Review of Biofiltration - Effect of Support Media on Biofilter Performance

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INTRODUCTION

Technologies for removal of hazardous pollutants from air have gained increased importance following the 1990 Clean Air Act Amendments (CAAA). Biofiltration is an emerging and attractive technology for the removal of volatile organic chemicals (VOCs) present at low concentrations in air. Traditional VOC removal technologies involve physical or chemical processes such as adsorption, condensation, thermal incineration or catalytic conversion, etc. Compared to these technologies, biofiltration is cheap and reliable. More importantly, biodegradable VOCs can be degraded to non-hazardous products such as carbon dioxide and water without the generation of other secondary wastes. It can be applied to any biodegradable VOCs emission problem - from manufacturing and processing units, wastewater and landfill leachate treatment plants and soil remediation operations such as vacuum extraction.

However, since biofiltration is an emerging technology, fundamental knowledge regarding the mechanisms that affect biofilter performance is limited. Though a wide range of biofilter support media have been used for biofiltration of VOCs and other air pollutants, the effect of support media has not been systematically studied. The objective of this study is to provide a brief overview of the current status of VOC biofiltration, with a focus on the effect of support media.

BACKGROUND

A biofilter is a column containing biologically active biomass. Organic compounds present in the gas stream are degraded while they are used as substrates for biomass growth. During the process, newly synthesized biomass, carbon dioxide and water are typical final products of the biodegradation process.

Support media used in biofilters were classified into two major groups: natural media and synthesized media. In natural media, such as soil, bark, peat and compost, microorganisms were distributed quite evenly inside these particles. The nutrients needed for biomass growth and synthesis were usually supplied by these materials themselves. Almost all biofilters using natural media were packed-beds decided by the nature of the materials involved. Synthesized support media, on the other hand, were normally biologically inactive. They only supplied the surface on which biomass were immobilized to form a bioactive layer called biofilm. The media could be adsorbent or non-adsorbent. The shape could also be different, such as pelletized particle, flat plate, straight passage monolith etc.

Natural Support Media

For biofiltration of air pollutants, most of the early work dealt with odorous gases using biofilters packed with natural support media. These biofilters were used to treat sewage gas,[1] hydrogen sulfide containing gases,[2,3] and odors from rendering plant.[4] Later, biofilter was used for elimination of VOCs. Biofiltration process was described as a mass transfer process through both gas and liquid phases followed by simultaneous microbial degradation and regeneration.[5,6] The maximum loading, relative humidity and temperature were all important in the operation. The theory and potential applications of soil beds for odor control have also been discussed.[7,8] Soil bed biofiltration technology was applied for removal of organic compounds. Aliphatics such as propane, butane can be effectively removed by biofiltration.[8] It was also shown that the moisture content of the bed can play an important role in determining the removal efficiency of the biofilter.[9]

A number of different natural support media have been studied for biofiltration applications. Composted bark biofilter was used for removal of ethanol with significant removal (>90%).[10] Pine bark biofilters were used for removal of odors from poultry rendering plants.[11] Compost biofilters were successfully applied for hydrogen sulfide removal.[12] It was also proposed that biofilters using natural support media was one of the most cost effective treatment method compared with the other alternative technologies for control of VOC emission, especially at low concentration.

In resent years, biofiltration systems have been used extensively in Europe. Some of them have already been commercialized. These commercialized biofilter systems were widely used for control of odors and VOCs. Most of these systems were packed-beds using particulate natural support media.

Though natural support media were relative cheap and easy to get, there were still a lot of disadvantages while using them. Usually it is difficult to maintain temperature and moisture content in the bed. Further, there is a limited amount of nutrients in the natural bioactive media, which results in decreased support media bioactivity after some operating time. Usually, peat/compost media are replaced after some time to prevent filter bed clogging due to biomass growth and replenish the mineral nutrients in the bed.

Synthesized Support Media

Associated with biofilm, synthesized support media were used in waste water treatment far before they were used in biofilters. In waste water treatment, the most commonly used fixed-film systems were trickling filters, rotating biological contactors, and submerged packed beds. Biofilters and trickling filters were later used for VOC biofiltration. The concentration of biomass at the surface of the support media was much higher than what in the soil beds. This gave the possibility that these systems could handle higher organic loading and variation. Also, the property and shape of the support media can be chosen to achieve best performance.

Activated carbon was used as packing material in the biofilter for degradation of ketones and esters.[14] Removal efficiencies above 70% were observed even at high flow rates. Different support materials such as clay, stoneware rings, and sintered glass rashing rings were also tested.[15,16,17] Among them, activated carbon had the advantage. It could tolerate the variation of the organic loading because of its high adsorption capacity. Recently, a lot of new synthesized ceramic materials were tested as support media in biodegradation of different kind of VOCs, high removal of VOCs were observed.[18,19,20]

Though the fixed-film systems had a lot of advantage, there were some drawbacks need to overcome. One main concern was about the cleaning of the excess biomass. Most previous related studies focused on substrate removal. The effect of the properties of the support media were not addressed.

EXPERIMENTAL METHODOLOGY

The objective of this study is to test the effect of support media on biofilter performance. Iso-pentane was the target VOC in this study. The results presented in this paper have been selected from a two-year study involving different support media. The experimental system used to complete all the research is described below. Experiment-specific conditions are described in the following Results and Discussion section.

Experimental Set-up

A schematic of the experimental system is shown in Figure 1. Series of glass biofilters were made to test different support media. Each glass biofilter was made in two sections with the total height of 90 cm and diameter of 5 cm. It had provisions of six side ports for withdrawing gaseous samples. Another small glass biofilter was built to carry out the temperature and water content effect tests. This small biofilter was 2.5 cm in diameter and had total volume of 100 ml. It has a water jacket outside whose temperature was controlled by a water bath. Compressed air was delivered to the bottom of the biofilter after passing through a counter-current packed pre-humidifier column. The gas flow rate was controlled by a thermal mass flow controller (MKS Industries, Type 1259, Control channel type 247). The desired concentration of the iso-pentane in the air stream was obtained by injecting the pure chemical into the air stream using a syringe pump (Harvard Apparatus, model 11). Nutrient solution (Composition shown in Table I) was pumped from the nutrient reservoir bottle to the top of the biofilter. The contaminated air stream flowed counter-currently to the trickling nutrient solution.

