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Biofiltration Using Compost and Hog Fuel as a Means of Removing Reduced Sulfur Gases from Air Emissions

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ABSTRACT

Biofilters using compost, hog fuel and a 50:50 mixture of the two were used to evaluate the removal from air of hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyl disulfide, individually and in combination. Rates of biofilter media degradation were measured. These rates were higher in the presence of reduced sulfur gases compared to the passage of air only through the biofilters. Hog fuel was more resistant to degradation than compost. Monod kinetics parameters were evaluated for the removal of H_2S, dimethyl sulfide and dimethyl disulphide using all three biofilter media and are reported. The initial start up times for the biofilters and their response times to transient changes in H_2S, methyl mercaptan and dimethyl disulphide pollutant gas concentration and airflow rate were measured and are reported. Supply of moist air to the biofilters during periods in which no contaminants were present in the air (e.g. during mill shutdowns) resulted in shortened restart times.

INTRODUCTION

Biofiltration [1] is a process in which air containing pollutants is passed through a bed of moist, porous material in order to remove the pollutants. In this bed the air borne pollutants are transferred from the carrier gas into a water layer which surrounds the solid particles in the biofilter bed. Microorganisms, resident on the moist bed particle surfaces or within the water film surrounding these surfaces, consume these pollutants, usually converting them to simple, environmentally innocuous compounds such as carbon dioxide and water. Biofiltration is suitable for the removal of those compounds that are biologically oxidizable and which are not present, in the air to be cleaned, at concentrations which are toxic to the microbial population. Some of the nutrients for the growth of the microorganisms are provided by the gaseous pollutants, some come from the biofilter materials themselves, which contain both organic and inorganic materials.

The biofiltration process is relatively cheap [2] and is suitable for use in cleaning up of high volume, low concentration air emissions. For such emissions it is said to have significantly lower capital and operating costs than incineration, adsorption or catalytic oxidation [1]. It is not suitable for treatment of air emissions containing high concentrations of organics nor for compounds that are resistant to microbial decomposition. It can occupy a large amount of floor/ground area when treating compounds that degrade at low rates. Several air emission streams from the kraft pulping process qualify as high volume, low concentration streams, see Table 1. In addition these

TABLE 1: Comparing the Reduced Sulfur Gas Concentrations and Temperatures Used in This Study to Odour Threshold Concentrations and Typical Kraft Mill Emission Source Concentrations and Temperatures [9,10].

	H2S	MM	DMS	DMDS	Temperature
Range Used In this Study (ppm)	10-615 ppm	37-141 ppm	3-25 ppm	5-54 ppm	25-27 °C
Odour Threshold Concentration	0.03-900 ppb	0.02-40 ppb	1-20 ppb	0.03-4 ppb	
Washer Hood Vent	0-5 ppm	0-10 ppm	0-15 ppm	0-3 ppm	20-45 °C
Washer Seal Tank	0-2 ppm	10-50 ppm	10-700 ppm	1-150 ppm	39-75 °C
Smelt Dissolving Tank	0-75 ppm	0-18 ppm	0-4 ppm	0-3 ppm	60-110 °C
Low Pressure Feeder Vented thru Chip Bin	0-300 ppm	10-250 ppm	40-270 ppm	0-2000 ppm	?
Knotter	0 ppm	0 ppm	4 ppm	2 ppm	32-60 °C
Black Liquor Oxidation System	0-5 ppm	0-10 ppm	0-3 ppm	0-1 ppm	33-48 °C

emissions are frequently variable in concentration. The compounds which need to be removed include a number of reduced sulfur (RS) gases [hydrogen sulfide H_2S, methyl mercaptan (MM) CH_3SH, dimethyl sulfide (DMS) $(CH_3)_2S$ and dimethyl disulfide (DMDS) $(CH_3)_2S_2$]. These gases, collectively part of a group of compounds known as total reduced sulfur (TRS) gases, have foul odours and low odour thresholds, see Table 1. They are cause for many complaints to pulp mills from residents living near these mills. The presence of these gases in low concentrations in the air can cause irritation to humans, can lower property values, can result in lowering of exposed worker productivity and in increased levels of lost work days [3].

MATERIALS AND METHODS

Figure 1 is a diagram of the biofilters used in the part of this work concerned with RS gas removal by biofiltration. The biofilter bed media were compost, hog fuel and a mixture of the two. Compost was chosen because it's commonly used as a biofilter bed material in practice and by other researchers who have shown it to be effective. Hog fuel was chosen because it's a waste material from the forest products industry and is available, cheaply, at most mills. The mixture (50% compost, 50% hog fuel by weight) was used to gain any advantages that might be unique to either one of them. To improve the air permeability of

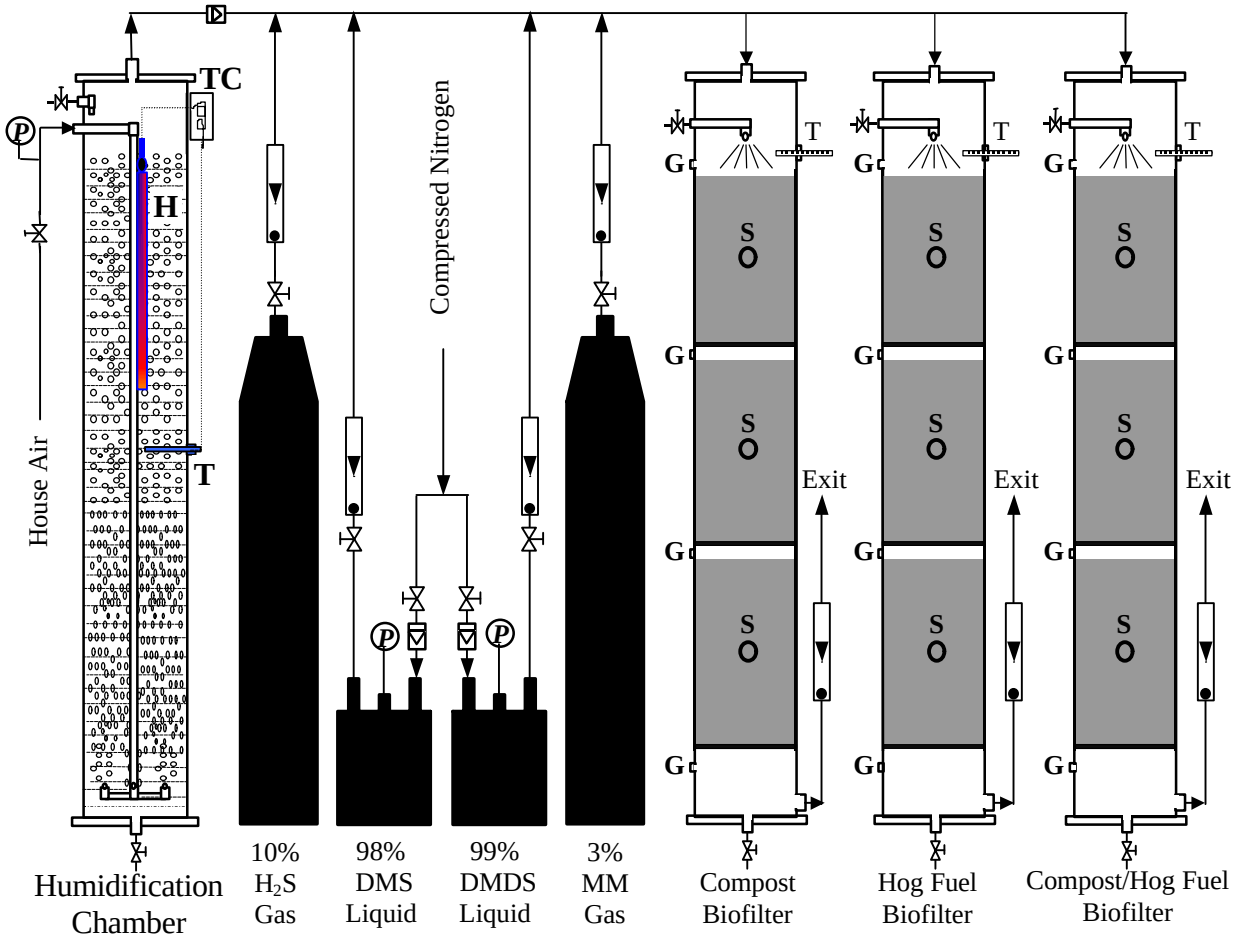

Figure 1. Diagram of experimental set-up: G, gas sampling ports; H, immersion heater; P, pressure gauge; S, media sampling points; T, thermocouple/thermometer; TC, temperature controller.

these biofilter beds perlite (1 part by weight of perlite to 4 parts of biofilter media) was added to various bed media. 25 kg of dolomitic lime were also added to each cubic meter of biofilter medium to try to keep the pH from becoming too acidic as a result of sulfuric acid generation which occurs during the microbial oxidation of the sulfur atoms in the

various gases. No liquid water was added to the biofilters since the amount carried into them by saturated air was adequate to keep the biofilter media moist. Downflow of the gas stream was employed to give a better, as compared to upflow, distribution of moisture content throughout the biofilter bed. No inorganic nutrients were added to the biofilters other than those noted above.

The biofilter operating temperatures in this study were in the range 25-27°C. These are on the low side for most of the pulp mill exhaust streams listed in Table 1, but are realistic for the washer hood emissions and the smelt dissolving tank emissions.

The biofilter media were seeded with activated sludge from local kraft pulp mills. This was done to introduce microorganisms into the biofilters that had previous exposure to RS gases. The gases used were synthetic mixtures prepared in known concentrations to be similar to kraft mill air emissions. Gas analysis was done by gas chromatography, using a flame photometric detector.

Gas mixtures were made up by metering the desired amount of RS gas into a metered flow of humidified air. H_2S and methyl mercaptan (MM) were obtained from gas cylinders having known concentrations of RS gas in nitrogen. Dimethyl sulfide (DMS) and dimethyl disulfide (DMDS) are liquids at room temperature. For these liquid RS compounds a metered flow of nitrogen was sparged into a stainless steel tank containing either DMS or DMDS. The vapor-laden steams from this procedure were then mixed with humidified air. RS gas concentrations in all tests were measured at the inlet to the biofilters and at their outlets.

The following parameters were calculated from the experimental measurements and used in analyzing the results of our tests.

$$\tau = (V/Q)(3600) = \text{empty bed residence time (s)} \ldots (1)$$

$$L_s = (Q/A) = \text{waste air surface loading rate } (m^3\ m^{-2}\ h^{-1}) \ldots (2)$$

$$L_m = [(Q/V)(C_{in}\ (ß)] = \text{contaminant mass loading (g RS gas } m^{-3} \text{ of biofilter } h^{-1}) \ldots (3)$$

$$RE = [(C_{in} - C_{out})/(C_{in})](100) = \text{removal efficiency (\%)} \ldots (4)$$

$$EC = (Q/V)(Cin - Cout)(ß) = \text{elimination capacity (g RS gas removed } m^{-3} \text{ of biofilter } h^{-1}) \ldots (5)$$

where, V is the volume of biofilter medium (m^3); Q is the waste airflow rate ($m^3\ h^{-1}$); A is the cross-sectional area of the biofilter bed (m^2); C_{in} and C_{out} are the inlet and outlet contaminant concentrations respectively (ppmv); ß is a units conversion factor = $[(M)(1\times10^{-3})]/(24.45)$; and M is the contaminant molecular weight.

The biodegradability of the biofilter media was done by determining the amount of CO_2 evolved as moist air was passed through the media with or without the presence of RS gases. Details of these filter media degradation experiments can be found elsewhere [4].

RESULTS AND DISCUSSIONS

Biofilter Media Degradation

The biofilter media are a source of carbon, and other nutrients, for the microbial population resident on these media. Thus, over time, some of the media's carbon will be converted to carbon dioxide as a result of microbial respiration processes. This means that as time in service proceeds, the mass of the biofilter medium will diminish.

Plots of the natural log of the amount of carbon remaining in the biofilter sample vs. time showed three distinct, straight-line regions [4]. Figure 2 is typical of such plots. For each of these three stages a first order rate constant was calculated and is reported in Table 2 as is the amount of carbon lost over the duration of the test. At first these studies were done in the absence of RS gases using air only. Later studies were done in the presence of H_2S and MM. Half lives for the various media were estimated and are presented in Table 2. The hog fuel bed was more resistant to degradation than the mixture bed, which in turn was more resistant than the compost bed both in the presence and absence of RS gases. The presence of RS gases accelerated the degradation of the biofilter media, MM more so than hydrogen sulfide [4].

TABLE 2: Rates and Extents of Degradation of Biofilter Bed Materials in Air and Air Containing H_2S or Methyl Mercaptan.

