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TEMPERATURE EFFECTS ON BIOFILTRATION OF OFF-GASES

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ABSTRACT

Several previous studies have indicated that off-gases resulting from soil and groundwater remedial operations can be treated economically with the use of biofilters to reduce air pollution. The efficiency of a biofilter depends on several factors such as retention time, uniformity of vapour flow, composition of biofilter, type of micro-organisms available for biodegradation, moisture content, and temperature. This paper presents a pilot study conducted on biofilters to evaluate their performance under summer and winter temperature conditions of Calgary. The mean monthly summer and winter temperatures in Calgary vary from 17 to 23 ºC and from -18 to –3 ºC respectively.

Three biofilter reactors were constructed using three steel containers each 1.22 m in diameter and 1.52 m in height. One of the three reactors was insulated on the outside with polyurethane foam insulation. Another reactor was heat-traced and was also insulated on the outside. The third reactor was not provided with any thermal insulation. Humidified gasoline vapours were mixed with fresh air to provide off-gas contaminants to the biofilters. The performance of biofilters under various ambient temperatures, contaminant concentrations, and gas flow rates was evaluated. Design and practical aspects relevant to the operation of biofilters in cold temperatures were discussed.

INTRODUCTION

Biofiltration is the process in which an air stream containing volatile organic chemicals (VOCs) is passed through a biologically active medium called biofilter. The contaminants are transferred from the air phase to the water/biofilm phase, where they are biologically degraded by microorganisms to less harmful substances, usually carbon dioxide and water. Biofiltration has been identified as an economical and efficient method in the treatment of VOCs present in air streams at low concentrations. An excellent review on the various aspects of biofiltration was presented by Wani et al. (1997). Biofiltration is an attractive alternative in the long-term treatment of gasoline vapour at low concentrations resulting from the vapour extraction of contaminated soils.

Biofiltration efficiency depends on several factors including retention time, uniformity of vapour flow, composition of biofilter, type of microorganisms available for bio-degradation, moisture content, and temperature. The purpose of the research presented here was to evaluate the performance of biofilters in the treatment of VOCs extracted from gasoline contaminated soils under summer and winter temperature conditions in Calgary, Alberta. The mean monthly summer and winter temperatures in Calgary vary approximately from 17 to 23 ºC and from -12 to –3 ºC respectively.

MATERIALS AND METHODS

Three biofilter reactors were constructed using three steel containers, each 1.22 m in diameter and 1.52 m in height (Figure 1). The major components of the biofilter were organic compost, pine bark, peat moss and spent activated carbon. The spent activated carbon added to the biofilter material had been used earlier in the treatment of off-gases consisting of gasoline vapours. The detail composition of the biofilter material is listed in Table 1. The total cost of the biofilter material was approximately C$100 per cubic metre. Physical properties of the biofilter are presented in Table 2. The filter material was placed in a thickness of 1.22 m in each container and was supported by a deck built at a height of 15 cm above the base of the container. A water sprinkler system was installed at the top of each container to add water and nutrients to the biofilter when necessary.

