based on a face velocity of 60-100 feet per minute (fpm) through the scrubbing media. This is deemed through experience and various performance tests to provide sufficient removal of the odorous gases from these applications (Stanley, 2003; Stanley, 2004).

Now the face velocity used in odor scrubbers is being reevaluated. The main impetus for this being the reduction of the overall scrubber size and initial capital cost. The face area of the scrubber is inversely proportional to the velocity, as is intuitive, and can be seen in the following equation.

$$A = \frac{F}{v} \qquad [1]$$

A = face area of the system in square feet (ft^2)
F = total airflow of the system in cubic feet per minute (cfm)
v = velocity of air through the media bed in feet per minute (fpm)

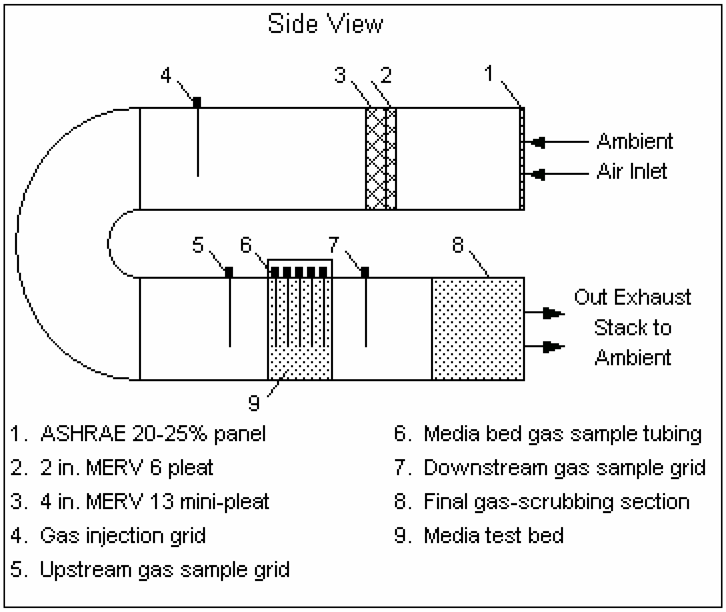
Thus, increasing the velocity of the system by a factor of 1.5 decreases the face area of the scrubber by a factor of 1.5. This can have a significant impact on the initial capital cost of the system which is realized in the cost of the vessel or housing material (fiberglass, steel, etc.) and in the amount of dry-scrubbing media required to fill the scrubber.

The performance of the system and the maintenance costs are also items to investigate at a higher velocity. Performance can be investigated by looking at breakthrough of odorous gas over the scrubber and at the mass transfer zone of the gas within the scrubber. Maintenance can be simplified to media replacement cost and utilities to power the scrubber.

Methods Used in Investigation

The affect on performance of the media at higher velocities was carried out by challenging a system at 100 fpm and 150 fpm with similar concentrations of hydrogen sulfide (H_2S) gas and measuring breakthrough of the gas in the media bed. The effects on capital and maintenance costs were investigated by comparing two designs for 3,000 cfm, one at each velocity.

A diagram of the test apparatus is shown in Figure 1. The face area was 4 square feet (ft^2) with a media bed depth of 1 foot (ft). The incoming air was filtered by the indicated particulate filters before gas was injected to the system. A 14 point grid of stainless steel tubing was used to inject the gas across the face area of the ductwork. The gas concentration upstream and downstream of the media bed was measured with a 6 point grid. The gas concentration within the bed was measured with stainless steel tubing inserted every 2 in. along the depth of the media bed. Each tubing length had 3 sampling points spaced evenly along the height of the bed. Thus, concentrations could be measured at the following depths: upstream, 2 in., 4 in., 8 in., 10 in., and downstream. Finally, a final gas scrubbing section is included for any breakthrough from the media bed.



The mass transfer zone was investigated using an equation similar to that put forth by Kovach to and by review of the media bed breakthrough curves (Kovach, 1978). The equation used is shown below as Equation 2. Kovach's equation also uses a degree of saturation which appears to lengthen the MTZ slightly. Here that degree of saturation was not used.

Figure 1 – Schematic of test apparatus

$$MTZ = (total\ bed\ depth)\left(\frac{t_2 - t_1}{t_2}\right) \qquad [2]$$

t_1 = time to breakthrough

t_2 = time to saturation

The total bed depth used in these calculations was 6 in., corresponding to the 6 in. sample port. The time to breakthrough was based on a detection of 50 ppb of hydrogen sulfide at the 6in. sample port. Complete saturation was not observed at the 6 in. sample port because of the long testing time required for saturation at this depth. Therefore, the time to saturation was based on the time elapsed until the concentration of hydrogen sulfide at the 2 in. sample port leveled off. This time was added to the breakthrough time at the 6 in. sample port to estimate the time to saturation at 6 in. These results were then compared to the actual breakthrough curves to check whether the assumptions used had validity.