Biomass from a pilot scale activated sludge plant treating hazardous waste was suspended in an aerated aqueous phase bioreactor (column 100 mm diameter, 700 mm height). The bioreactor was fed daily with iso-pentane. Nutrients were also added periodically. The acclimated biomass from the bioreactor was immobilized on the synthesized support media later.

Five different support media were tested in this study. Peat and compost (Mobil) were chosen as the samples of natural support media. The effective diameter were 3.5 mm and 2.5 mm respectively. The water content of peat was 0.645 g water/g dry peat. The compost water content of compost was 0.536 g water/g dry compost. Celite pellets (Manville Corp., Denver, CO) with the diameter of 6 mm were packed into the biofilter. Cordierite monolith with and without activated carbon coating (DawCorning) were chosen. These monolith had 50 square channels per square inch with the channel dimension of 2 mm.

The biofilter was operated continuously and the inlet and outlet composition data were collected over a period of time. The concentration profiles of the compounds in the biofilter were obtained by withdrawing samples from the side ports and analyzing them using gas chromatography. Once the biofilter performance reached steady state, the concentration difference of carbon dioxide in the gas phase were measured to assess the mineralization of all compounds.

Analytical Procedure

The gas samples taken from the sampling ports were analyzed by gas chromatography in Tracor 585 gas chromatography fitted with DB-624 column (60 cm long, 0.53 mm diameter) using photoionization and electrolytic conductivity detectors. Helium was used as the carrier gas. pH of the solutions was measured by combination pH electrode connected to above meter. Carbon dioxide concentration in gas streams was determined in a Fisher 1200 gas partitioner.

RESULTS AND DISCUSSION

Adsorption Capacity

The pure physical adsorption capacity tests of different support media have been tested. 400 ml fresh samples of support were take for each media. The contaminated gas was introduced at the flowrate of 100 ml/min with the inlet concentration of 350 ppmv. The break through curves of all five support media were shown in Figures 2 to 6. It has been found that the natural support media like peat and compost had limited adsorption capacity. The adsorption capacity differed for different synthesized support media. The celite pellets and cordierite monolith systems had low adsorption capacity while the activated carbon coated monolith system had much higher one.

Water Content Effect

The water content was critical for natural support media since no additional water was added to the bed during the study. The removal efficiency of iso-pentane in peat and compost biofilters at different water content were tested in the small glass biofilter. The contaminated gas was introduces at 20 ml/min with the inlet concentration of 470 ppmv. Samples of media at different water content were tested at steady state.

Figure 7 shows the effect of water content on the operating efficiency of a peat packed-bed. The removal efficiency was maximized when the compost had a water content in the range of 0.62 - 0.67 g water / g dry peat. When the water content was less than 0.61 g water / g dry peat, There resulted an irreversible loss of the efficiency shown in dotted line. This was mainly because of the permanent deactivate of the biomass due to the loss of water. Above the water content of 0.67 g water / g dry peat, there was a significant decrease in operating efficiency. This kind of loss in efficiency was mainly due to the blanketing of the material macropores by free water, which prevented the exposure of the biomass to the contaminant in the gas phase. For VOCs like iso-pentane which had very limited solubility in water, the blanketing effect due to the presence of water in macropores was very significant. Figure 8 shows the similar effect of water content on the operating efficiency of a compost packed-bed. For peat, the irreversible loss of efficiency occurred around the water content of 0.47 g water / g dry compost. It also had wider range of maximum operating efficiency than the compost.

These results show the importance of maintaining water content in these kind of packed-beds. Less or more water in the bed would reduce the operating efficiency. It would be better that these kind of packed-bed biofilters have to be designed as shallow beds so that it will be easier to control the water content. But it will also increase the area of system significantly.

Temperature Effect

This series of tests were carried out at column temperature between 25 - 40 ^{o}C. The results were shown in Figure 9, 10. The degradation rates for both compost and peat were low at the lower temperature. The reaction rate increased more quickly from 25 ^{o}C to 30 ^{o}C than from 30 ^{o}C to 40 ^{o}C. This indicated that there have some kind of decay or deactivate of the biomass. The reaction rate was sensitive even under the room temperature which indicated the activation of this kind of reaction is low.

From these experiments, the activation energy of the degradation reaction can be estimated. These are beyond the scope of this paper and will be discussed in later papers.

Steady State Operation

Biofilters with different support media were operated under various operating conditions. Figures 11 - 15 show the effect of gas retention time on the removal efficiency at various iso-pentane inlet concentrations at steady state. The carbon dioxide concentration in most gas samples were also measured. The difference of carbon dioxide gave a fairly well agreement with the conversion of the substrate at steady state.

For peat and compost biofilters, the rate of iso-pentane removal was basically decided by the amount of active biomass in the bed as well as the supply of nutrients. In the raw materials like compost and peat, there are limited supplies of ammonia nitrogen and other micro-nutrients required for the growth and maintenance of active biomass. Deficiency of nitrogen and other nutrients could result poor bed performance. In order to increase the population of the microorganisms, periodic addition of nutrients by spraying with water containing dissolved nitrogen, phosphorous and other needed nutrients would be a necessity. During the steady state operation, contaminated air introduced to the both biofilter was pre-humidified to keep the packed bed dry. Channeling was not an important issue for biofilters with the configuration in this study, but would be important for large shallow bed biofilters.

For synthesized support media, celite pellets and cordierite monolith showed similar performance at steady state since they had similar surface area for biofilm growth. Though carbon-coated cordierite biofilter had the same configuration as the non-coated one, it showed 10 ~ 20% better removal. The reason might be that part of the substrate were absorbed by the activated carbon coating and then diffused from the biofilm-support interface back to the biofilm. This helped to improve the biofilter performance. Overall, all the biofilters with synthesized support media had better removal than the ones using natural support media. The unit iso-pentane removal rate of all five support media were compared in Figure 16.

CONCLUSIONS:

The objective of this study was to investigate the effect of support media on biofilter performance. Five different support media were tested in biofilters to representing both natural support media and synthesized ones. Important observations and conclusions included:

1. Natural support media were cheap and easy to obtain. They gave could be used in VOC biofiltration fairly well. To keep the bed in optimum operating conditions was the key. Water content and temperature of the bed directly affected the performance.
2. Synthesized support media were more adapted for various operating conditions. They had better performance on substrate removal. Compared with natural support media, they would be easier to get replaced and cleaned. Among them, adsorbent support media seemed to perform better because of the adsorption capacity.