	Compost	**Mixture**	**Hog Fuel**
Air Only			
Stage 1 Duration (d)	3	23	24
Stage 1 Rate Constant (d^{-1})	0.0054	0.0023	0.0015
Stage 2 Duration (d)	21	17	3
Stage 2 Rate Constant (d^{-1})	0.0022	0.0011	0.009
Stage 3 Duration (d)	103	87	100
Stage 3 Rate Constant (d^{-1})	0.0013	0.0006	0.0003
% Biofilter Bed Carbon Lost During Test	17.6	12.3	6.4
Half Life of Medium Air Only (d)	533	1155	2310
Half Life of Medium Air + 300 ppm H_2S	207	544	1344
Half Life of Medium Air + 300 ppm MM	192	524	1185

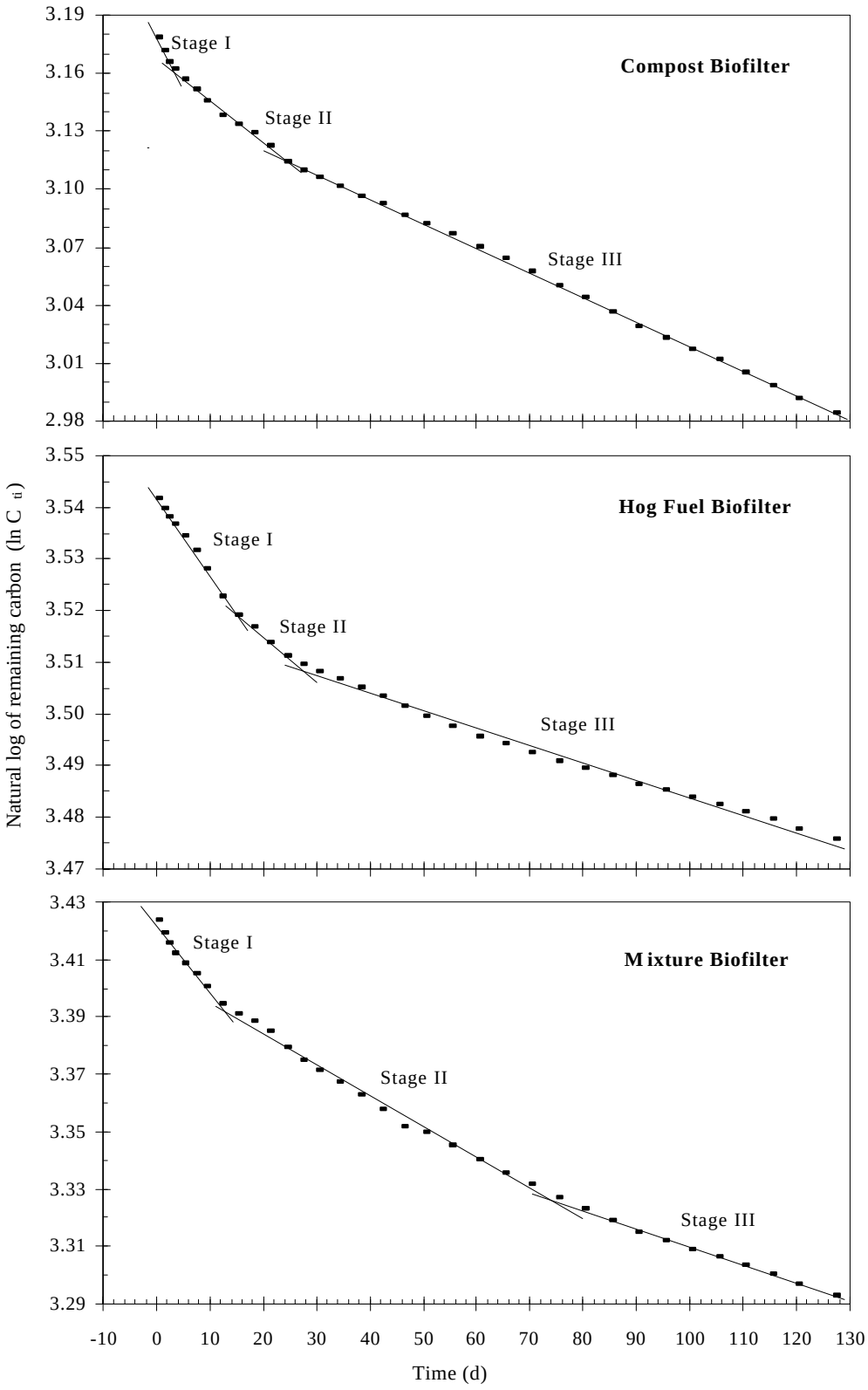

Figure 2. Degradation stages and reaction rate kinetics of biofilter media materials.

Kinetics of RS Gas Removal

Experimental data were fitted to a Monod type kinetic model for the rate of RS gas removal. For such kinetics

$$EC = \frac{V_{max} \cdot C_{ln}}{(K_m + C_{ln})} \quad \ldots (6)$$

where, V_{max} is a kinetic constant, the maximum rate of RS gas removal, (g RS gas removed m^{-3} of biofilter h^{-1}); Km is another kinetic constant, (the log-mean RS gas concentration when EC = ½ V_{max} ppmv); and C_{ln} is the log mean concentration (ppmv) of RS gas between the biofilter inlet and outlet (C_{ln} = [C_{in} - C_{out}]/(ln [C_{in}/C_{out}). The higher the value of V_{max} the greater the elimination capacity, the higher the value of Km the lower the elimination capacity.

Figures 3, 4 and 5 show the data for removal of H_2S, using the compost, mixture and hog fuel biofilters respectively. These data were fitted to a Monod model. The data are for removal of H_2S alone from air and H_2S removal from air in the presence of DMS and DMDS. Figures 6, 7 and 8 are for the removal of DMS in the compost, mixture and hog fuel biofilters and similarly Figures 8, 9 and 10 are for the removal of DMDS [5]. The Monod kinetic model fits the data reasonably well in all cases. The best kinetic parameter values, least square fitted to Equation 6, are reported in Table 3.