The total amount of hydrogen sulfide gas removed until breakthrough (50 ppb) at the 6 in. sample port was calculated based on ideal gas relationships at normal temperatures and pressures (77ºF, 1 atm). This is dependent on the average inlet concentration and airflow as shown using the following equation.

$$lb\ H_2S = \frac{C}{100} \times F \times T \times \frac{28.32\,L}{ft^3} \times \frac{1\,mole}{24.45\,L} \times \frac{34.08\,g\ H_2S}{mole} \times \frac{lb}{453.6\,g} \times \frac{60\,\mathrm{min}}{hr} \qquad [3]$$

C = concentration of hydrogen sulfide (H_2S) in air in volume %
F = total airflow in cubic feet per minute (cfm)
T = time to 50 ppb breakthrough in hours

This equation simplifies to:

$$lb\ H_2S = C \times F \times T \times \left(5.221 \times 10^{-2}\right) \qquad [4]$$

Results of Investigation - Performance Experiments

The mass transfer zones were estimated to be less than 4 in. at both face velocities as shown in Table I. The target face velocities for the tests were 100 fpm and 150 fpm with actually achieved velocities of 90 fpm and 152 fpm. The results of the MTZ calculation, showed the lower face velocity case to have a slightly longer MTZ than the higher velocity. This is opposite to the traditional thought and what has been shown in other work of MTZ elongation with increasing velocity (Kovach, 1978). One source of this difference may be the estimated time to saturation. If both tests were run to complete saturation, it is expected that the lower face velocity case would show the shorter MTZ length. Moreover, these values are not intended to be exact calculations of the MTZ length, but to give some indication of its length in relation to the full bed depth. Full scale scrubber bed depths are 36 in., which is about 10 times this MTZ length. Thus, the actual scrubber bed depths would more than contain these MTZ lengths, at either face velocity. This is also displayed visually in Figure 2.

Table I – Estimated mass transfer zone (MTZ) at two tested face velocities

Face Velocity (fpm)	**Bed Depth** (in)	**t_1** (hr)	**$t_{2, est}$** (in)	**MTZ $_{est}$** (in)	**Full Scale Depth / MTZ$_{est}$ ***
90	6	121.0	298.0	3.6	10
152	6	53.9	121.9	3.3	11

est = estimated value
* Full scale scrubber bed depth is 36 in.

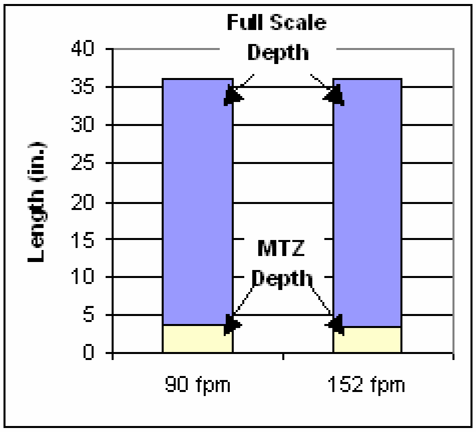


Figure 2 – Visual representation of MTZ depth relative to full scale bed

These relative MTZ lengths were also confirmed by plotting the concentration of hydrogen sulfide at various bed depths, Figures 3 and 4. The MTZ can be thought of as the portion of the bed where the contaminant concentration in the air progresses from the challenge concentration down to essentially 0. As is shown, the bed depth of 2 in. increased much more rapidly toward the challenge concentration than the latter depths. The 4 in. and 6 in. bed depths showed a significant period of time without breakthrough occurring. This points to the fact that the MTZ length is more than 2", but less than 4" or 6". The reason 4 in. data is not shown for the lower velocity is because there was a malfunction in the sampling tube at that depth, whereas the higher velocity case was able to sample at 4 in. At any rate, these concentration curves support the estimated 3-4 in. range of the MTZ lengths shown in Table I.