ACKNOWLEDGMENTS

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Table 1: Composition of nutrient solution

Component	Concentration (mg/L)
KH_2PO_4	85.0
K_2HPO_4	217.5
Na_2HPO_4	266.4
NH_4Cl	25.0
$MgSO_4.7H_2O$	22.5
$CaCl_2$	27.5
$FeCl_2.6H_20$	0.25
$MnSO_4.4H_2O$	0.0399
H_3BO_3	0.0572
$ZnSO_4.7H_2O$	0.0428
$(NH_4)_6Mo_7O_{24}$	0.0347
$FeCl_3$.EDTA	0.10
Yeast Extract	0.15

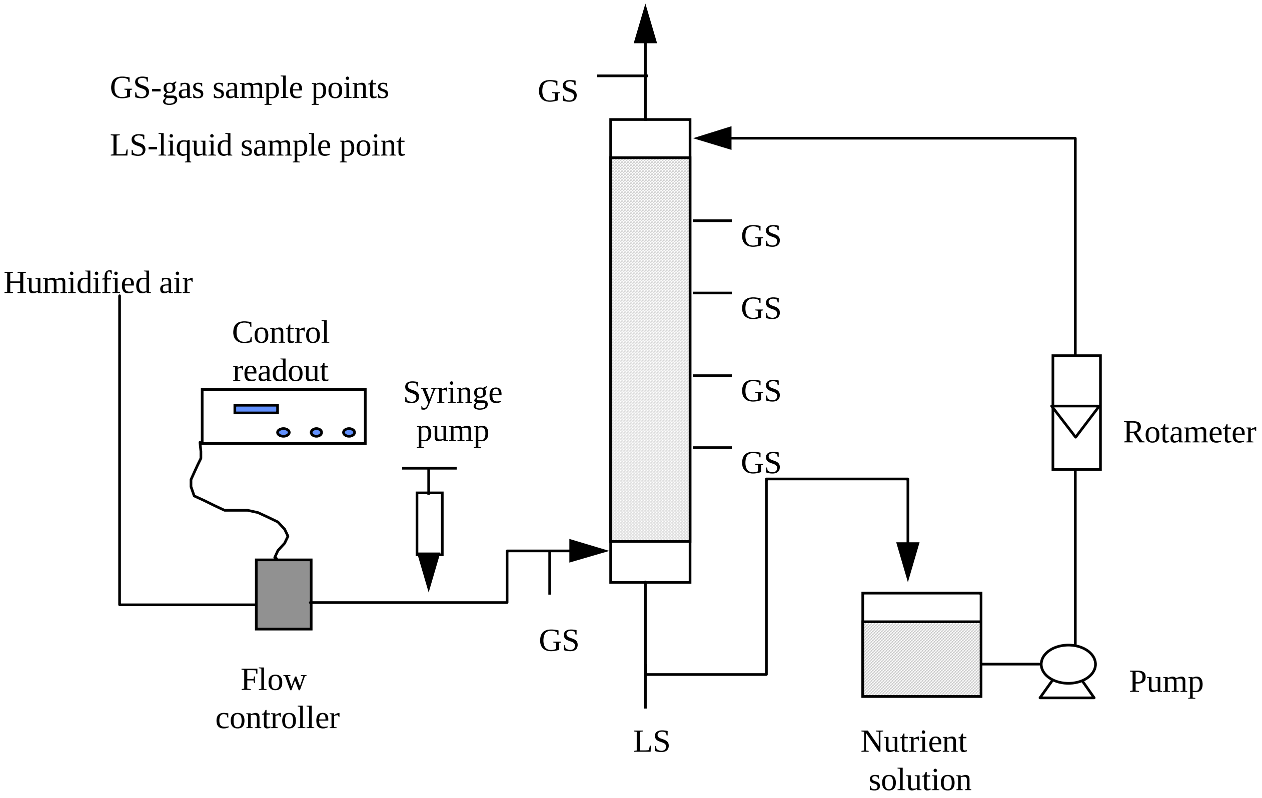

Figure 1. Schematic of the experimental biofilter set-up.