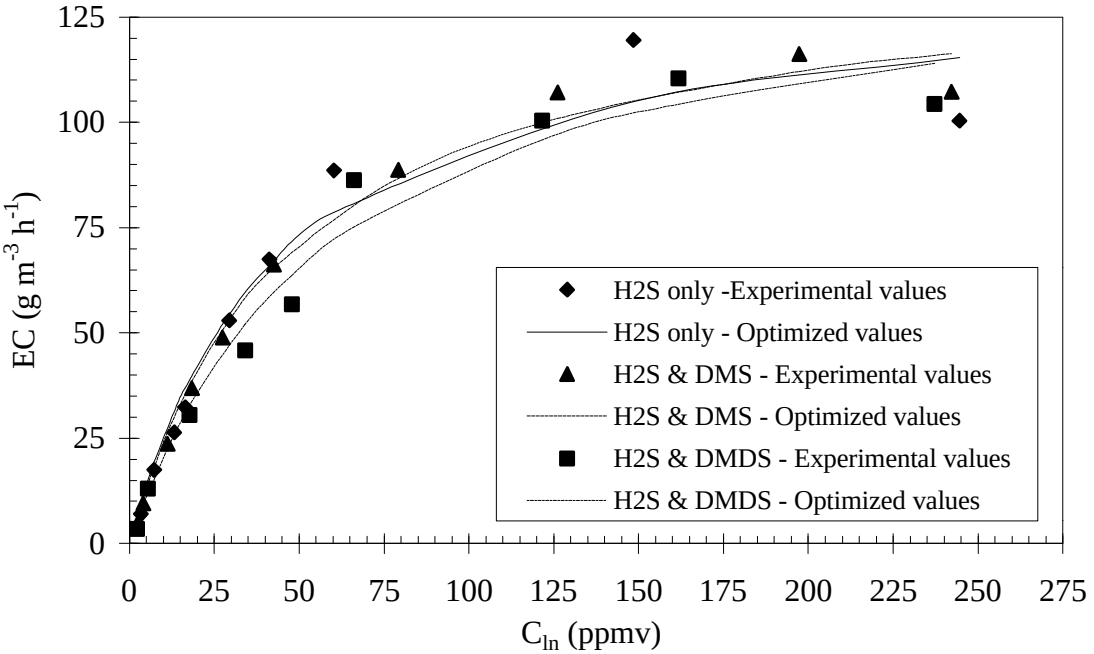

Figure 3. Hydrogen sulfide elimination capacity of compost biofilter

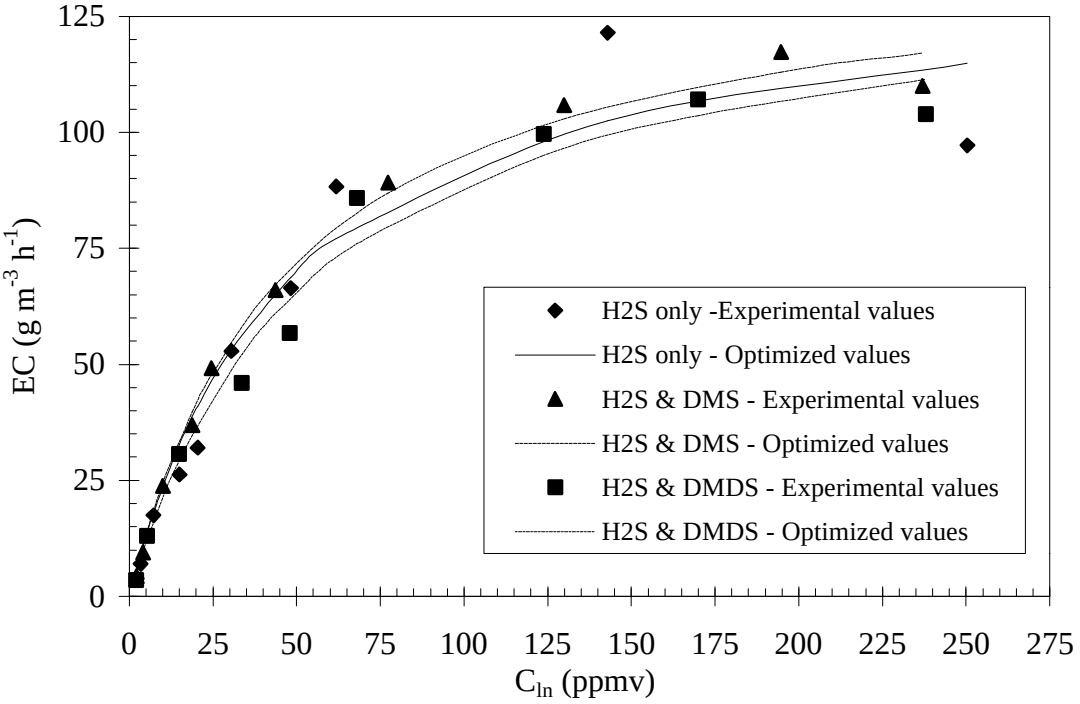

Figure 4. Hydrogen sulfide elimination capacity of hog fuel biofilter

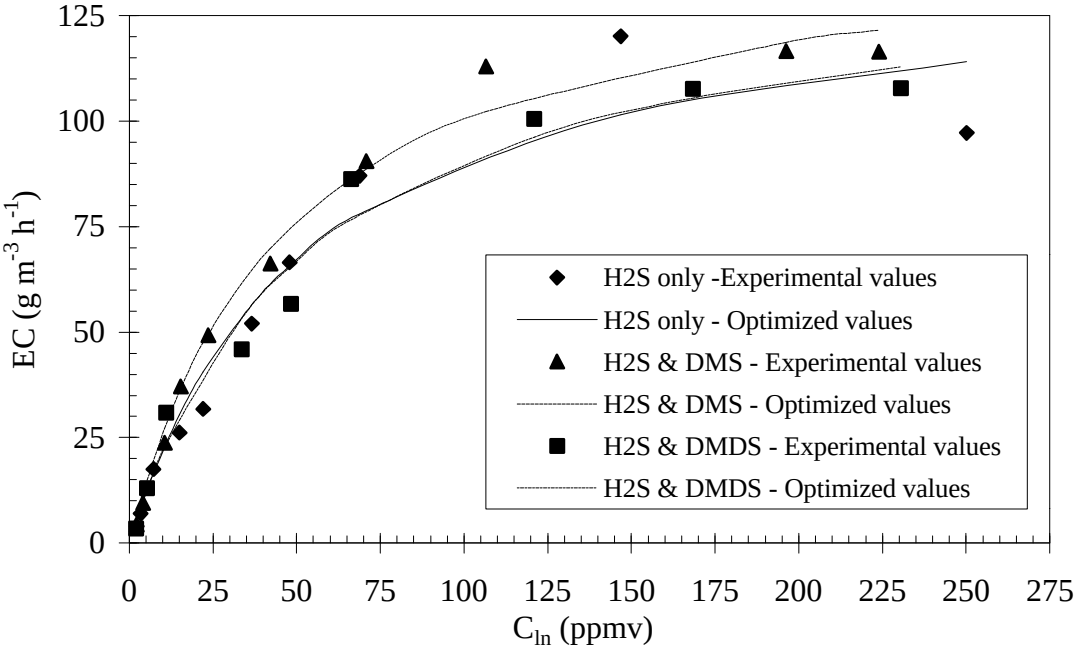

Figure 5. Hydrogen sulfide elimination capacity of mixture biofilter

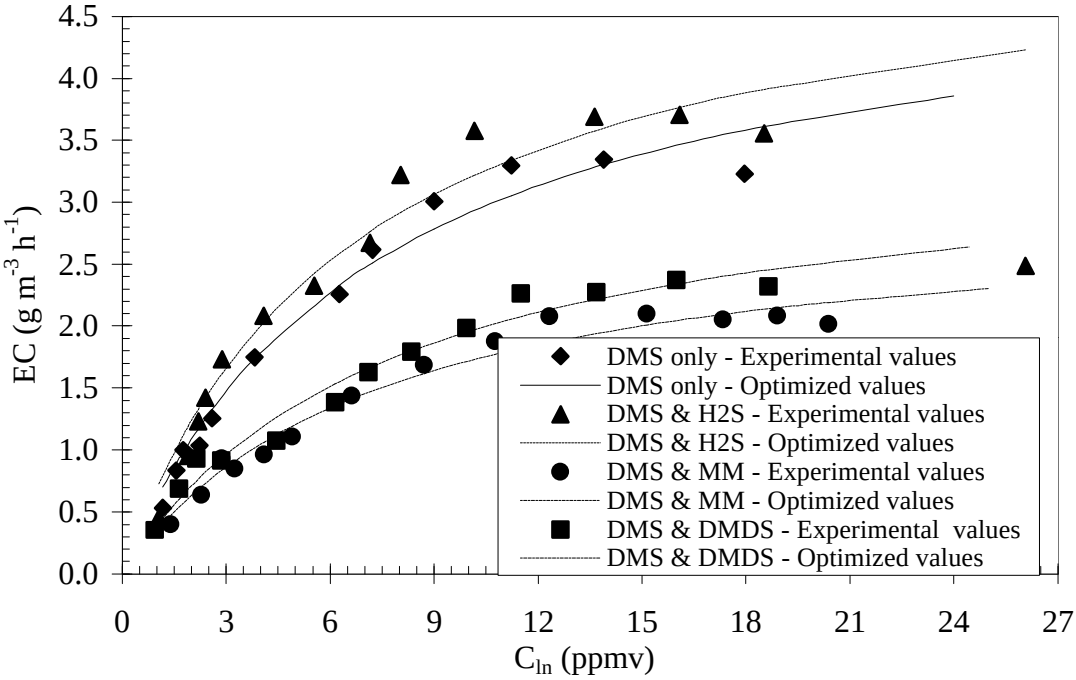

Figure 6. Dimethyl sulfide elimination capacity of compost biofilter

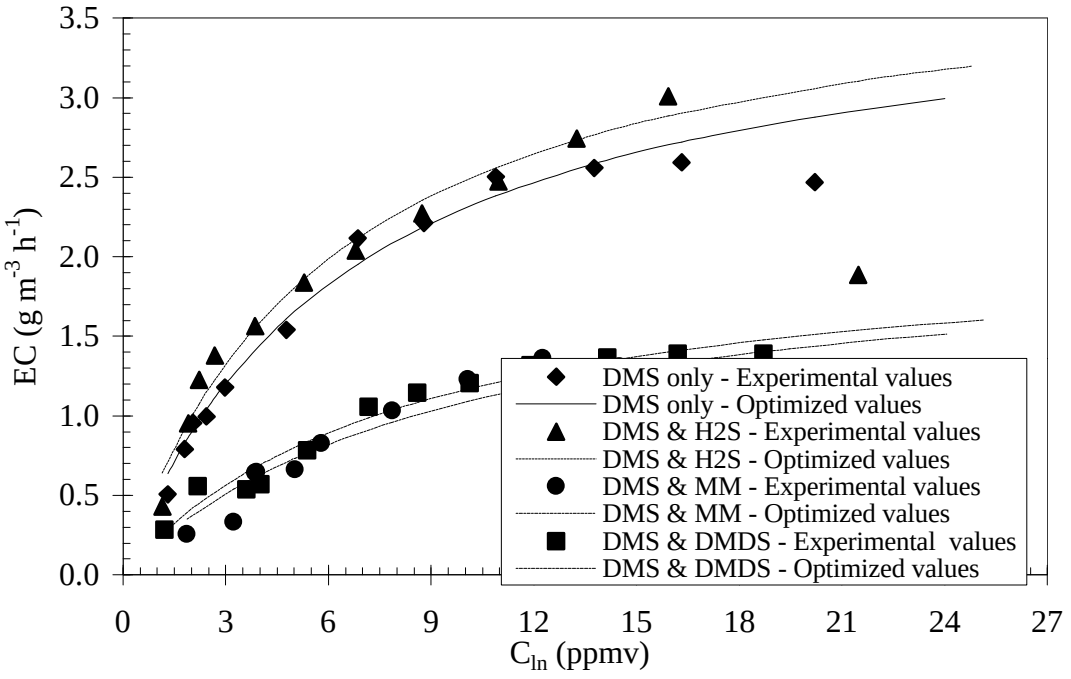

Figure 7 Dimethyl sulfide elimination capacity of hog fuel biofilter

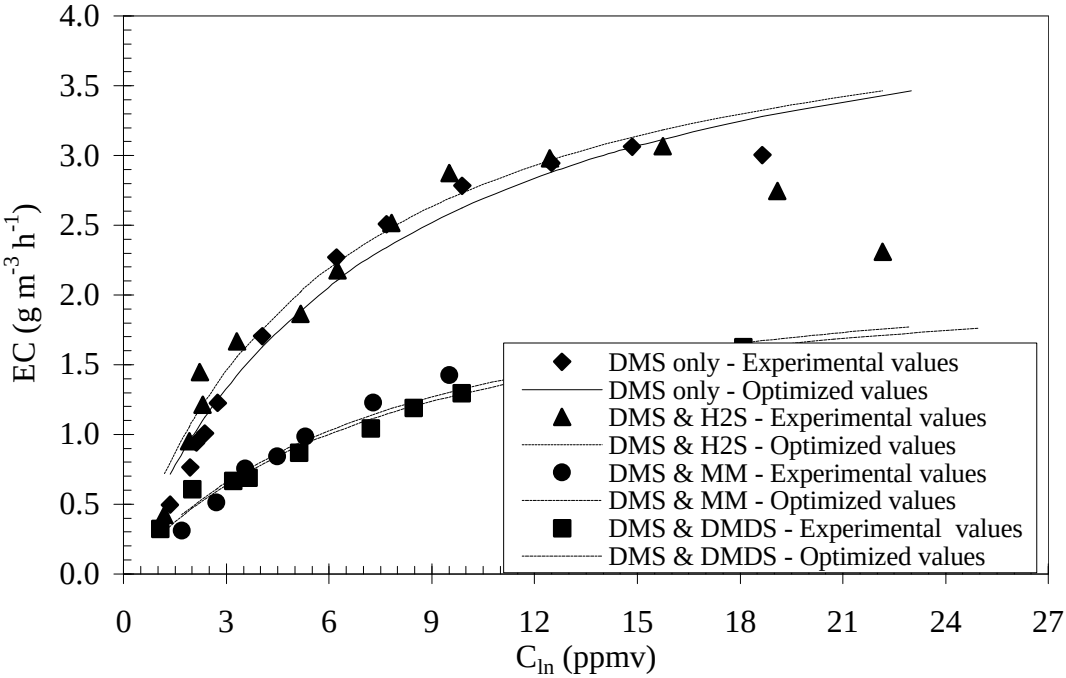

Figure 8. Dimethyl sulfide elimination capacity of mixture biofilter

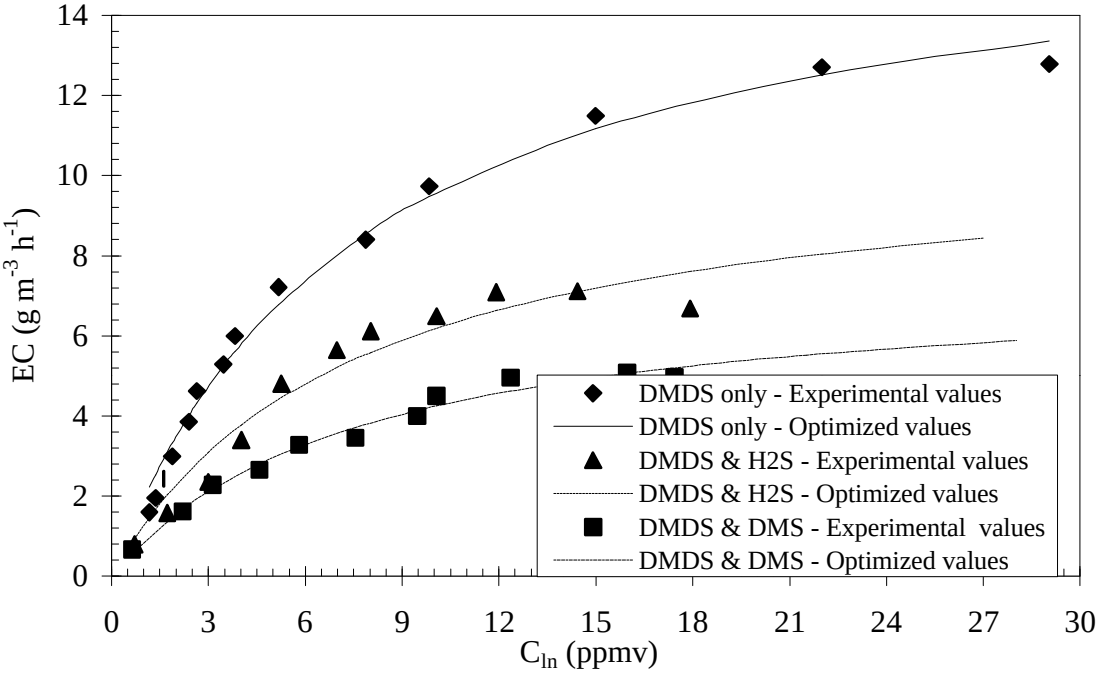

Figure 9. Dimethyl disulfide elimination capacity of compost biofilter

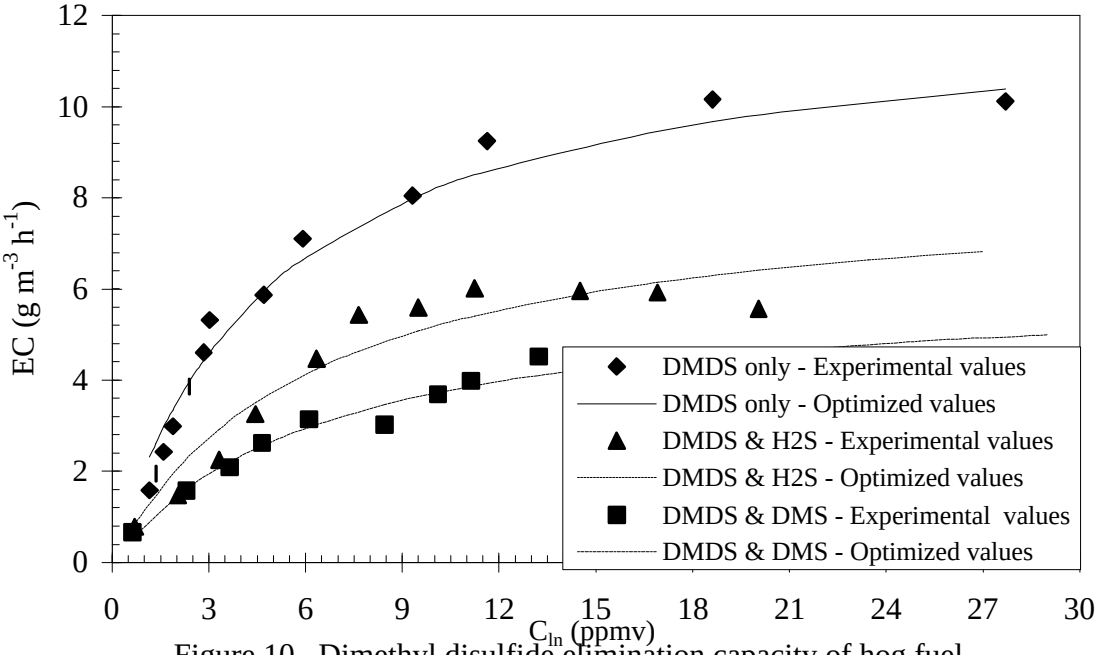

Figure 10. Dimethyl disulfide elimination capacity of hog fuel biofilter

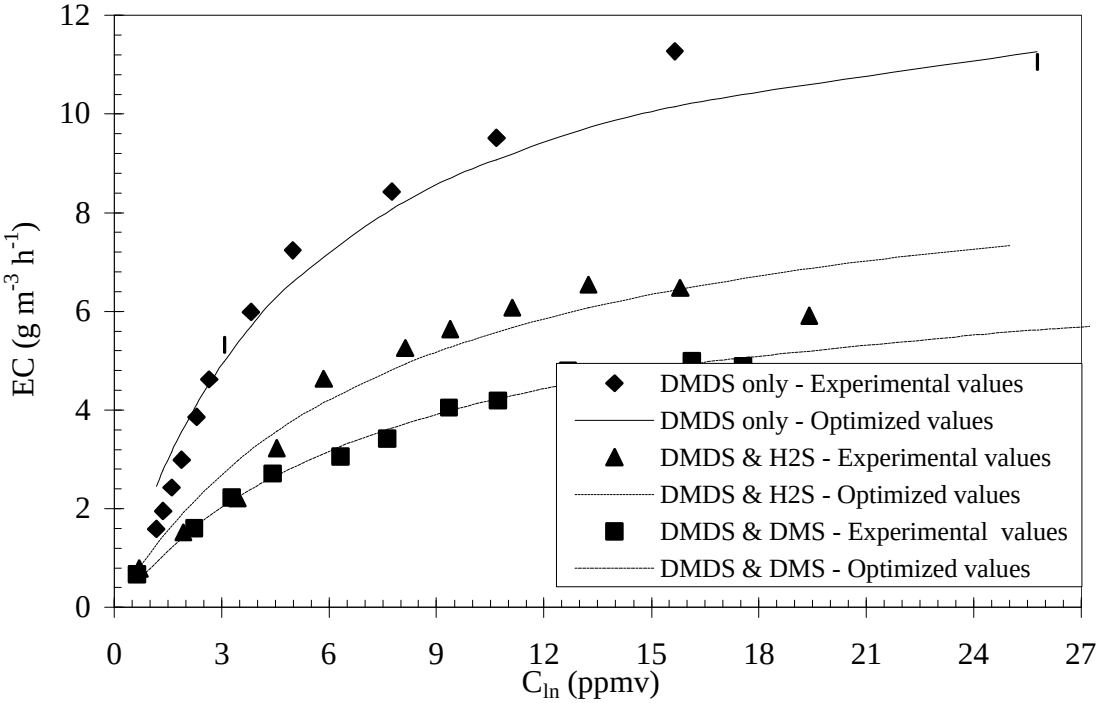

Figure 11. Dimethyl disulfide elimination capacity of mixture biofilter

TABLE 3: Kinetic Parameters for Biofiitration of Reduced Sulfur Gases Individually and in Mixtures.

