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# The Treatment of Volatile Organic Compounds Using a Pilot-Scale Biofilter

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# Pilot 규모의 바이오필터를 이용한 휘발성유기화합물질 제거

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## ABSTRACT

Two biofilter tests were conducted under different operating conditions. Test # 1 was performed to treat VOCs generated from a paint booth. The second test was performed to treat VOCs generated from chemical manufacturing processes. The volume of biofilter media was 4.3 $m^3$. For the test # 1, the biofilter was operated for 30 days with 99.9% reduction ratio. Range of temperature of each stage of the biofilter media was measured between 34°C and 73°C. All the temperatures of stages reduced gradually after the initial dramatic increase. For the test # 2, the biofilter experiment was conducted for 14 days. In this case, the biofilter was installed outdoor and the experiment was performed during wintertime. Therefore, temperature management for the biofilter was needed. Seven-centimeter thick fiberglass insulation and 150°C steam heating were used to overcome the outside freezing cold weather during test # 2. Temperature of stage # 5 was measured the highest and that of stage # 1 was the lowest. More acclimation time and test period was needed to determine the maximum loading rate.

**Keywords:** VOC, biofilter, pilot-scale, temperature, steam heating

## 요 약

실제 규모(pilot-scale)의 바이오필터 시스템에 대한 연구가 진행되었으며, 각기 다른 운영 여건하에서 두번에 걸친 바이오필터 테스트가 행하여졌다. 첫 번째 실험은 페인트 부스에서 발생하는 휘발성유기화합물질 처리에 맞추어져 행하여졌다. 바이오필터의 미디어 자체 부피는 4.3 $m^3$이다. 첫 번째 실험에서는 바이오필터를 30일 동안 운영하였는데, VOC제거효율이 99.9%에 이르렀다. 바이오필터 미디어 내부의 각 단계(stage)에서 측정한 온도의 범위는 34°C-73°C였다. 미디어 각 단계에서 측정된 온도는 실험 초기에는 급격히 상승하였고 이후에 점차로 낮아짐이 관찰되었다. 두 번째 실험에서는 바이오필터를 14일간 운영하였는데, 반응기가 실외에 설치되었고 실험이 겨울에 행해짐에 따라 바이오필터의 온도 조절이 필요하였다. 7 cm 두께의 단열재와 150°C의 스팀이 온도조절을 위해 이용되었다. 본 연구에서, 겨울철 바이오필터 운영상에 발생할 수 있는 온도조절 문제에 대하여 단열재와 스팀이 훌륭한 대안이 될 수 있음을 보였다. 미디어 내부의 온도는 단계 5(stage # 5)에서 가장 높았으며, 단계 1(stage # 1)에서 가장 낮았다. 두 차례에 걸친 실험에서, 실제 규모(pilot-scale)의 바이오필터 내부의 높이 위치별, 단계별 온도변화에 대한 밀도있는 연구가 이루어졌다. 하중이 바이오필터의 운영에 미치는 영향이 본 실험들을 통해 관찰되어졌고, 바이오필터에 대한 최대 하중 결정 과정에는 추가적인 적응시간 및 실험기간이 요구되었다.

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# I. Introduction

Biofiltration is an emerging and promising air pollution control technology. Various toxic air pollutants and volatile organic compounds from a variety of industrial and public sector sources have been effectively removed with biofiltration.[1-4] Biofilter can effectively degrade a wide variety of organic contaminants, including volatile aliphatic compounds, such as hexane and pentane, and recalcitrant compounds, such as halogenated hydrocarbons.[5-9] Presently, researches are actively conducted on application of biofiltration technology to an even wider variety of compounds.[5]

As the temperature of biofilter rises, chemical and enzymatic reactions in the microbial cell proceed at more rapid rates and growth becomes faster in a biofilter media. However, above a certain temperature, proteins, nucleic acids, and other cellular components may be irreversibly damaged. Four groups of microorganisms in relation to their temperature optima can be broadly distinguished: psychrophiles, with low temperature optima, mesophiles, with midrange temperature optima, thermophiles, with high temperature optima, and hyperthermophiles, with very high temperature optima.[10]

Lackey[11] reported significantly higher styrene removal efficiency at biofilter during the summer season than winter. The average temperature of inlet air stream to biofilter was 32.2°C for the summer season, while 13.8°C for the winter season. According to Lackey, optimum inlet gas temperature ranges between 20 and 40°C.