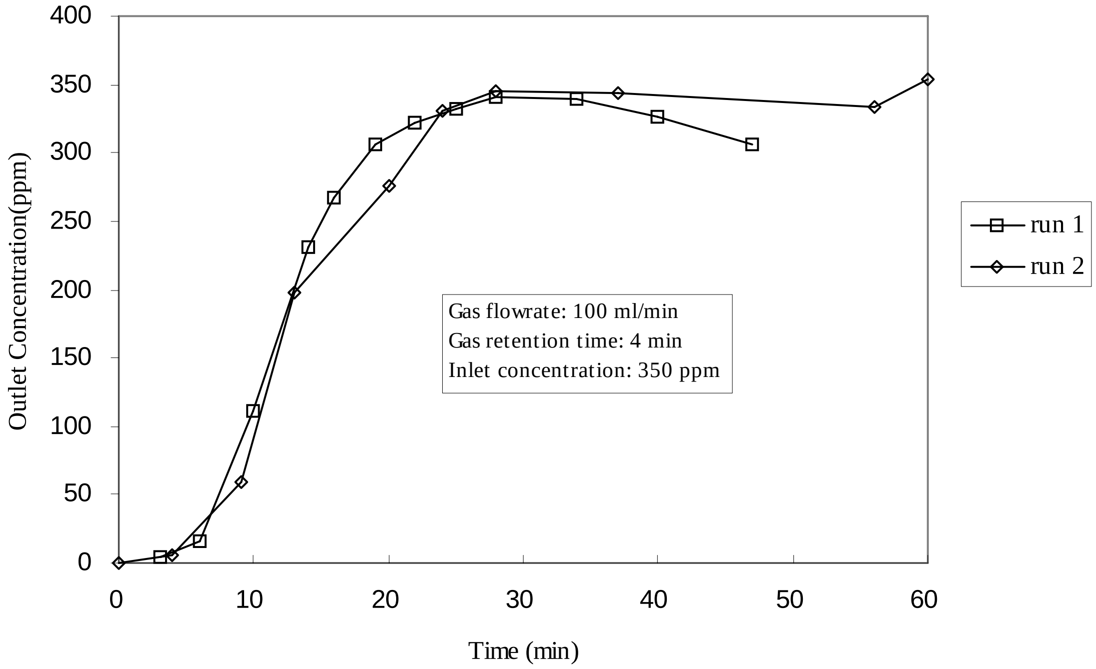

Figure 2 Break-through of iso-pentane in peat biofilter

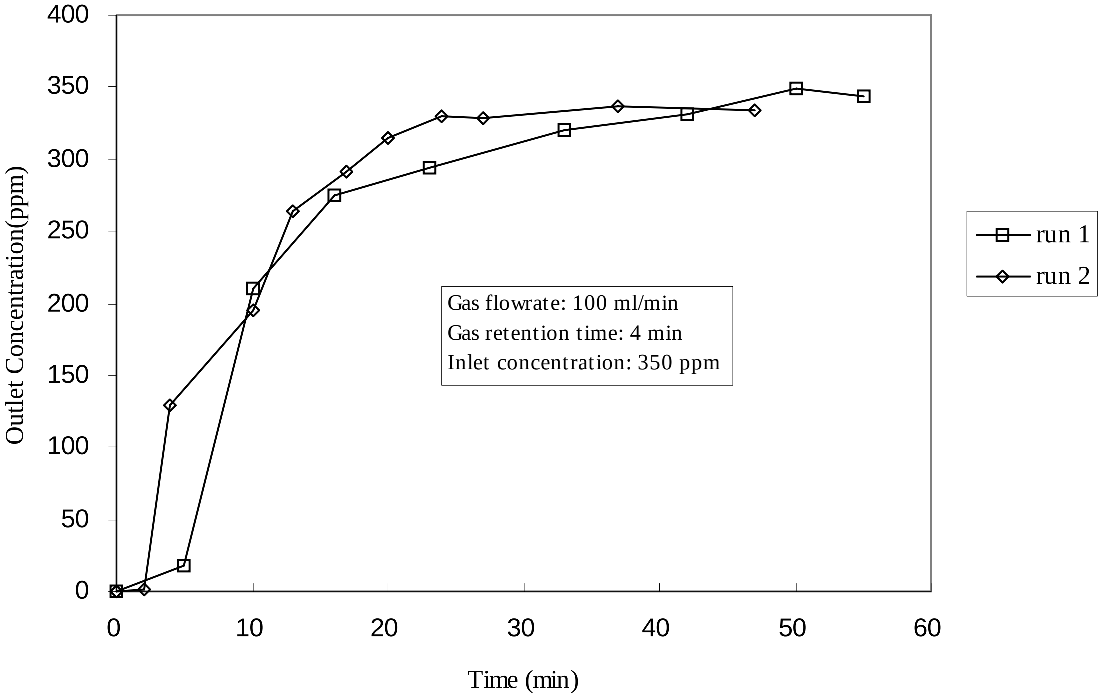

Figure 3 Break-through of iso-pentane in compost biofilter

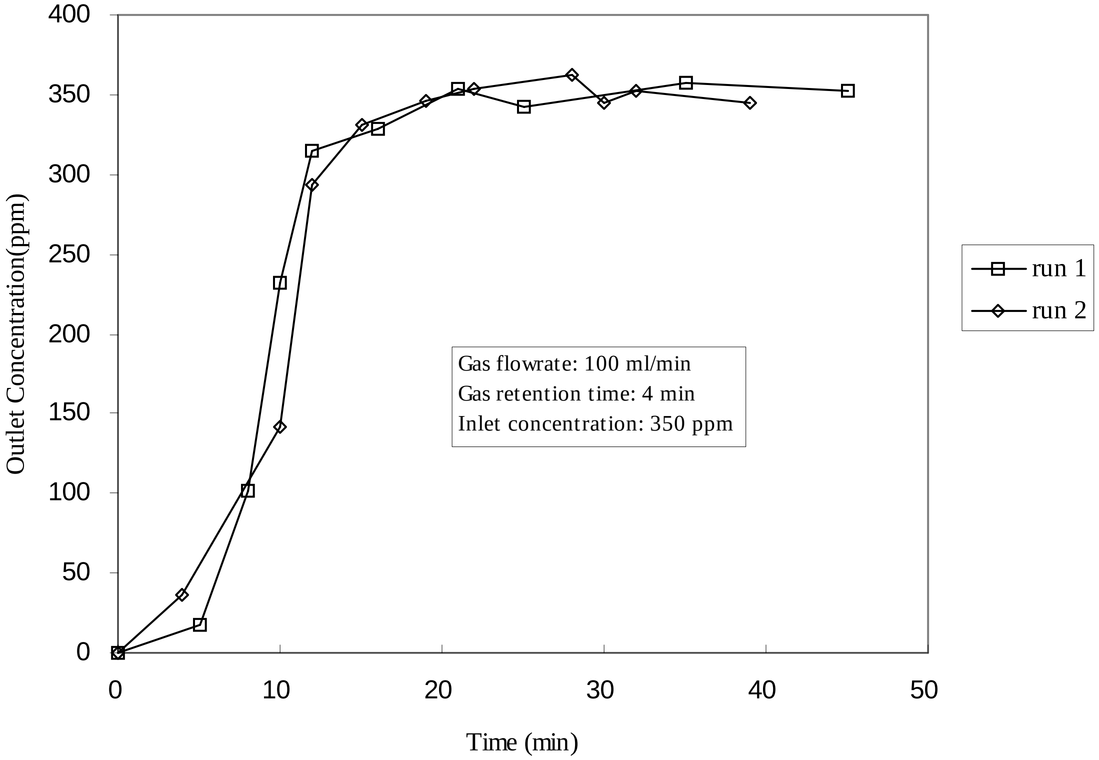

Figure 4 Break-through of iso-pentane on celite pellets

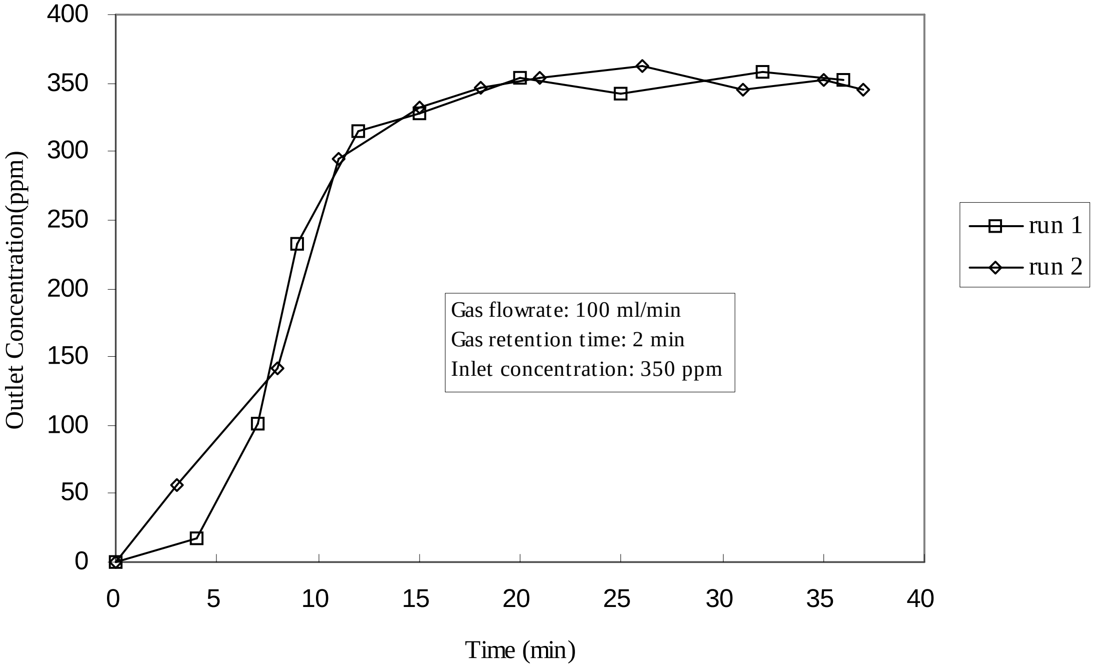