Gas Composition	Compost			Mixture			Hog Fuel		
	Measured Maximum EC $g\ m^{-3}\ h^{-1}$	V_{max} $g\ m^{-3}\ h^{-1}$	K_m ppmv	Measured Maximum EC $g\ m^{-3}\ h^{-1}$	V_{max} $g\ m^{-3}\ h^{-1}$	K_m ppmv	Measured Maximum EC $g\ m^{-3}\ h^{-1}$	V_{max} $g\ m^{-3}\ h^{-1}$	K_m ppmv
H_2S	120	136.1	43.9	120	138.3	53.1	120	136.8	47.9
H2S + 10.8 ppm DMS	115	139.5	48.3	115	146.8	46.5	115	140.7	47.8
H2S + 6.6 ppm DMDS	110	142.6	59.3	105	139.7	54.6	105	137.1	54.8
DMS	3.5	5.0	7.2	3.0	4.6	7.3	3.0	3.8	6.5
DMS + 23.6 ppm H2S	3.7	5.3	6.6	2.5	4.4	6.1	3.0	4.0	6.0
DMS + 15.4 ppm MM	2.0	3.5	7.4	1.3	2.4	7.9	1.6	2.1	9.4
DMS + 7.2 ppm DMDS	2.4	3.5	7.8	1.3	2.3	7.9	1.6	2.1	8.3
DMDS	12.8	16.9	7.7	10.4	13.6	5.3	11.2	12.3	5.0
DMDS + 15.9 ppm H2S	7.6	10.8	7.5	6.0	9.6	7.7	6.8	8.4	6.2
DMDS + 9.1 ppm DMS	5.2	7.5	7.7	4.2	7.4	7.9	5.0	6.1	6.5

The data in Table 3 include the measured values for the maximum elimination capacities which were read from graphs like Figures 3 - 11. The Table also includes values for the kinetic parameters V_{max} and K_m to be used in Equation 6. To incorporate the opposing effects of V_{max} and K_m , i.e. EC increases as V_{max} increases but decreases as K_m increases, Table 4 was produced.

The entries in Table 4 are the elimination capacities required to reduce an RS concentration of 33 ppm (the sum of the maximum concentrations of H_2S, MM, DMS and DMDS in a typical washer hood emission as shown in Table 1) to an odour threshold of 1 ppb (typical of the odour thresholds of these RS gases as indicated in Table 1). From these inlet and outlet concentrations the log mean RS gas concentration (C_{ln}) can be calculated. Insertion of this C_{ln} value and the values of V_{max} and K_m from Table 3 into Equation 6 allows the calculation of the values in Table 4. These calculated values can be used to compare the performances of the three kinds of biofilters when treating various combinations of RS gases.

Now let's consider the data of Table 4. Note that the entries in all of the categories are less than the measured maximum elimination capacities for the appropriate gas compositions of Table 3. Thus the reduction in RS gas concentration from 33 ppm to 1 ppb should be possible. For H_2S, on occasion, the outlet gas concentration from the biofilters was so low as to be undetectable by the gas chromatograph (lower limit of detectability $\approx$ 250 ppb). For MM outlet concentrations as low as 1 ppmv were observed, For DMDS the lowest outlet concentration noted was 0.5 ppmv. With the possible exception of the undetectable values noted for H_2S, these lowest observed outlet values are above the odour thresholds of MM and DMDS, see Table 1. Thus in these laboratory tests elimination of odour was not achieved. But remember that these data were collected from a laboratory scale biofilter. Greater volumes of biofilter medium and longer residence times could result in outlet concentrations less than the odour threshold.

Comparison of the EC values calculated with H_2S as the principal RS gas, to the values where DMS and DMDS were the principal RS gases shows that H_2S, alone or in combination, was much more rapidly removed than DMDS, which, in turn, was more rapidly removed than DMS. The addition of DMS or DMDS to H_2S did not have an appreciable effect on biofilter performance. No significant differences among the three biofilter materials were noted with H_2S as the principal RS gas.

When DMS was the principal RS gas the addition of H_2S did not have any effect, but the addition of MM or DMDS resulted in worsened performance. It also appears that with DMS as the principal RS gas that the compost biofilter was a little more effective than the mixture biofilter which was a little more effective than the hog fuel biofilter. With DMDS as the principal RS gas the addition of H_2S resulted in lower performance and the addition of DMS made the performance even worse. No significant differences among the different biofilter media were observed.

Based on the elimination capacities of Table 4 the volume of biofilter medium necessary to reduce the concentration of H_2S from 33 ppm to 1 ppb from a typical washer hood air

emission flow rate of 3750 m^3/ton of pulp produced would be 0.8 m^3/ton of daily pulp production. To reduce 33 ppm of DMS to 1 ppb with the same gas flow rate the required volume would be 8.6 m^3/ton. For a reduction of 33 ppm to 1 ppm the required volumes of biofilter medium would be 0.3 m^3 for H_2S and 4.5 m^3 for DMS. It should be noted that these scale-up calculations are based on a kinetic model, Equation 6, which is not very sophisticated.

TABLE 4: Biofilter Elimination Capacity Required to Reduce an RS Gas Concentration from 33 ppmv to an Odour Threshold of 1 ppbv.

Gas Composition	**Compost**	**Mixture**	**Hog Fuel**
	($g\ m^{-3}\ h^{-1}$)	($g\ m^{-3}\ h^{-1}$)	($g\ m^{-3}\ h^{-1}$)
H_2S	9.2	7.8	8.5
H2S + 10.8 ppm DMS	8.6	9.4	8.8
H2S + 6.6 ppm DMDS	7.2	7.7	7.5
DMS	1.5	1.4	1.2
DMS + 23.6 ppm H2S	1.7	1.5	1.4
DMS + 15.4 ppm MM	0.9	0.7	0.5
DMS + 7.2 ppm DMDS	1.0	0.7	0.6
DMDS	4.9	5.1	4.8
DMDS + 15.9 ppm H2S	3.2	2.8	2.8
DMDS + 9.1 ppm DMS	2.2	2.1	2.8

pH Effects

Over an operating period of approximately 6 months treating air containing H_2S the pH the of the biofilters dropped from an initial value of 7 to between 2 and 3 in the uppermost two stages of each biofilter (compost, hog fuel and mixture). In the third stage of the compost biofilter the pH was 5, in the mixture biofilter it was 4 and in the hog fuel biofilter it was 3. Thus acid was generated during these experiments probably as the result of microbial oxidation of H_2S to sulfuric acid. See Figure 12.

Over a 2 month operating period treating air containing DMS there were no significant changes in biofilter media pH. See Figure 13. Over a 4 month period treating air

containing DMDS, the pH dropped from 7 to 5.5 in stage 1, to 6 in stage 2 and to 6.5 in stage 3 for all three biofilter bed materials. See Figure 14.

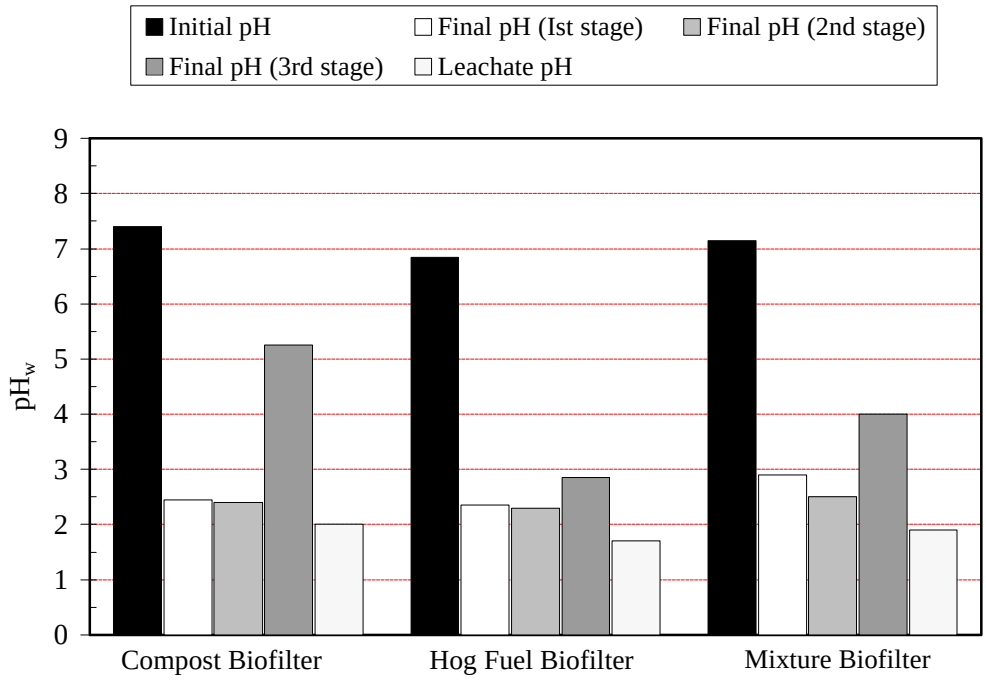

Figure 12. Biofilter media and leachate pH after degrading hydrogen sulfide

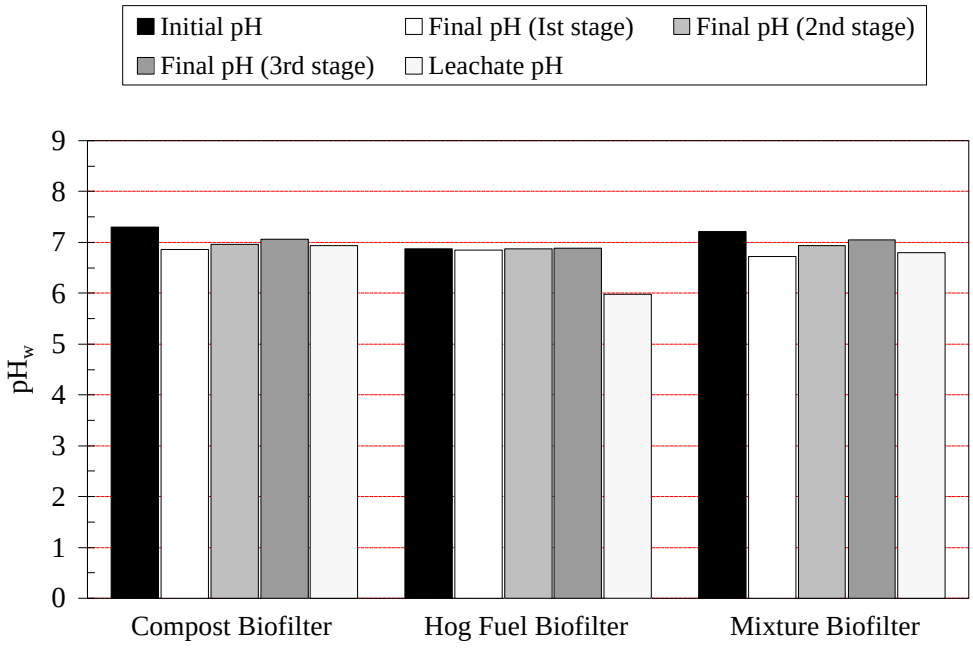

Figure 13. Biofilter media and leachate pH after degrading dimethyl sulfide

The greater pH effect observed with H_2S is partly attributable to the higher concentrations of RS gas used and the longer operating period. The sulfur oxidizing bacteria *Thiobacilli* are known to oxidize H_2S but do not oxidize organic reduced sulfur gases such as MM, DMS or DMDS.