Swanson[8] recommended 35°C as the optimal temperature for the aerobic microorganisms in biofilters. Cox[12] reported that styrene degradation rates at biofilter were similar between 22.5 and 33°C. However, the decrease was observed at higher temperatures. More research is needed for the optimum temperature range for the biofilter operation with various operating conditions.

The relationship between loading rate and removal efficiency was investigated by many researchers[1,3,9,12,13]. Table 1 shows some of removal efficiencies of biofilters from selected literature. According to previous studies, removal efficiency decreases as the loading rate increases. Determination of maximum loading rate is an essential part of full-scale biofilter design. Devinny and Hodge[13] experienced a granular activated carbon (GAC) biofilter upset when the biofilter was overloaded with ethanol. According to Devinny and Hodge, biofilter upset caused by overload can result in the reactor performance being degraded and toxic intermediates being carried out of the biofilter.

**Table 1.** Removal efficiency of biofilter from selected literature

| Author | Compounds | Removal Efficiency (%) |
|---|---|---|
| Sorial *et al.*[3] | Toluene | 95-99 |
| Morgenroth *et al.*[6] | Hexane | 99 |
| Devinny and Hodge[13] | Ethanol | 33-69 |
| Auria *et al.*[7] | Ethanol | 33 |

In the present study, two different biofilter experiments were performed under different operating conditions. The first experiment (test # 1) was performed to treat VOCs generated from a paint booth where a variety of coatings are applied to vehicles and parts. A pilot-scale biofilter was installed indoor at a construction equipment vehicle manufacturing company, located at Changwon, Kyungsangnam-Do, Korea.

The second experiment (test # 2) was performed to treat VOCs from chemical manufacturing factory, located in Ulsan Industrial Complex, Korea. The company produces a variety of chemical products, including PVC, polyurethane, polyester, biphenol, agrochemicals, etc. The biofilter was installed outdoor in the factory and tested during the winter season (January 2003).

# II. Materials and Methods

## 1. Biofilter Media

Composting material was used as the biofilter media for the experiment. It was manufactured from the local composting facility (Jung-Won Farm, Changwon, Korea). The compost was produced with two different types of hardwood saw dust and cow manure after 30 days of composting retention. Saw dust was purchased from a local carpenter shop and was used as received without further sieving. It was consisted of a variety of wood wastes, but was predominantly from white pine and chestnut. The ratio for the raw materials of saw dust and cow manure was about 50% each. The compost manufacturing process was conducted aerobically. Usually, it took about 40 days for the composting facility to produce their final products. However, in the case of the compost used for the experiment, it took only 30 days, because of their hectic production schedule. Therefore, relatively immature material could be used for the tests. The pH of the compost was 7.2 (±0.1). The content of nitrogen in the compost material was 0.92% and the content of phosphorous was 0.87% by weight, respectively.

## 2. Biofilter Design

A schematic of the biofiltration system is shown in Fig. 1. The body of the biofilter reactor was constructed with steel with an internal diameter of 230 cm and a height of 260 cm. The biofilter consisted of the following sections, from top to bottom.