Figure 5 Break-through of iso-pentane on plain cordierite monolith

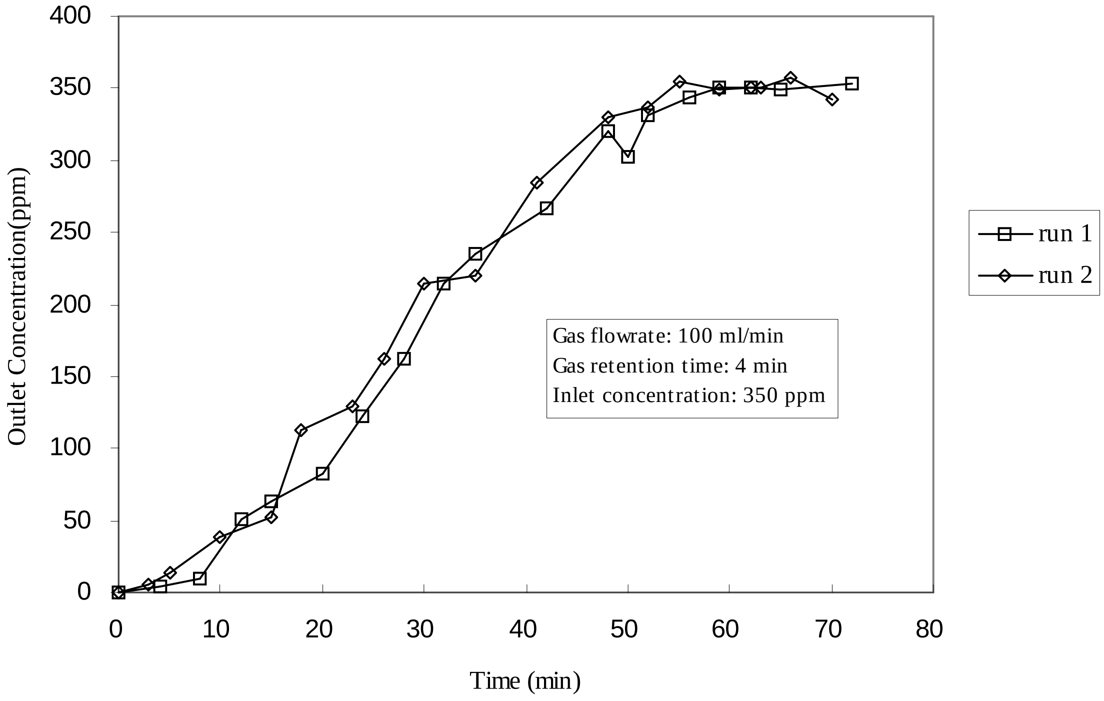

Figure 6 Break-through of iso-pentane on carbon-coated monolith

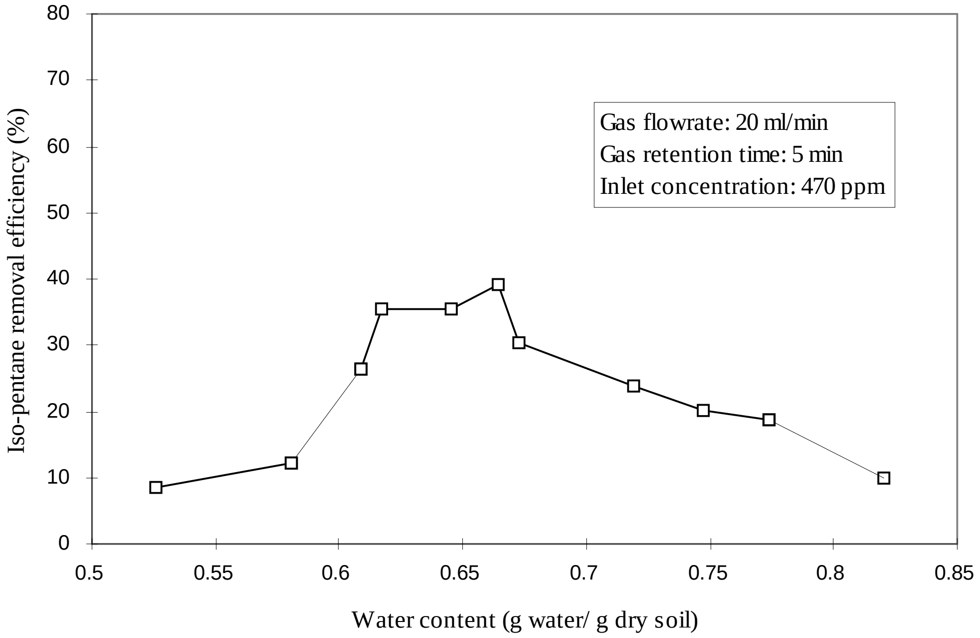

Figure 7. Effect of water content in peat biofilter

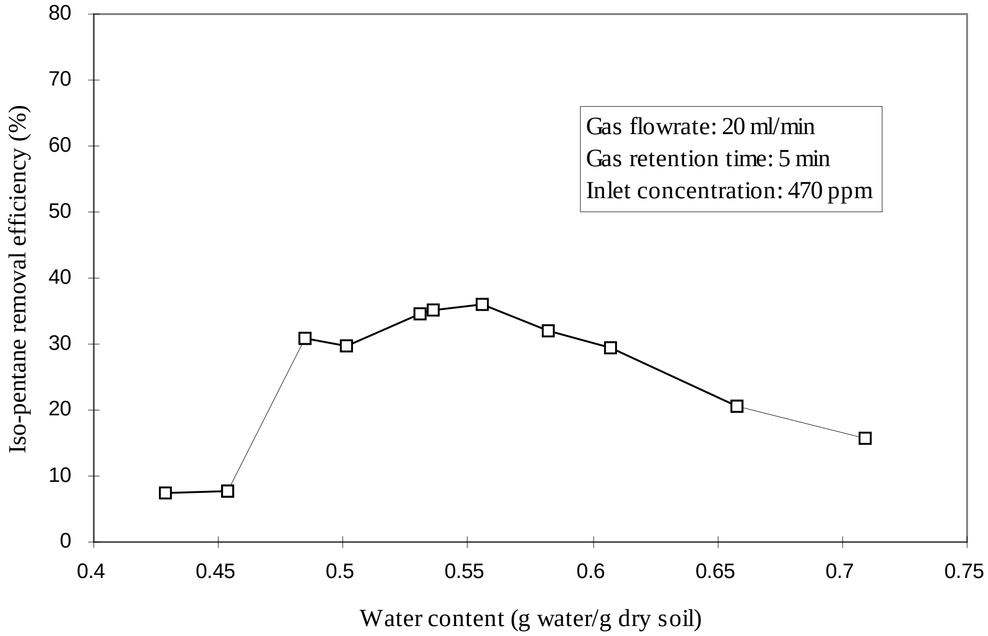