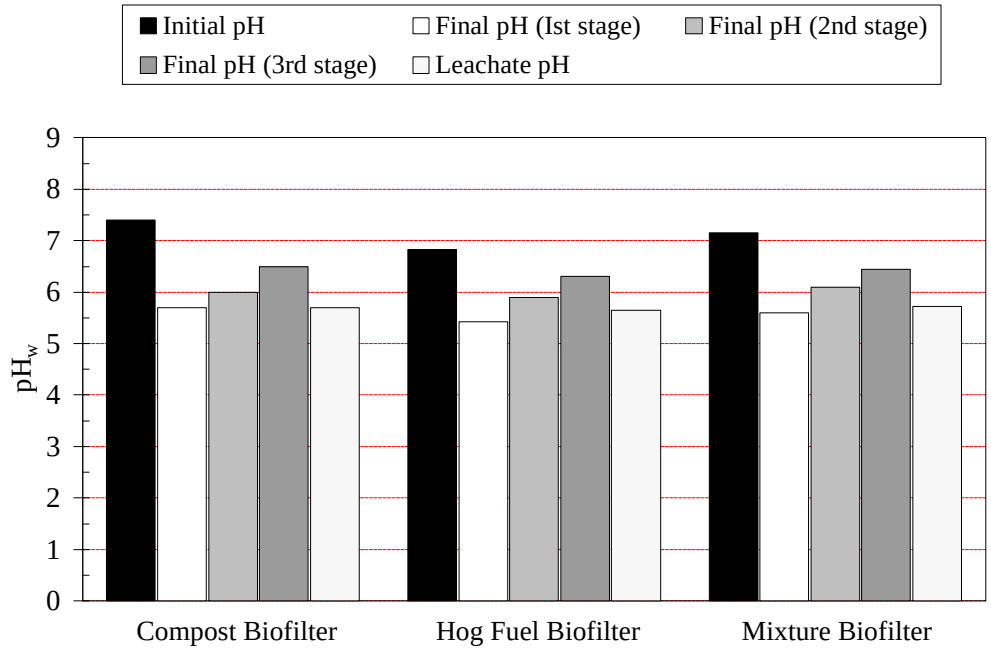

Figure 14. Biofilter media and leachate pH after degrading dimethyl disulfide

Response of Biofilters to Transients in Gas Flow Rate and Contaminant Concentration

When a biofilter starts up some time is required to establish a steady state in which the microorganisms are removing pollutant gases as fast as they are transferred from air into the biofilm. In practice the air flow rates and concentrations of pollutants in air discharges from industrial operations change with time. Studies were done to see how long it would take to start up a biofilter and how quickly it would respond to step changes in RS gas concentration and air flow rate. Tests were also done to see how quickly a biofilter could restart after a shut down and whether or not moist air should be passed through a biofilter during such shutdowns.

Figure 15 plots MM concentration into the three biofilters, elimination capacity and the % removal of MM vs. time. This figure is for the initial acclimation of the biofilters to MM.

It took about 32 hours for all three biofilters to achieve > 95 % removal of MM when exposed to a MM concentration of 35 ppmv at an air flow rate of 1.7 m^{-3} h^{-1}. This is a shorter acclimation time than what has been reported in the literature probably because

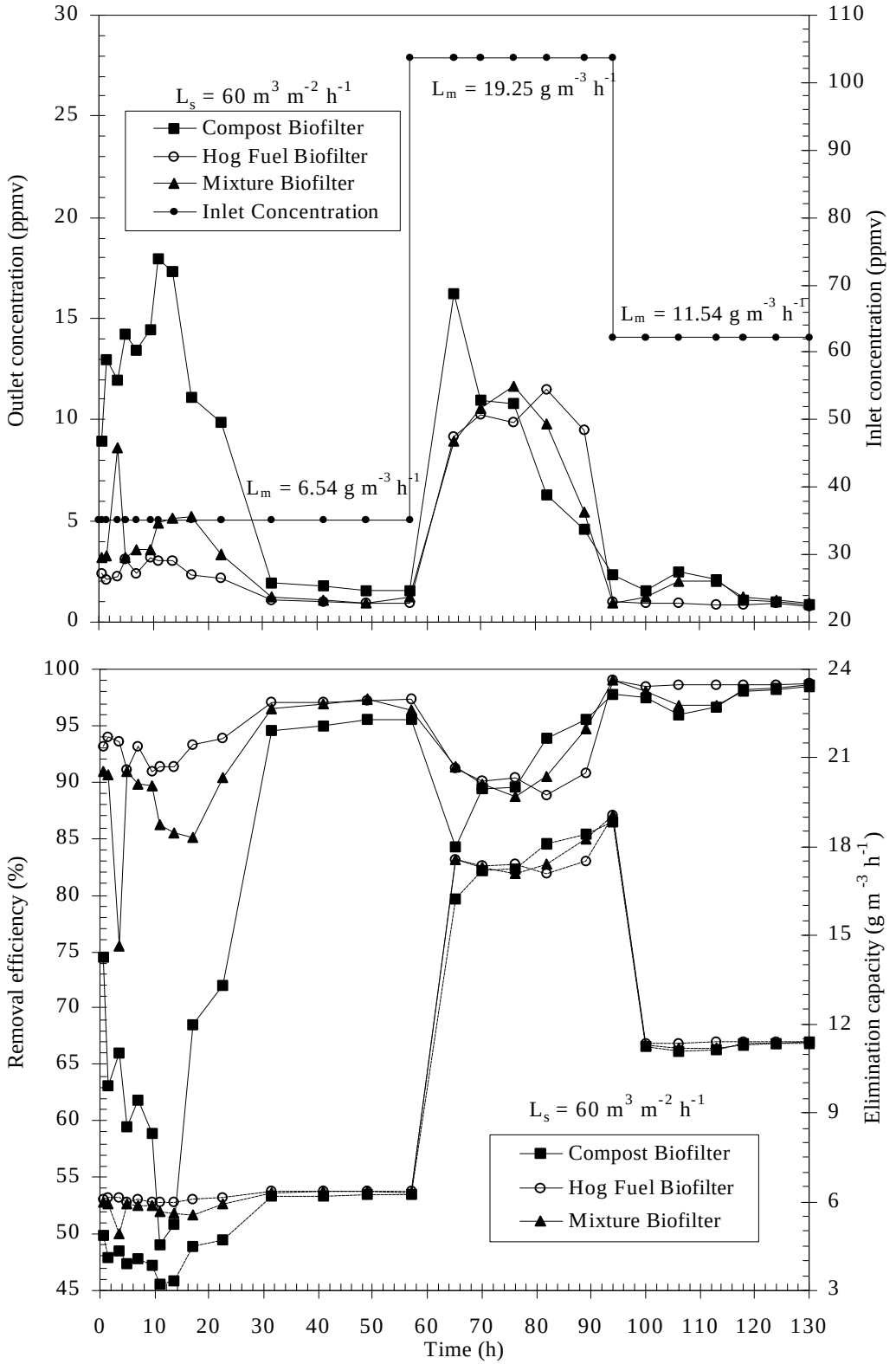

Figure 15. Initial acclimation time course of biofilters for methyl mercaptan degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

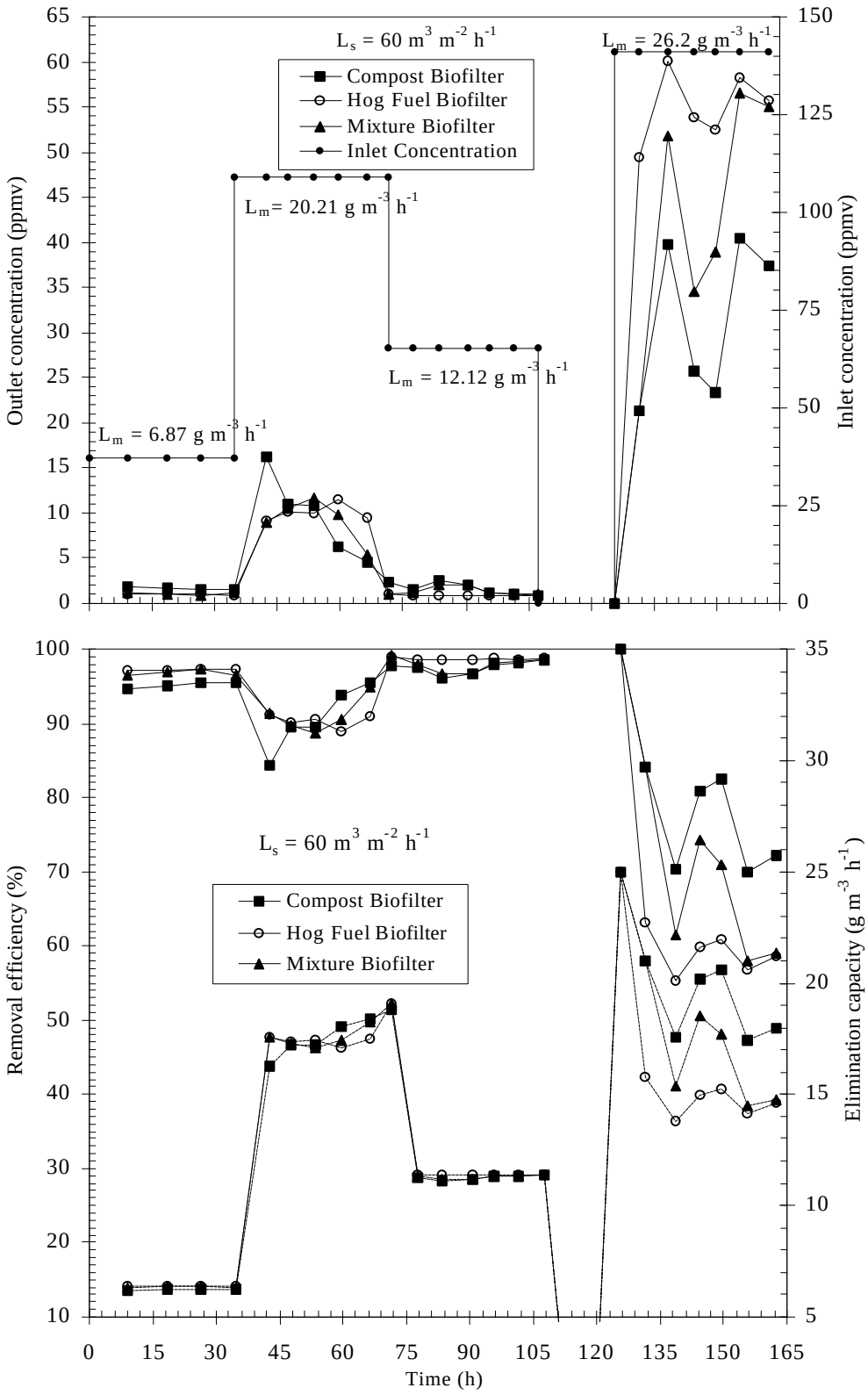

Figure 16. Transient behavior of biofilters to step-changes in contaminant concentration for methyl mercaptan degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity

our biofilters were seeded with microbial cultures that had previously been exposed to RS gases. Hirai et al. [6] found acclimation times of 17 days. Allen and Phatak [7] found little activity over the first 10 days. It can also be seen in Figure 15 that after the inlet MM concentration rose from 35 ppm to 104 ppm the biofilter performance dropped, then regained its original % removal in about 32 h. Similar studies have been done with H_2S and DMDS; see below.

Figure 15 also shows that after the MM concentration was raised to 104 ppmv there was a drop in the % removal of MM, a rise in outlet MM concentration and an increase in elimination capacity. After about 40 h the biofilters' performance returned to where it was before the increase in inlet MM concentration to 104 ppmv, and remained there after the inlet MM concentration was reduced to 62 ppmv.

Figure 16 presents the results of some more testing of the transient responses of the biofilters to changes in MM mass loading rate (L_m). The changes were achieved by varying the inlet MM concentration while holding the waste air surface loading rate (L_s) constant. When the inlet MM concentration was raised from 37 to 109 ppmv the biofilters were able to recover their pre-change level of performance in about 36 h. The same high level of performance was observed when the inlet MM concentration was lowered to 65 ppmv. Next the inlet MM concentration went to 0 ppmv for 18 h after which the inlet MM concentration was set at 141 ppmv. This caused a major decline in the performance of all three biofilters from which they showed no sign of recovering in 45 h. This implies that the biofilters were overloaded under these conditions. The overload could have been due to inhibition of the microbial population of the biofilter by too high a MM mass loading, or perhaps the microorganisms were removing MM at their fastest possible rate which was not high enough to deal with all the MM supplied. Similar behavior was observed when the mass loading rate of MM was held constant and the waste air flow surface loading rate was changed. See Figure 17.

Figure 18 illustrates the biofilters response to a spike loading of MM. The spike was an increase in inlet MM concentration from 88 ppmv to 158 ppmv. The MM concentration was held at 158 ppmv for 30 minutes then reduced back to 88 ppmv. There was an immediate increase in outlet MM concentration after the application of the spike causing a decrease in % removal and an increase in elimination capacity. The compost biofilter was least affected by this spike; the hog fuel and mixture biofilters were more affected and behaved similarly. The compost biofilter recovered its original level of performance in about 1 h while it took the other two biofilters about 6 h to recover. The elimination capacities rose in response to the imposition of the spike in inlet MM concentration, peaked, then fell below their original elimination capacities. This drop below the original value could have been due to desorption of MM adsorbed at the higher concentration prevailing during the spike, but later desorbed to attain equilibrium with the lower concentration after the spike.