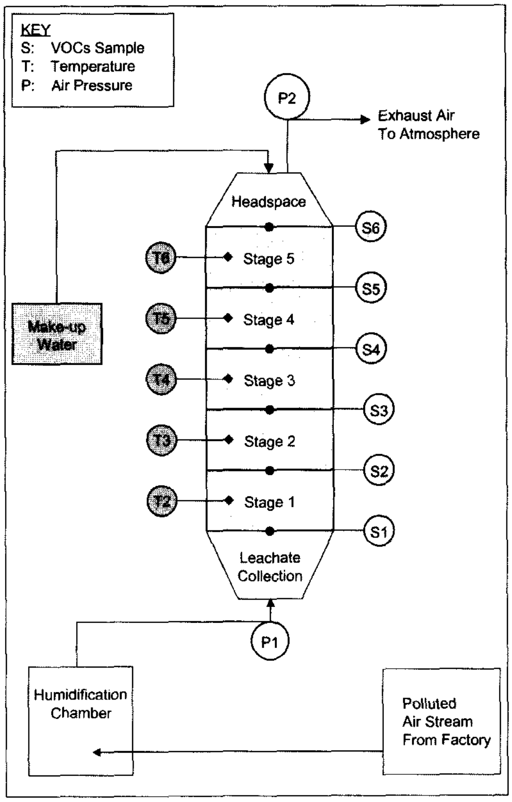

**Fig. 1.** Schematic of the Biofiltration System.

A headspace for housing the water spray nozzle.

A section containing biofilter media. The height of the biofilter media was one meter and the size of the media was about 4.3 $m^3$. Conceptually, the biofilter was divided into five different consecutive stages. The height of each stage was 20 cm.

A bottom space to collect leachate from biofilter.

Inlet and outlet relative humidity ($R.H._1$ and $R.H._2$) were measured using a model duo humidity indicator and a model Capacitive relative humidity (RH) Sensor (rbr-Computertechnik, Germany). Relative humidity of inlet air stream was maintained almost 100% for most of the experimental period. The body of the humidifying water chamber was constructed with steel with an internal diameter of 76 cm, and a height of 130 cm. Water was sprayed through nozzles inside the humidification chamber against the air flow and relative humidity was measured for the entire experimental periods.

Inlet and outlet air pressure ($A.P._1$ and $A.P._2$), respectively was measured with a model SS-3011 pressure gauges (Woo-Jin Electronics, Co. Ltd., Korea). Temperatures of the biofilter media at five different consecutive stages (stage # 1, # 2, # 3, # 4, and # 5) were measured using a model 865F thermistor meter and model OL-710-PP probes (Omega Engineering Inc., Stamford, CT). Temperature sensors were spaced at the center location of the media at each stage.

For an initial irrigation of the biofilter, about 10.0 $m^3$ of chlorine-free water were sprayed through the nozzle in the headspace of the reactor. The leachate in the bottom of the reactor was recycled until the whole biofilter media was thoroughly saturated. After the initial water irrigation of the biofilter media, no exterior water was directly added to the reactor for the remainder of the experimental period.

For test # 1, the pilot-scale biofilter was installed indoor and the season was early fall (September 2002). However, for test # 2, the pilot-scale biofilter was located outdoor and it was operated during winter time (January 2003). Therefore, during test # 2, temperature management for the biofilter was needed. To overcome the outside freezing cold weather, 7 cm thick fiberglass insulation and 150°C steam heating was used. Seven millimeter diameter copper pipe circulated the main body of the biofilter reactor for steam heating. Total height of the biofilter reactor body was 2.6 meter and the height of media was one meter. Around middle section of the wall of the biofilter reactor where the media attached inward, copper pipe circulation was installed at 10 cm interval. At the lower and upper sections of the wall of the biofilter reactor (where the media is not attached inward directly), it was installed at 20 cm interval. Fiberglass insulation covered the outside of the reactor body over the copper pipe circulation. In the case of humidifying water chamber, only fiberglass insulation was made without steam heating.

### 3. VOC Analysis

Inlet and outlet air samples from each stage of the biofilter ($S_1$, $S_2$, $S_3$, $S_4$, $S_5$, and $S_6$) were collected in one liter Tedlar sample bags. The concentrations of VOCs were measured using a Varian Saturn-3 Gas Chromatography/Mass Spectrometry (GC/MS). Five hundred micro-liters from the Tedlar bag sample were injected into the GC injection port with a Hamilton Gastight #1750 syringe. For species separation, a 0.25-mm ID * 30 m DB5 capillary column (J & W Scientific, Folsom, CA) containing 0.25 mm film thickness was used. Helium (He) was used as the carrier gas at a flow rate of 8 m*l*/min. The injection temperature was 220°C and the transfer line temperature to mass spectrometry was set at 220°C. Total sample run for each VOC analysis was 28 minutes in duration. For the initial 5 minutes, the GC oven temperature was maintained at 30°C and then the temperature was increased until 130°C with the rate of 10°C/min, then it was increased until 250°C with the rate of 15°C/min. At 250°C, the GC oven temperature was maintained for 5 minutes. A single point external standard calibration method was used. All results are given in parts per million (ppm) by volume.