Figure 8. Effect of water content in compost biofilter

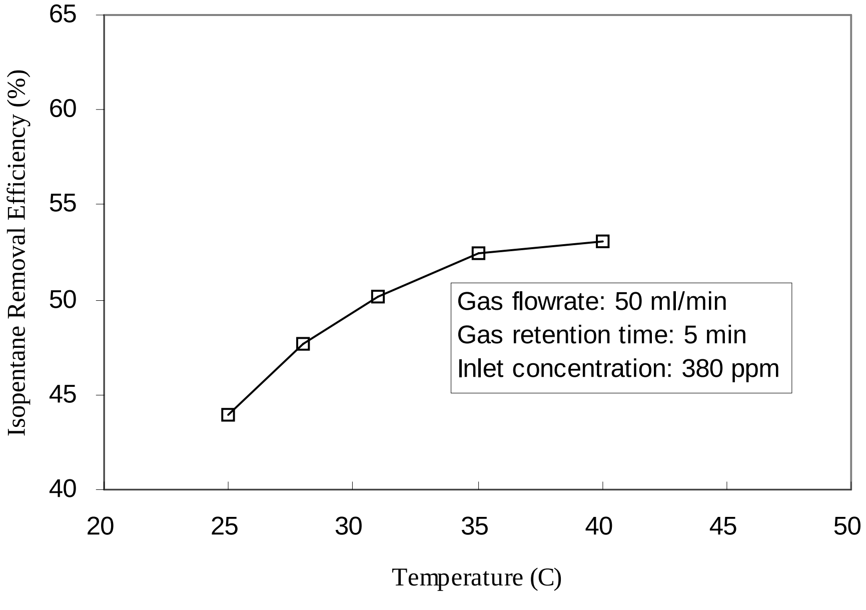

Figure 9. Effect of temperature on iso-pentane removal in a peat biofilter

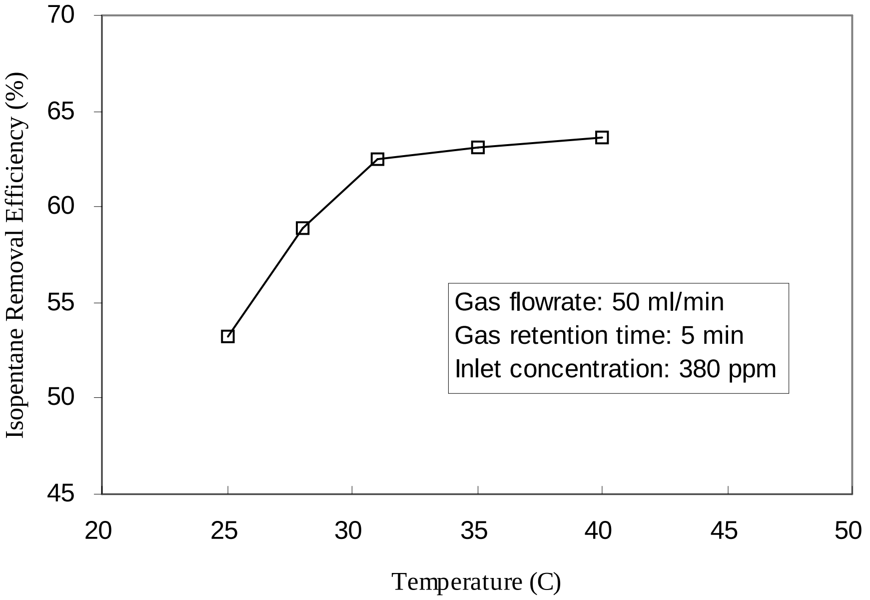

Figure 10. Effect of temperature on iso-pentane removal in a compost biofilter

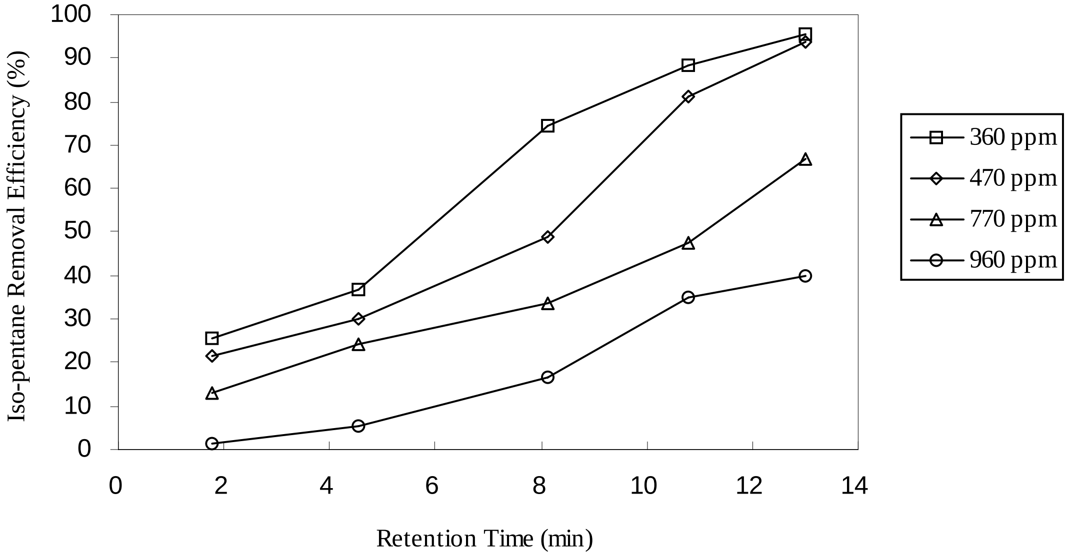