Figure 19 provides some information on the restart of the biofilters after an idle period of 1 week during which no air or MM was supplied. After the 1-week idle period the same

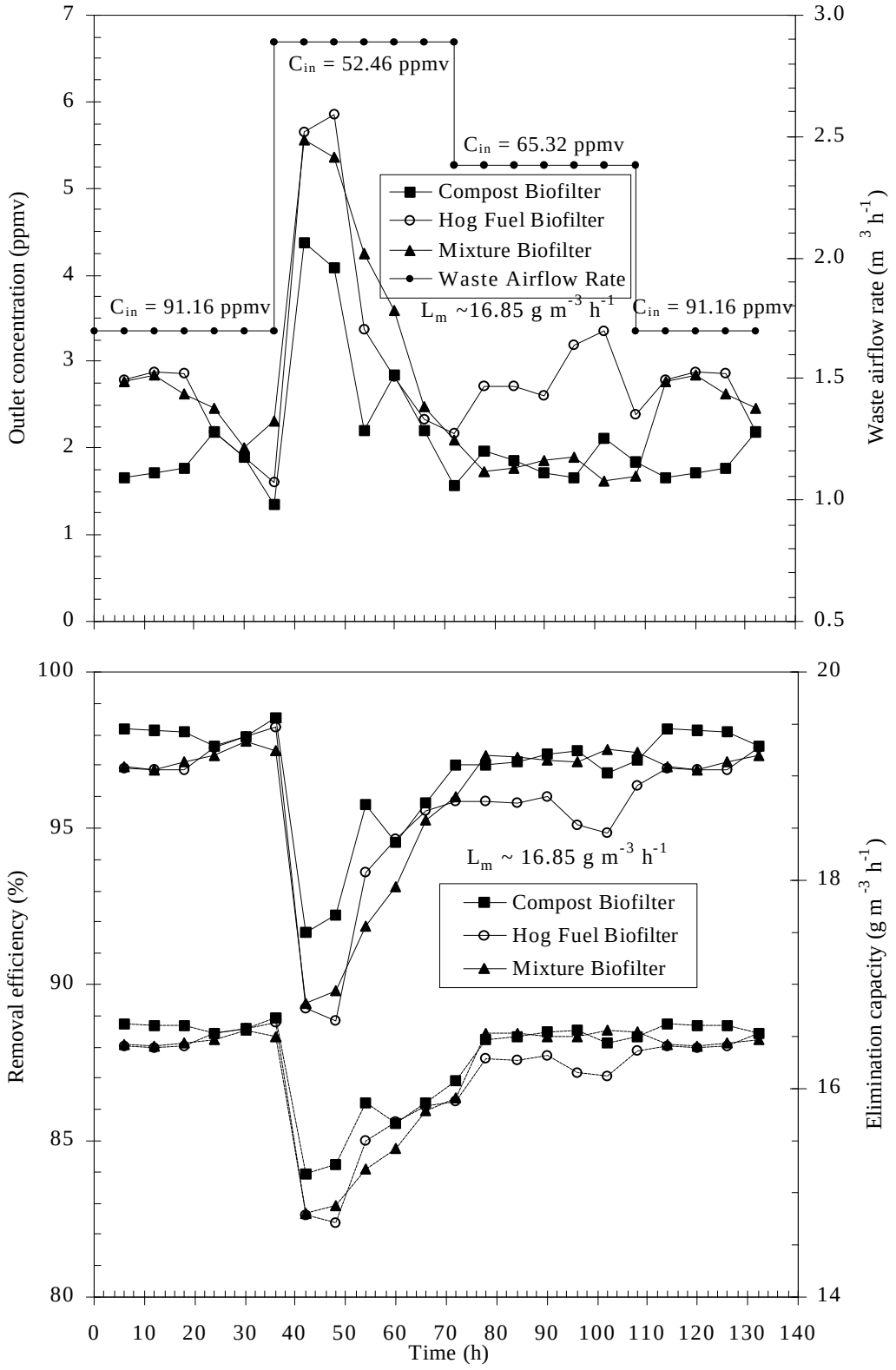

Figure 17. Transient behavior of biofilters to step-changes in waste airflow rate for methyl mercaptan degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

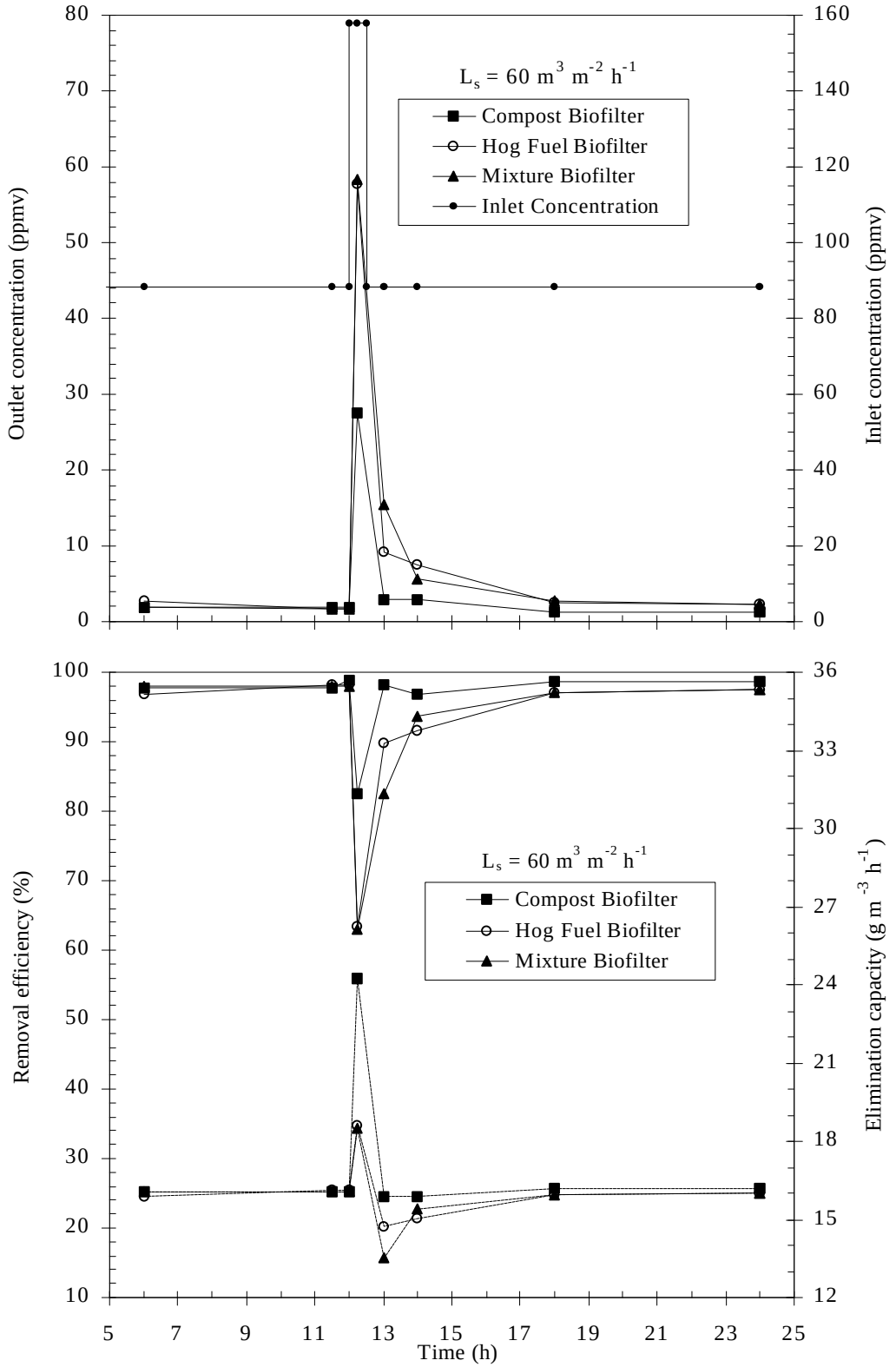

Figure 18. Transient behavior of biofilters to concentration spike for methyl mercaptan degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

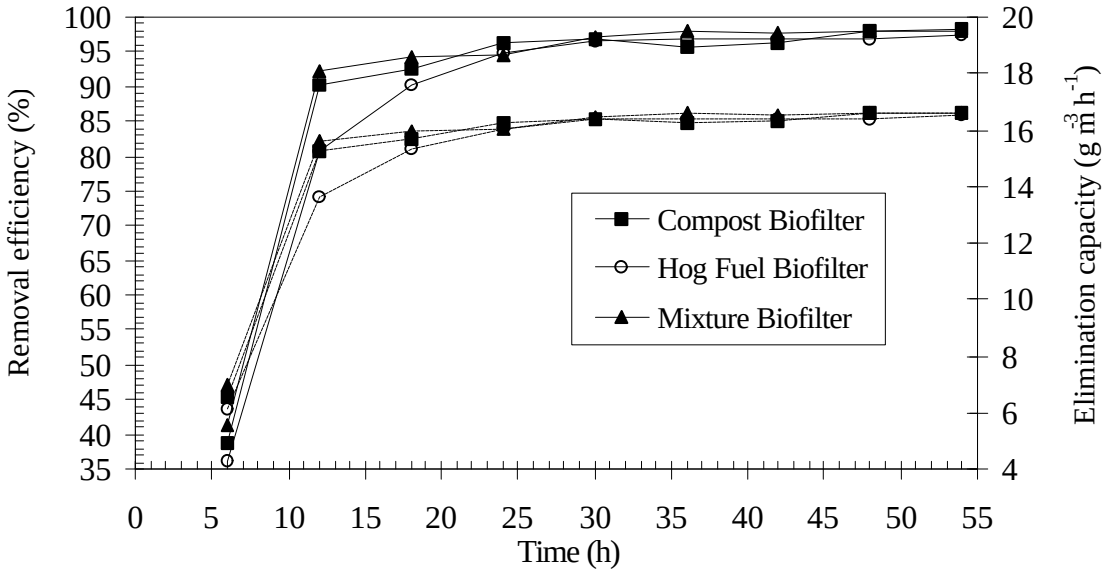

Figure 19. Reacclimation time course for biofilters degrading methyl mercaptan after one week idle phase. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

loading was applied as before the biofilters' shutdown. Recovery to before idle period conditions took about 25-30 h. Another test using a 2 day idle period showed that the recovery time was about 10-15 h. Further tests on idle periods in which moist air was provided but no MM was supplied showed that recovery from a 2 day idle period took 6 h. This latter test result indicates that it would be good practice during downtime periods to keep moist air flowing through the biofilters.

Similar transient studies were done using H_2S and DMDS. Figures 20, 21, 22 and 23 respectively illustrate the effects of step changes in H_2S concentration, air flow rate, spike increase in H_2S concentration and a one week idle period. Figures 24, 25 and 26 respectively show the effects of step changes in DMDS concentration, air flow rate and a one week idle period. More details on these transient studies can be found in references [5, 8, 11].

CONCLUSIONS

Hog fuel biofilter beds were more resistant to microbially induced bed degradation than beds of compost or mixtures of compost and hog fuel. Because of this and because compost beds exhibited little or no advantage over hog fuel beds in terms of RS gas elimination capacity, hog fuel beds are concluded to be superior.

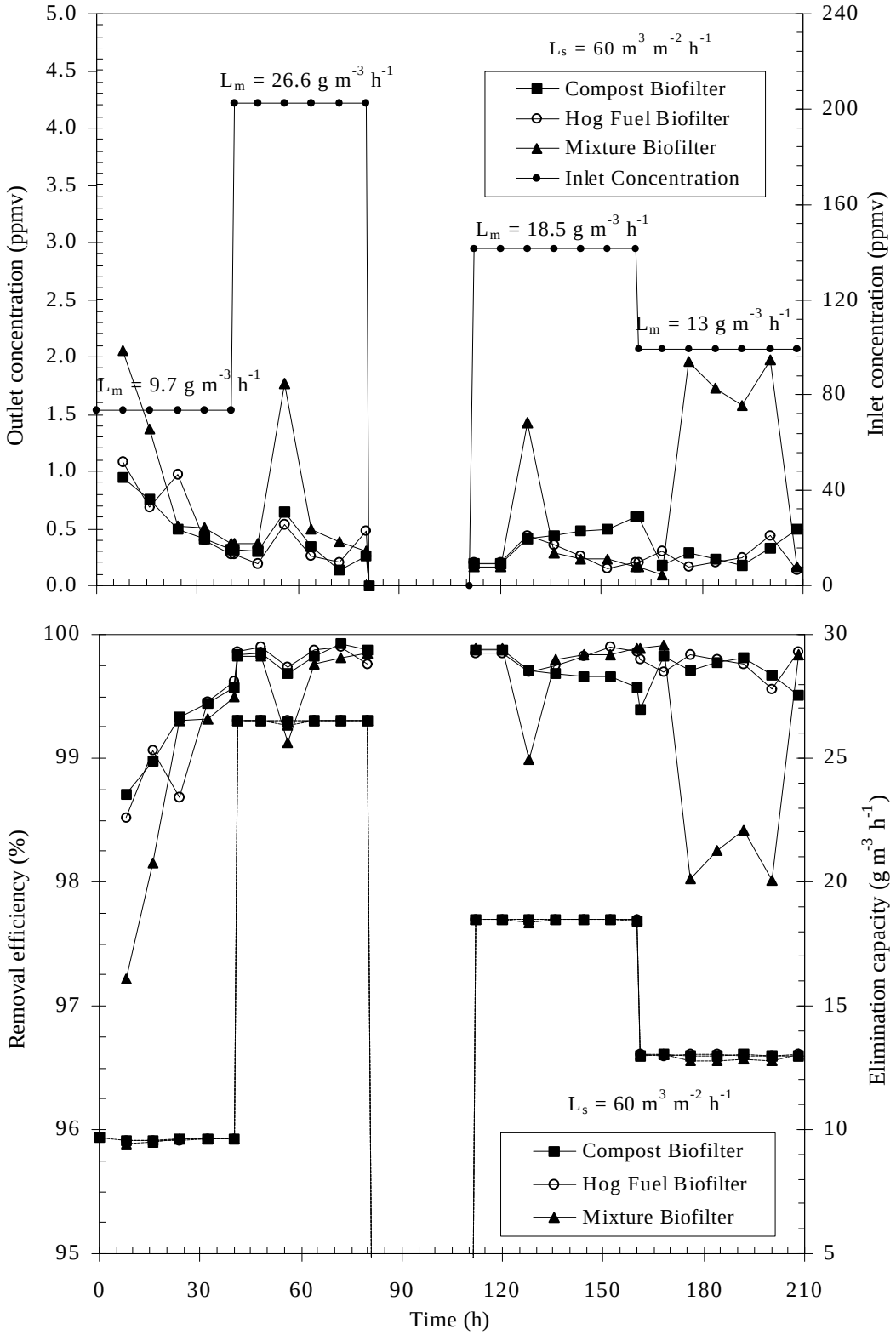

Figure 20. Transient behavior of biofilters to step-changes in contaminant concentration for hydrogen sulfide degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