### 4. Retention Time and Loading Rate to the Biofilter

For test # 1, during the earlier period of the experiment (day 1 to 19), a 1.04 minute empty bed residence time (62.5 seconds) was used. This is equivalent to 0.21 minutes (12.5 seconds) for each individual stage. A 6.1 seconds empty bed residence time was used for the humidifying water chamber. During the experimental day 20 to 30 of test # 1, a 0.73 minute empty bed residence time (44 seconds) was used for the biofilter reactor. This is equivalent to 0.15 minutes (8.7 seconds) for each individual stage. A 4.3 seconds empty bed residence time was used for the humidifying water chamber. Volatile organic compounds (VOCs) COD loading rate (kg COD/m$^3$) to the biofilter was calculated based on the individual stage volume (0.83 m$^3$). For test # 2, only on the day 2 to 7 and 14, the contaminated air stream was provided to the biofilter system. On other days, ambient air was supplied to the system to maintain proper operational condition.

## III. Results and Discussion

### 1. Applied VOC Concentration and Loading Rate

During the test # 1, the biofilter was operated for 30 days to treat VOCs from a paint booth, where a variety of coatings are applied to construction equipment vehicles. Unfortunately, VOC measurement was not available until the day 14$^{th}$, because of mechanical problem of GC/MS. Fig. 2 shows VOCs measurement of the inlet air flow to the biofilter. It shows VOCs concentrations and the

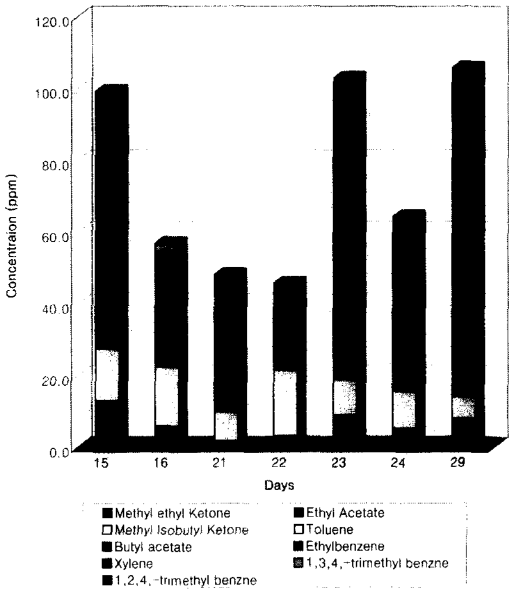

Fig. 2. Daily VOCs measurement of the inlet air flow at test #1.

**Table 2.** Average VOCs concentrations of the inlet air flow to the biofilter system

| Compounds | Test # 1 (ppm) | Test # 2 (ppm) |
|---|---|---|
| Dimethyl-hexene | -- | 87.4 |
| Trimethyl-pentene | -- | 3632.0 |
| trimethyl-hexene | -- | 1047.8 |
| methyl-heptene | -- | 126.0 |
| ethyl-hexane | -- | 5.6 |
| dimethyl-hexane | -- | 99.5 |
| Toluene | 14.4 | 124.3 |
| dimethyl-cyclohexane | -- | 432.4 |
| phenol | -- | 0.5 |
| Methyl ethyl Ketone | 1.9 | -- |
| Ethyl Acetate | 8.1 | -- |
| Methyl Isobutyl Ketone | 0.3 | -- |
| Butyl acetate | 17.2 | -- |
| Ethylbenzene | 7.1 | -- |
| Xylene | 36.6 | -- |
| 1,3,4,-trimethyl benzne | 1.3 | -- |
| 1,2,4,-trimethyl benzne | 1.2 | -- |
| Total Concentration (ppm) | 88.1 | 5555.5 |