Figure 11. Removal efficiency of iso-pentane in peat biofilter

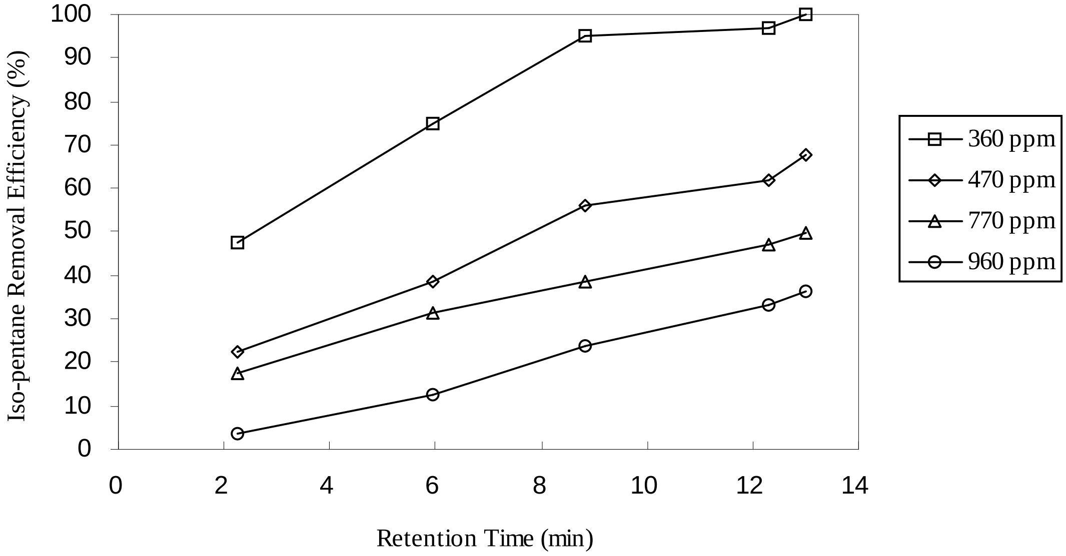

Figure 12. Removal efficiency of iso-pentane in compost biofilter

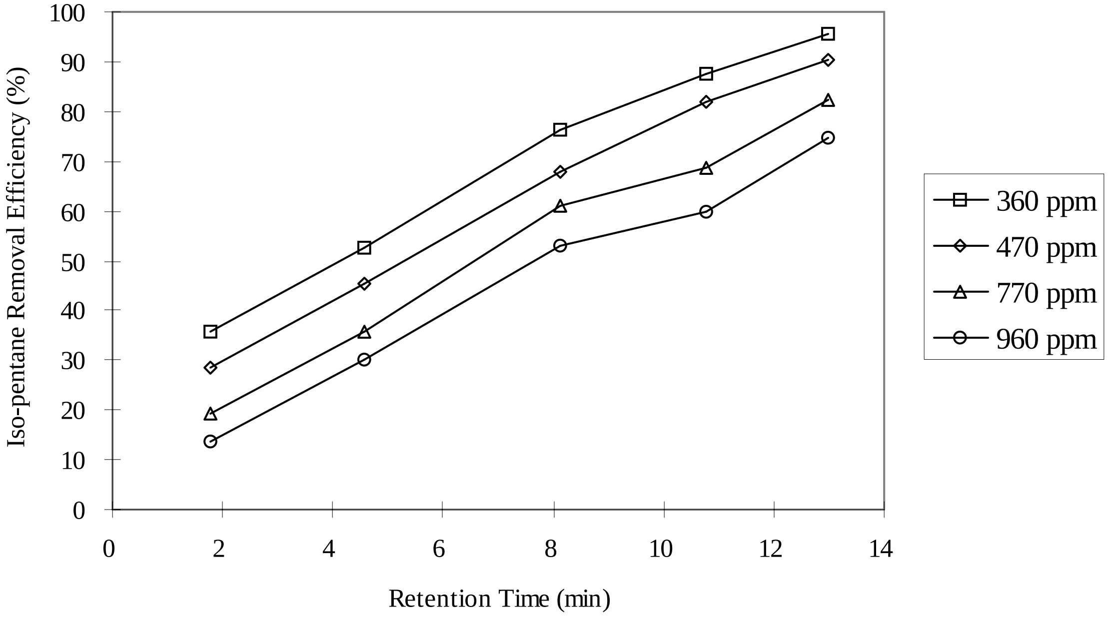

Figure 13. Removal efficiency of iso-pentane in celite packed bed biofilter

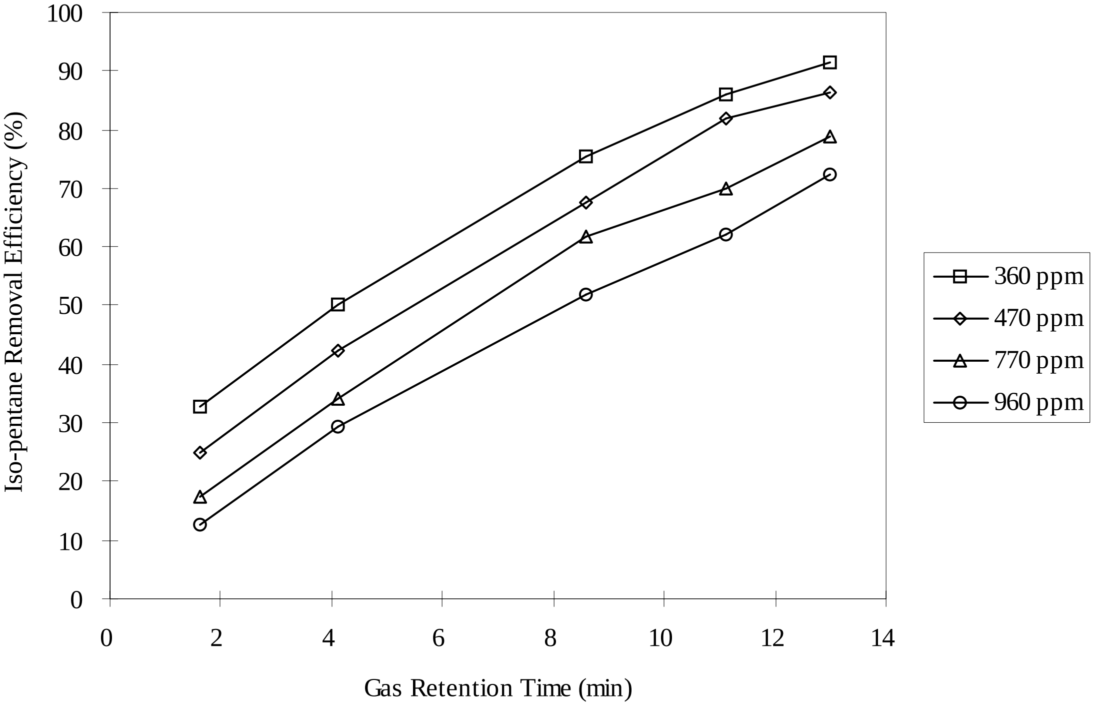