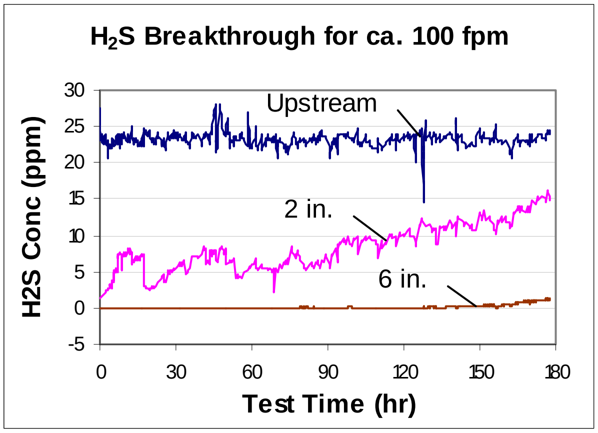


Figure 4 - Breakthrough concentration curves at bed depths of 2 in. and 6 in. for the 90 fpm case

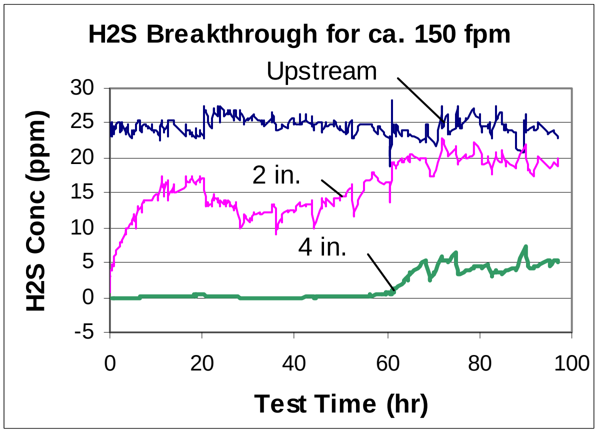


Figure 3 - Breakthrough concentration curves at bed depths of 2 in. and 4 in. for the 152 fpm case

The impact on media capacity was investigated next. The experimental results did show approximately 20% less hydrogen sulfide removed at the 152 fpm case, see Table II. This difference could have been caused by a smaller particle size that was found in the 90 fpm experiment. An atypical amount of smaller particles was noticed visually at test completion and during the test a high pressure drop was measured in the system. Table III shows the pressure drops realized during the tests and those expected with 1/8 in. media. The 152 fpm case appeared to be similar to 1/8 in. media in pressure drop as well as by visual inspection. Thus, the difference in mass removed is attributed (at least in part) to the decreased particle size of the media used in the lower velocity test. This could be further confirmed by subsequent testing as was carried out here, or through small scale testing at these velocities.

Table II – Comparing amounts of H_2S removed at 6 in depth & 50 ppb breakthrough

Face Velocity (fpm)	Bed Depth (in)	$Conc_{avg}$ (ppm)	C_{avg} (vol %)	F_{avg} (cfm)	T (hr)	mass H_2S (lb)
90	6	23.2	0.0023%	358.1	121.0	5.25
152	6	24.5	0.0025%	607.8	53.9	4.19

Table III – Experimental pressure drops versus those expected for 1/8 in. media.

Face Velocity (fpm)	Experimental Avg ΔP (iwg)	Expected 1/8" ΔP (iwg)
90 fpm	3.4	1.5
152 fpm	4.2	4.2

Results of Investigation - Comparison of Costs (3000 cfm at 100 and 150 fpm)

The topic is now turned to the impact on cost of these two face velocities. The first cost is less for the higher velocity. On the other hand, the utilities cost is somewhat higher for the higher velocity case. This section carries out an investigation of a typical system at these two face velocities and some of the impacts on cost that are realized.

A typical unit design considered here is shown in Figure 5. This system consists of a mist eliminator section to drop out physical water, 3 ft. of dry-scrubbing odor control media in the direction of airflow, and finally a blower drawing air through the system which is exhausted to the ambient atmosphere.

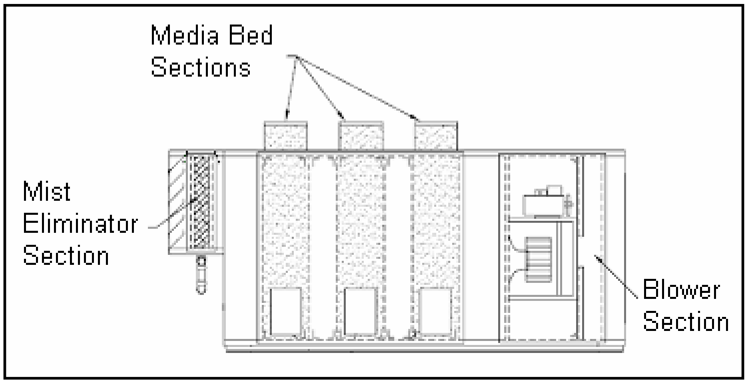
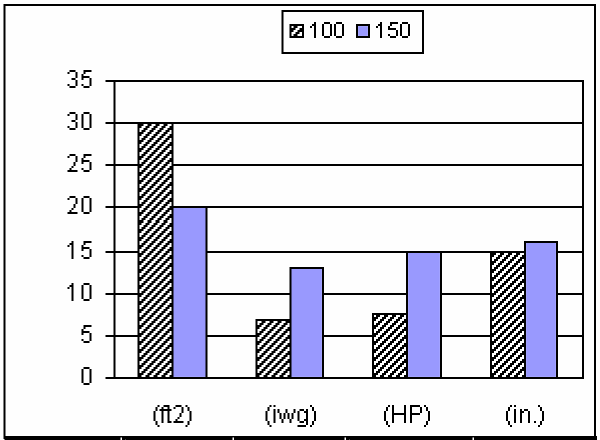