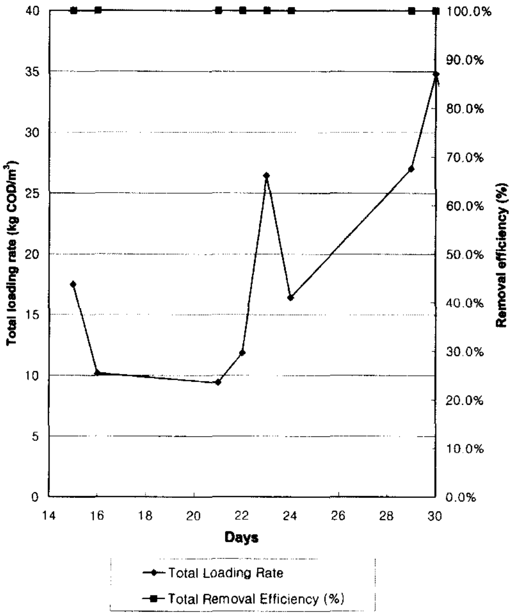

**Fig. 3.** Input loading rate (kg COD/m$^3$) and removal efficiency (%) at test #1.

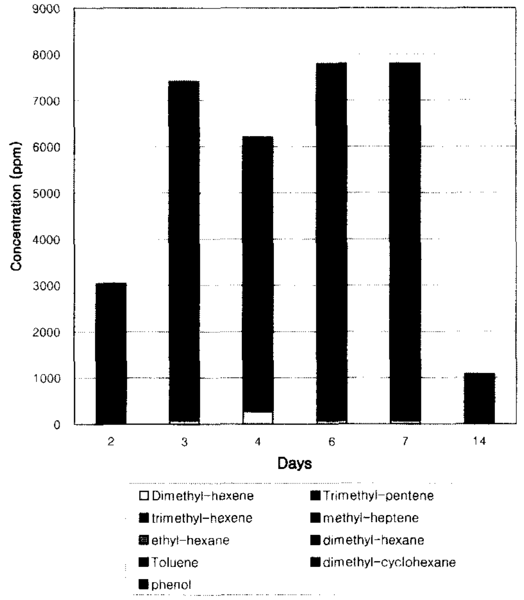

**Fig. 4.** Daily VOCs measurement of the inlet air flow at test #2

compositions of each chemical compound on a daily bases. Table 2 shows the average concentrations of chemical compounds of VOCs. Total average concentration was 88.1 ppm and butyl acetate, xylene, and toluene are the most dominant compounds and they occupy more than 77 percent. The range of daily VOCs concentration was between 45 to 140 ppm. The total removal efficiency of the system was maintained more than 99.9% for the whole experimental period (Fig. 3). Total loading rate to the system was calculated between 9.4 to 35 kg COD/m$^3$ based on the inlet air flow VOCs concentration.

Second biofilter test was performed to treat VOCs from contaminated air stream during the winter season. The polluted air stream was produced from manufacturing processes of PVC, polyurethane, polyester, biphenol, agrochemicals, etc. The second experiment was conducted for 14 days. Fig. 4 shows VOCs measurement of the inlet air flow to the biofilter system. It shows VOCs concentrations and the compositions of each chemical compound on selected days. Table 2 shows the average concentrations of chemical compounds of VOCs. Total average concentration was 5,555 ppm and trimethyl-pentene and trimethyl-hexene were the two most dominant compounds, which occupied 84 percent of total VOC concentration.

Initially, misinformation was provided from the

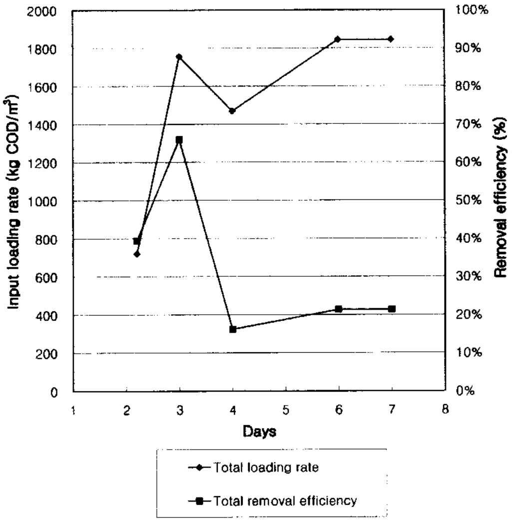

Fig. 5. Input loading rate (kg COD/m$^3$) and removal efficiency (%) at test #2.