Figure 14. Removal efficiency of iso-pentane in cordierite biofilter

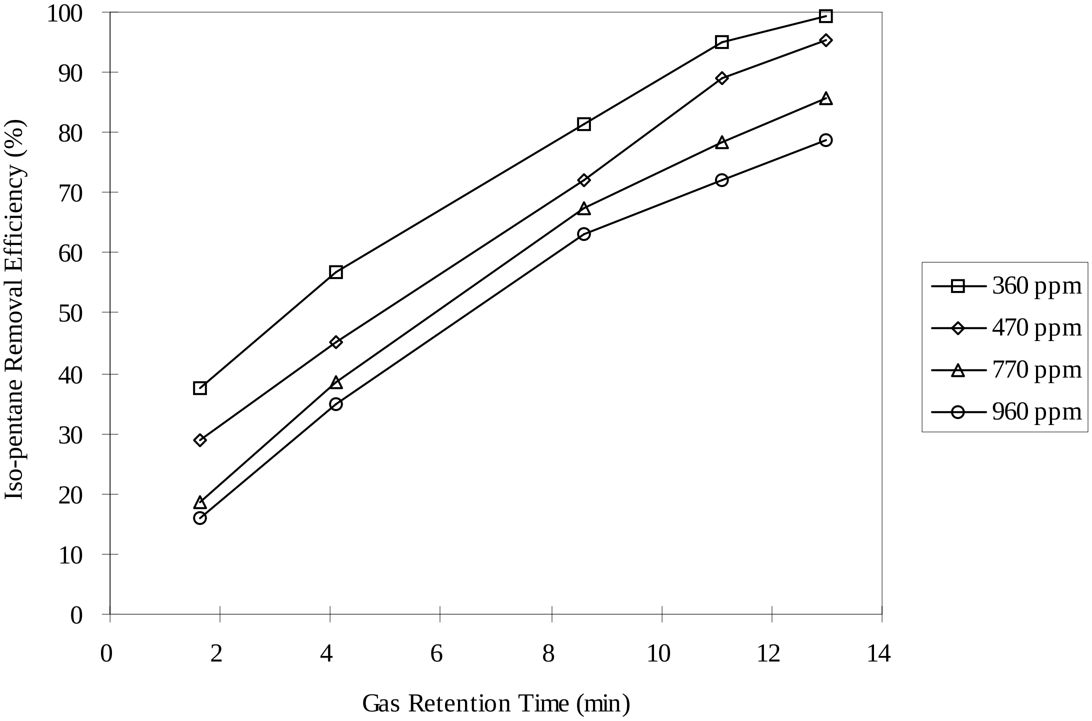

Figure 15. Removal efficiency of iso-pentane in carbon coated cordierite biofilter

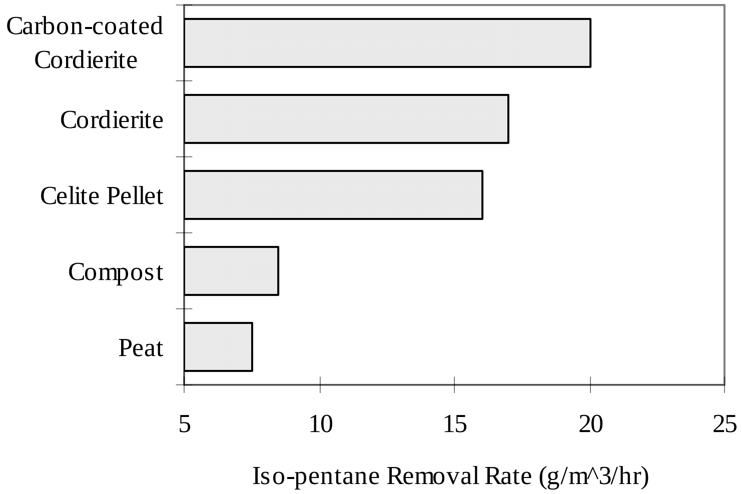

Figure 16. Comparison of iso-pentane removal rate on different support media