Figure 5 – Typical draw through deep bed scrubber used for odor control

Increasing the velocity will impact the size of the scrubber and the resistance to airflow through the scrubber which affects the motor and blower required. The changes in system properties are shown in Figure 6.

Reducing the face area can have a significant impact on the cost of the housing material as well as the odor control media contained in the system. Thus, the savings realized for designing at 150 fpm is 22%. Relative savings for increasing the velocity are shown in Figure 7. Actual costs are not provided for protection of the vendor supplying this information. The increase in cost of the motor/blower assembly was also reviewed and is negligible compared to the total system cost.



Face Velocity (fpm)	Face Area (ft^2)	ΔP (iwg)	Motor (HP)	Blower Wheel (in.)
100	30	7.0	7.5	15
150	20	13.1	15	16

Figure 6 – Property comparison chart for various properties at 3,000 cfm

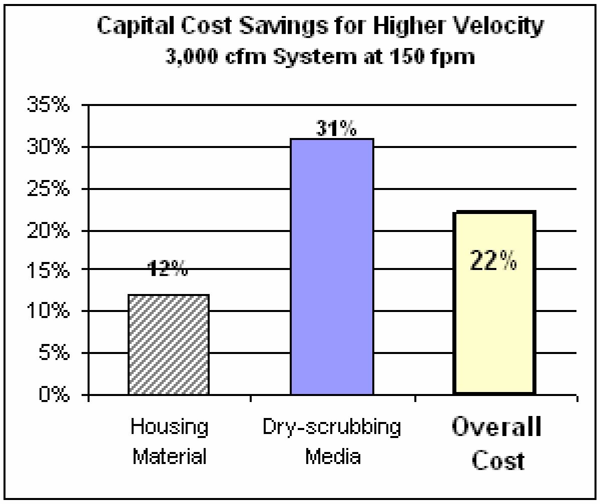


Figure 7 – Capital cost impact for increasing the velocity. Shown as percent savings for using a 150 fpm design versus a 100 fpm design.

Maintenance costs in terms of media replacement decrease per media change out when the face velocity is increased, as is shown in Table IV. The savings for each media replacement is 31%, mimicking the capital media savings. The annualized cost of the media is estimated to be the same in either case. Therefore, the intervals between media change out would be shorter.

The utilities cost in terms of motor electricity does increase for the higher velocity, as shown in Table IV. The annual electricity usage is estimated to increases to 213% of the lower velocity design. This is due to the higher pressure drop through the media and the subsequent motor/blower required.

Table IV – Maintenance cost comparison for increased velocity at 3,000 cfm

Test Case	Media Replacement		Motor Electricity*	
(fpm)	(Each)	(Annual)+	(Annual kW-hr)	(%)
100	100%	100%	35,811	100%
150	69%	100%	76,379	213%

* Based on 90% efficiency and running 8760 hr/year
+ Based on media consumption rate being the same

Conclusions

Redesigning an odor control scrubber by increasing the face velocity is a viable option for the type of deep bed scrubber investigated in this paper. The mass transfer zone against hydrogen sulfide was well within the bed depth and did not appear to increase with the increased velocity. Further experimentation could be performed to confirm this more fully.

The impact on capital cost was to realize a significant savings of 22% for the 3,000 cfm design. Individual replacements of media for the system also decreased in cost by 31 %. Finally, the electricity usage increased by 113% for the larger motor/blower. This information can be very useful to a wastewater plant, depending on how the individual plant's budget is organized. Some plants may have very tight budgets for capital equipment, and therefore desire to decrease the initial cost of the system. In this case the higher velocity may make much more since and the increased utilities are countered by the reduced capital cost as well as reduced single media replacement cost. On the other hand, if a plant has a freer capital cost budget in order to minimize other items like utilities, then the lower velocity scenario may make more sense.

References

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