vender and the range of inlet air stream VOCs concentration was expected from about 50 ppm to 300 ppm. However, actual incoming concentration to the biofilter system was measured from 1,000 ppm to 7,800 ppm. The unexpected heavy loading rate became a severe shock for the biofilter to operate properly. As a result, the contaminated air stream from chemical manufacturing process could not be provided to the biofilter all the time. On selected six days (days 2 to 7 and 14), the contaminated air stream was provided. On the other days, ambient air was supplied to the system.

The total removal efficiency of the system fluctuated on the days when polluted air stream was provided (Fig. 5). Total loading rate to the system was calculated between 60 to 1,840 kg COD/m$^3$ based on the inlet air flow VOCs concentration. Because of extremely heavy loading rate and severe fluctuation of loading rate (60 to 1,840 kg COD/m$^3$) to the biofilter system, acclimation period was essential. Until day 7, about 1500 kg COD/m$^3$ was provided to the biofilter system. On day 2, the removal efficiency of the biofilter was 39% and it increased to 66% on day 3. However, it dropped to 16% on day 4 and it was 21% on day 6 and 7, respectively. As it was too heavy for the biofilter, ambient air was provided from day 8. On day 14, the polluted air stream was provided to the biofilter system. The loading rate was 65 kg COD/m$^3$ and removal efficiency was about 67 percent.

The applied loading rate to the biofilter and removal efficiency are strongly negatively correlated with each other[1,3,9,12,13]. According to previous studies, removal efficiency decreases as the loading rate increases. Determination of maximum loading rate is an essential part of full-scale biofilter design. In the case of test # 1, applied loading rate to the biofilter was relatively low. In the case of test # 2, the situation was opposite. More acclimation time and test period was needed to determine the maximum loading rate for the pilot-scale biofilter to manage with given operating condition.

## 2. Temperature

Temperature was measured for the entire experimental periods. For test # 1, there was no temperature control inside the building where the pilot-scale biofilter was located. Outside temperature of biofilter system continued to be fluctuated and generally decreased. Fig. 6 shows the temperature of each stage of the biofilter media. Range of temperature of each stage was measured between 34°C and 73°C during the experiment.

As above mentioned, composting material was

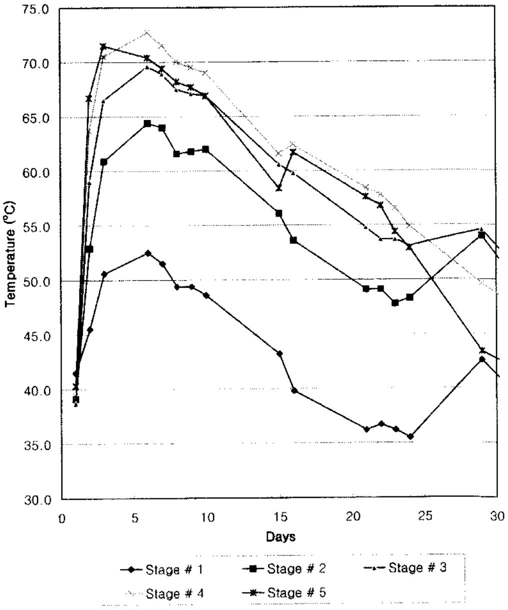

Fig. 6. Center temperature of each stage in the biofilter media at test #1.

the main biofilter media and only about 30 days were used for manufacturing the composting material. Because of the hectic production schedule at the composting facility, the manufacturing period for the composting material could not sufficient enough. Therefore, the final composting material used for the biofilter experiment might not be matured enough. As these compost material was located inside the biofilter reactor, saturated with water, and humidified air flow pass through the media, temperature of the media started to be increased dramatically. In the case of temperature of stage # 4 and # 5, it increased from about 40°C to 73°C for the first three days. However, all the temperatures of stages reduced gradually after the initial dramatic increase. Biofilter media itself might progress restabilization process inside the biofilter reactor. Unless more stabilized and fully matured compost material is used for the biofilter media, this kind of initial unnecessary temperature increase in the media cannot be avoided.