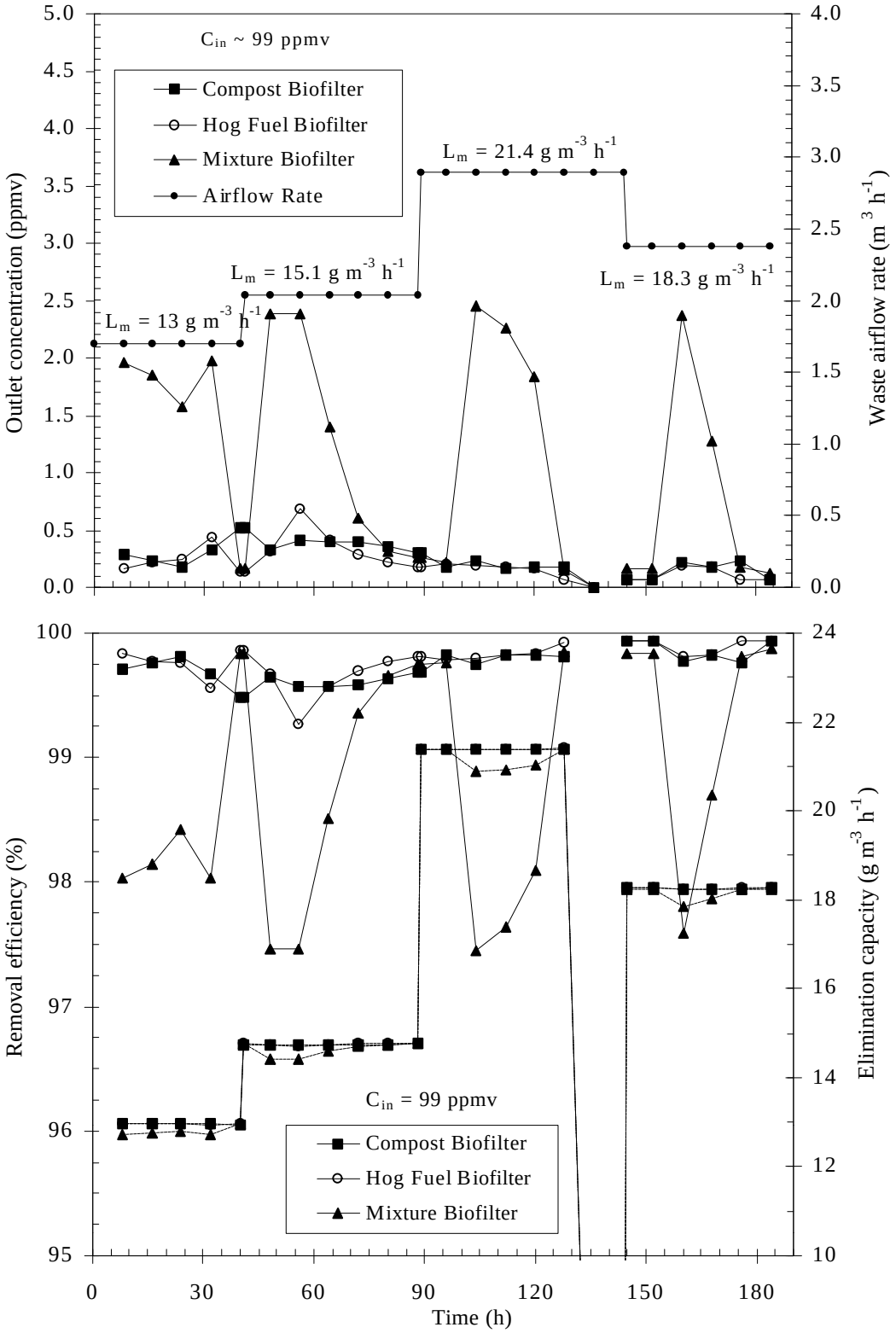

Figure 21. Transient behavior of biofilters to step-changes in waste airflow rate for hydrogen sulfide degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

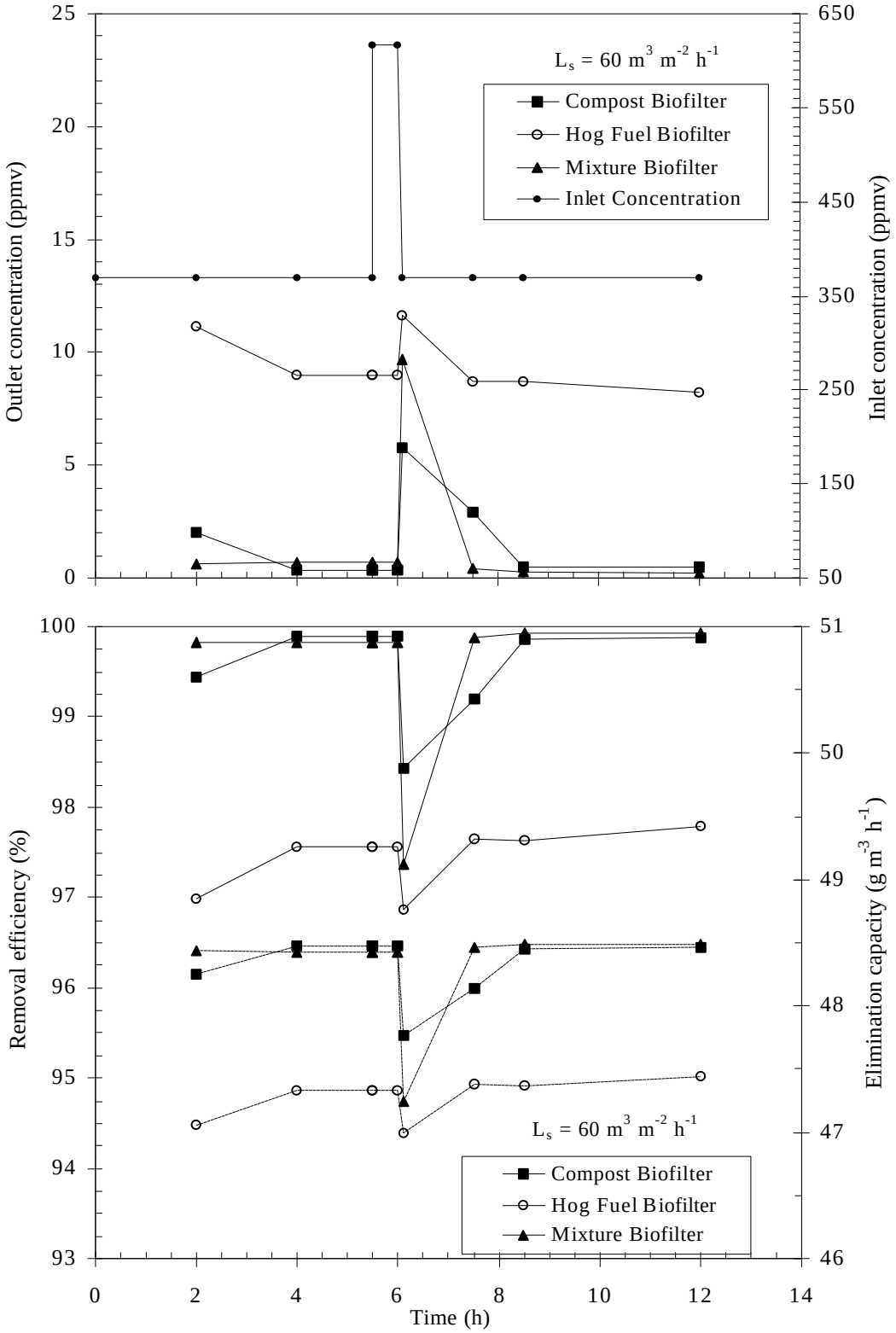

Figure 22. Transient behavior of biofilters to concentration spike for hydrogen sulfide degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

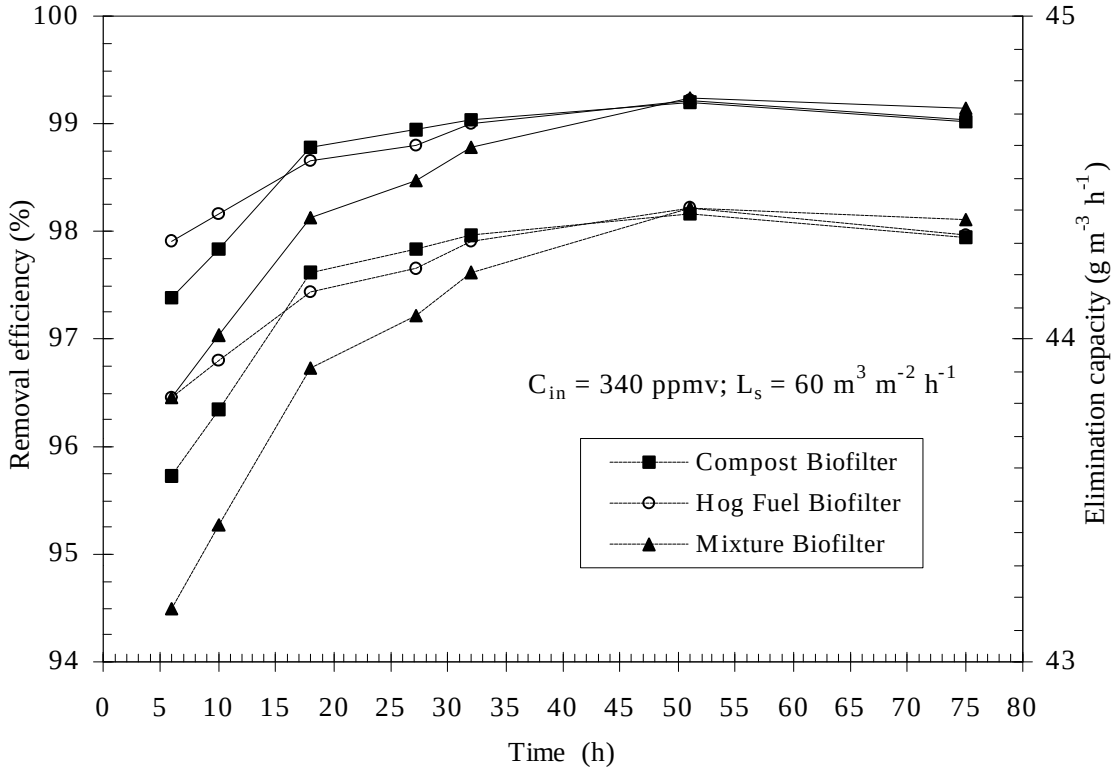

Figure 23. Reacclimation time course for biofilters degrading hydrogen sulfide after one week idle phase. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

Hydrogen sulfide was much easier to remove from contaminated air than the organic RS gases. Addition of DMS or DMDS to H_2S did not affect the H_2S elimination capacity over the range of DMS and DMDS concentrations tested.

Of the gases tested DMS was the most difficult to remove. Its elimination capacity was not affected by the presence of H_2S but it was reduced by the presence of MM or DMDS. When treating air containing high concentrations of H_2S pH drops were observed in all three kinds of biofilter. Some small pH drops were observed when treating DMDS. No pH drops were seen when treating DMS.

Start up times for the biofilters used in these tests was of the order of 30 hours when treating air containing MM. This is shorter than some of the start up times reported in the literature probably because microbes acclimated to RS gases were used to seed the biofilters.

It required 30 to 40 hours for the biofilters to regain a high level of performance after step changes in loading. Periods of 1 to 6 hours were necessary to recover from short term, spike increases in loading.