During test # 2, ambient temperature continued to be fluctuated and occasionally dropped below zero. Fig. 7 shows the temperature of each stage of the biofilter media. Temperature of each stage ranged from 1°C to 54°C. During test # 2, steam heating was provided until the end of the experiment. Temperatures of stage # 5 were measured the highest and temperature difference between media and outside ambient air increased as the operation proceeded. Temperatures of the top sections of the media were greater than those of bottom sections. Temperature management of inner media with fiberglass insulation and steam heating was possible even on the freezing cold weather outside.

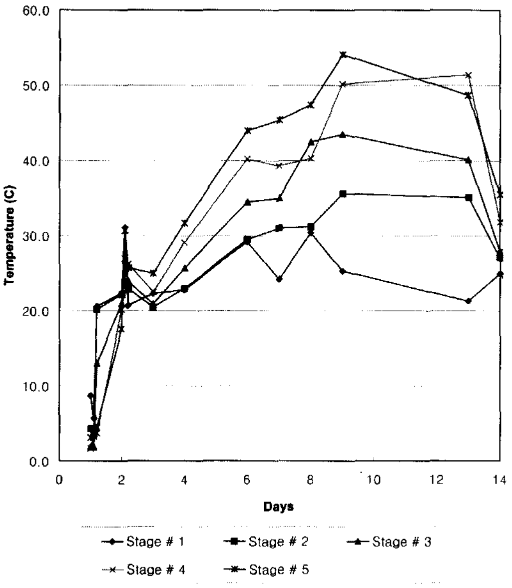

**Fig. 7.** Center temperature of each stage in the biofilter media at test #2.

## IV. Conclusion

Two different biofilter experiments were performed under different operating conditions. The first experiment (test # 1) was performed to treat VOCs generated from a paint booth. For test # 1, a pilot-scale biofilter was located indoor and was operated for 30 days during early fall. Total VOC concentration to the biofilter system was 88.1 ppm. Butyl acetate, xylene, and toluene are the most dominant compounds and they occupied 77 percent. The total removal efficiency of the system was maintained more than 99.9% for the whole experimental period.

The second experiment (test # 2) was performed to treat VOCs from chemical manufacturing processes. For test # 2, the biofilter was located outdoor and was operated for 14 days during winter season. Average VOC concentration of inlet was 5,555 ppm and it ranged from 1,000 to 7,800 ppm. Trimethyl-pentene and trimethyl-hexene were the most dominant compounds and they occupied about 84 percent of the total. Extremely heavy loading rate and severe fluctuation of loading rate (60 to 1,840 kg COD/m$^3$) were applied and caused a severe shock on the biofilter to operate properly. Therefore, only for six out of 14 test days, the contaminated air stream from the manufacturing line was provided to the biofilter.

Removal efficiency decreased as the loading rate increased. In the case of test # 1, applied loading rate to the biofilter was relatively low. In the case of test # 2, the situation was the opposite. During test # 2, the removal efficiency of the biofilter was relatively low. On day 2, it was 39% and it increased to 66% on day 3. However, it dropped to 16% on day 4 and it was 21% on day 6 and 7, respectively. On day 14, it was measured up to 67 percent. More acclimation time was needed for the maximum loading rate to manage with given operating condition.

Temperature effect on biofilter operation was also studied. For test # 1, the range of temperature of each stage was measured between 34°C and 73°C. In the case of temperatures of stage # 4 and # 5, they increased from about 40°C to 73°C for the first three days. However, all the temperatures of stages reduced gradually after the initial dramatic increase.

For test # 2, the pilot-scale biofilter was installed outdoor and the experiment was performed during winter season. For temperature management of the biofilter reactor, 7 cm thick fiberglass insulation and 150°C steam heating was used. Stage # 1 showed the lowest temperature during the entire experimental periods and stage # 5 was the highest. Temperature management of inner media with fiberglass insulation and steam heating was feasible even on the freezing cold whether outside.

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