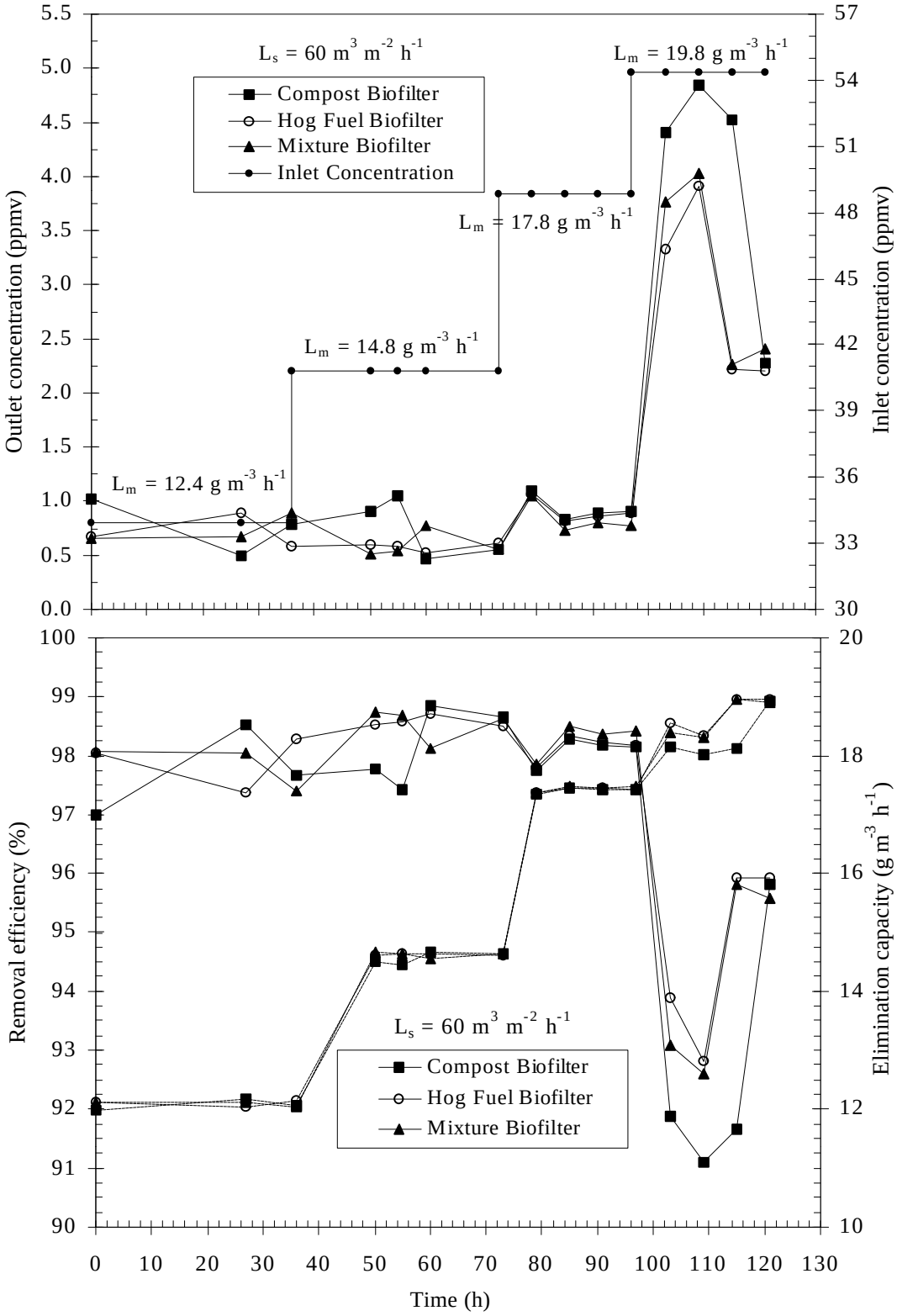

Figure 24. Transient behavior of biofilters to step-changes in contaminant concentration for dimethyl disulfide degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

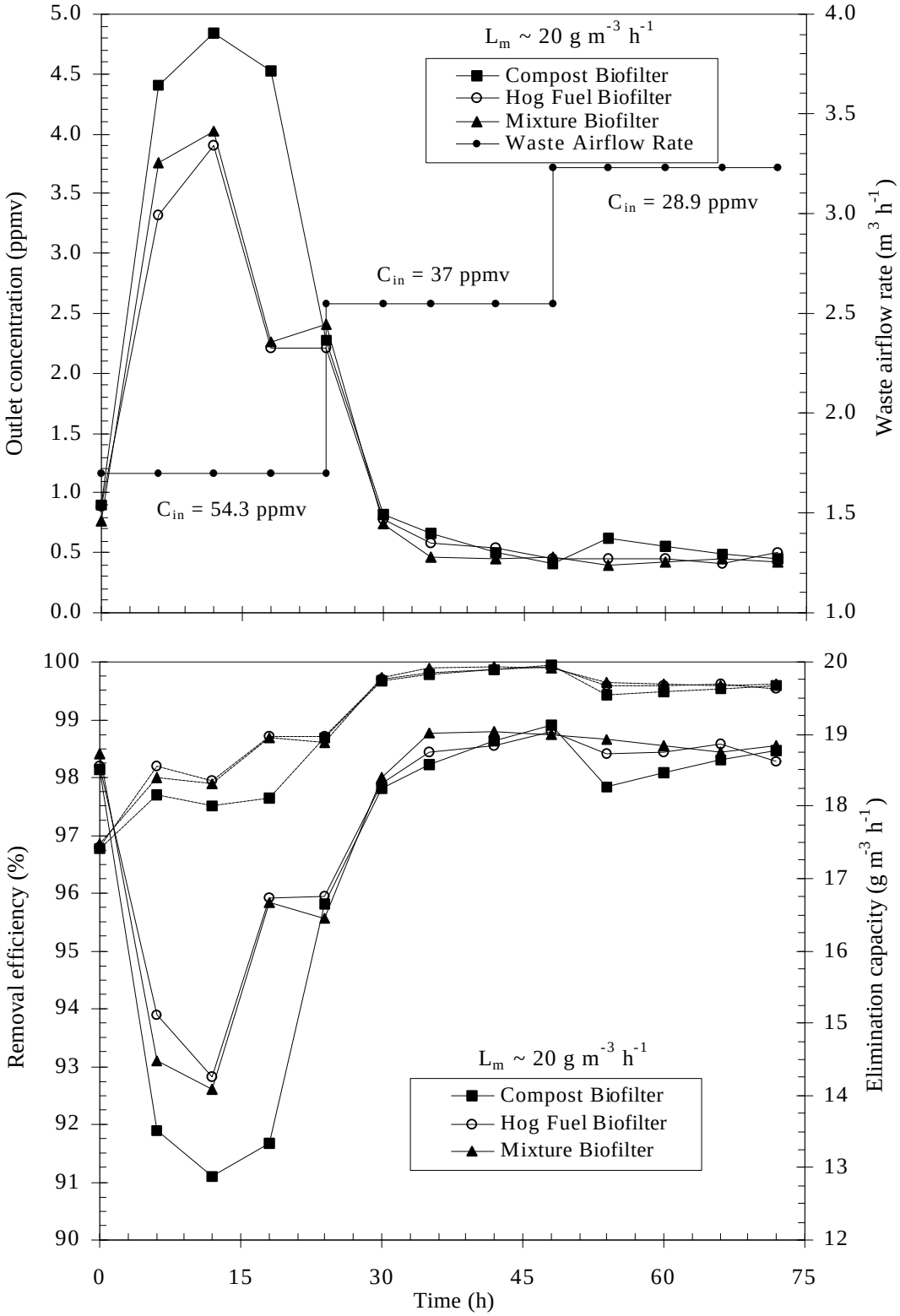

Figure 25. Transient behavior of biofilters to step-changes in waste airflow rate for dimethyl disulfide degradation. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

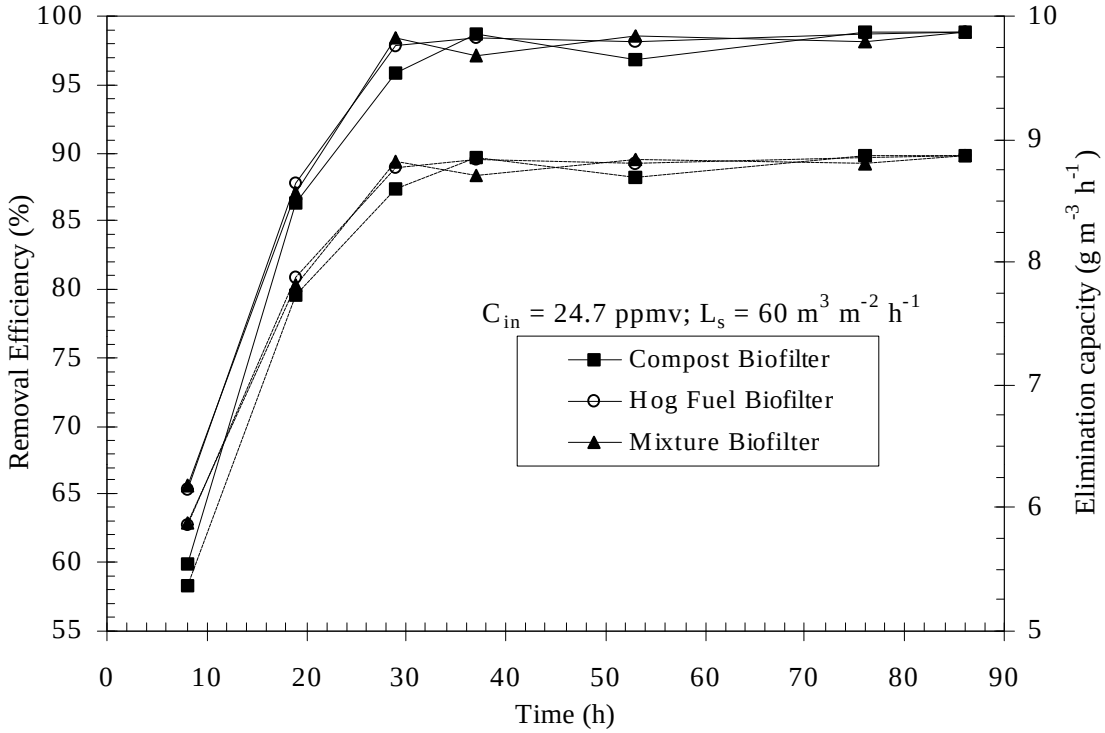

Figure 26. Reacclimation time course for biofilters degrading dimethyl disulfide after one week idle phase. Solid lines represent the removal efficiency and dashed lines the elimination capacity.

Biofilters should be supplied with moist air during periods wherein there is no contaminant loading.

NOMENCLATURE

Mm = methyl mercaptan
DMS = dimethyl sulfide
DMDS = dimethyl disulfide
EC = elimination capacity (see equation 5)
RE = removal efficiency (see equation 4)
RS = reduced sulfur
A = filter bed cross-sectional area
C_{in} = RS gas concentration into biofilter
C_{it} = carbon content of biofilter solids at the end of the particular stage of degradation
C_{ln} = log mean of RS gas concentration into and out of biofilter
C_{out} = RS concentration out of biofilter
K_m = kinetic constant (see equation 6)
L_s = waste air surface loading rate (see equation 2)
L_m = contaminant mass loading rate (see equation 3)
Q = total gas flow rate through biofilter
V = biofilter volume
V_{max} = kinetic constant (see equation 6)

β = units conversion factor
τ = empty bed residence time (see equation 1)

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REFERENCES

1. Devinny, J.S., Deshusses, M.A., Webster, T.S., "Biofiltration for Air Pollution Control", Lewis Publishers, Boca Raton, 1999.
2. Torres, E.M., Devinny, J., Basri, S.S., Carlson, L.J., Gossett, R., Kogan, V., Ahn, T., Kardos, D., Shao, J., Webster, T., Stolin, B., "Biofiltration: Controlling Air Emissions Through Innovative Technology", Project 96-VOC-1, Water Environment Research Foundation, Alexandria, 1997.
3. NCASI (National (USA) Council for Air and Stream Improvement), "Health Effects of Reduced Sulfur Gases", Technical Bulletin #691, New York, 1995.
4. Wani, A.H., Branion, R.M.R., Lau, A.K., "Degradation Kinetics of Biofilter Media Treating Reduced Sulfur Odors and VOCs", Journal of the Air and Waste Management Association, 48, 1183, 1998.
5. Wani, A.H., "Biofiltration Using Compost and Hog Fuel for the Removal of TRS Gases at Low Concentrations from Air", Ph.D. Thesis, Department of Chemical and BioResource Engineering, University of British Columbia, 1999.
6. Hirai, M., Ohtake, M., Shoda, M., "Removal kinetics of hydrogen sulfide, methanethiol and dimethyl sulfide by peat biofilters", Journal of Fermentation and Bioengineering, 70, 334, 1990.
7. Allen, E.R., Phatak, S., "Control of organo-sulfur compound emissions using biofiltration: Methyl mercaptan", Proceedings of the 86th Annual Meeting of the Air and Waste Management Association, Paper # 93-WA52B.03, 1993.
8. Wani, A.H., Branion, R.M.R., Lau, A.K., "Effects of Periods of Starvation and Fluctuating Hydrogen Sulfide Concentration on Biofilter Dynamics and Performance", Journal of Hazardous Materials, 60, 287, 1998.
9. Springer, A.M., "Industrial Environmental Control: Pulp and Paper Industry", TAPPI Press, Atlanta, 1993.
10. Burke, H.G., McCance K.E., "Dilute Odour Control" preprints Spring Conference, Technical Section, Canadian Pulp and Paper Association, Jasper, 1980.
11. Wani, A.H., Lau, A.K., Branion, R.M.R., "Performance of Compost and Hog-Fuel Biofilters: Impact of Periods of Non-Use and Varying Methyl Mercaptan Loading", Environmental Technology, 21, 271-283, 2000.