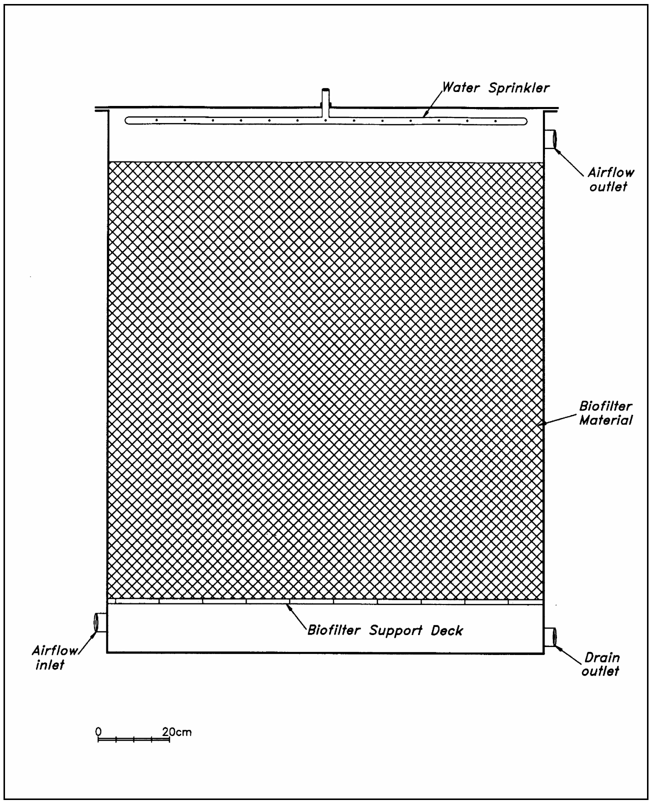


Figure 1. Schematic of a Biofilter Reactor

Experiments were carried out to determine the hydrocarbon removal efficiency of each biofilter reactor. Hydrocarbon removal efficiency is expressed as the percentage reduction in the concentrations of the inflow vapours after they have passed through the biofilter. The vapour inflow and outflow rates were determined by measuring flow velocities using a calibrated anemometer. Vapour concentrations were measured using a GasTech Model 1238 ME meter. Also air bag samples were collected and analysed for BTEX using a Model 311 HNU portable gas chromatography (GC) system. Inflow and outflow vapour temperatures and ambient air temperatures were measured to assess the impact of temperature variations on the performance of the biofilters.

The biofilters were assembled in February 1998 and the bacteria inside were conditioned for approximately three months prior to starting up the experiments. The conditioning involved pumping air, nutrients and hydrocarbons at low concentrations through the reactors to promote the growth of the microorganisms. The three reactors could be connected either in series or in parallel configuration. Figure 2 shows the details of these connection configurations. Typically, off-gas was simulated by pumping atmospheric air through a supply system made up of a blower, a chemical gas feed pump and a bubbler. Between the blower and the biofilters, air from the atmosphere was bubbled through water in a steel drum to which fresh gasoline was added through a chemical feed pump. The supply of moist gasoline vapours to biofilters prevented significant loss of moisture in the filters and helped in maintaining high relative humidities (95 to 99%) in the exhaust vapours. Experiments carried out could be divided into two distinct periods according to temperature. During the initial Warm Period, the biofilters were operated in April, June and July of 1998. In the subsequent Cold Period, they were operated in the winter of 1998.

Table 1. Composition and Cost of Biofilter Material

Material	***% by Volume***
Peat Moss	18.0
Vermiculite	7.5
Perlite	7.5
Limestone	2.0
Pine bark	20.0
Organic compost	30.0
Spent activated carbon	15.0
Bacteria triggering mechanism (BTM)	2 L/m^3 of filter
Humic acid	0.5 L/m^3 of filter
KNO_3	90 g/m^3 of filter
Cost of biofilter material: C$100 per m^3 of filter	

Table 2. Physical Properties of Biofilters in Reactors

Property	***Reactor R1***	***Reactor R2***	***Reactor R3***
Volume of filter (L)	1323.9	1344.6	1326.5
Water content (gravimetric)	144%	144%	144%
Water content (volumetric)	40%	39%	40%
Porosity	.701	.704	.701
Air Porosity	.303	.312	.304
Air Pore Volume (L)	401.6	419.4	403.5
Air Pore Volume (ft^3)	14.2	14.8	14.3

During the Warm Period, the reactors were installed at a job site with the client's approval. Reactors R2 and R3 were insulated all around with approximately 75 mm thick polyurethane foam insulation. In addition, Reactor R2 was equipped with a single 13.6 m (45 ft.) long heat-tracing wire capable of supplying 15W of heat energy per metre length. The third reactor (R1) was uninsulated.

During the April 1998 experiments, the uninsulated reactor (R1) was buried underground, where it could be protected from cold temperatures, while the other two reactors were installed above ground. Instead of pumping gasoline vapour using the chemical feed pump, off-gas from vapour extraction systems on the job site was passed through the biofilters connected in series. The bubbler was used to add moisture to the off-gas. The duration of each test was between two and three hours. During these experiments, Reactor R2 was heating using heat-tracing.

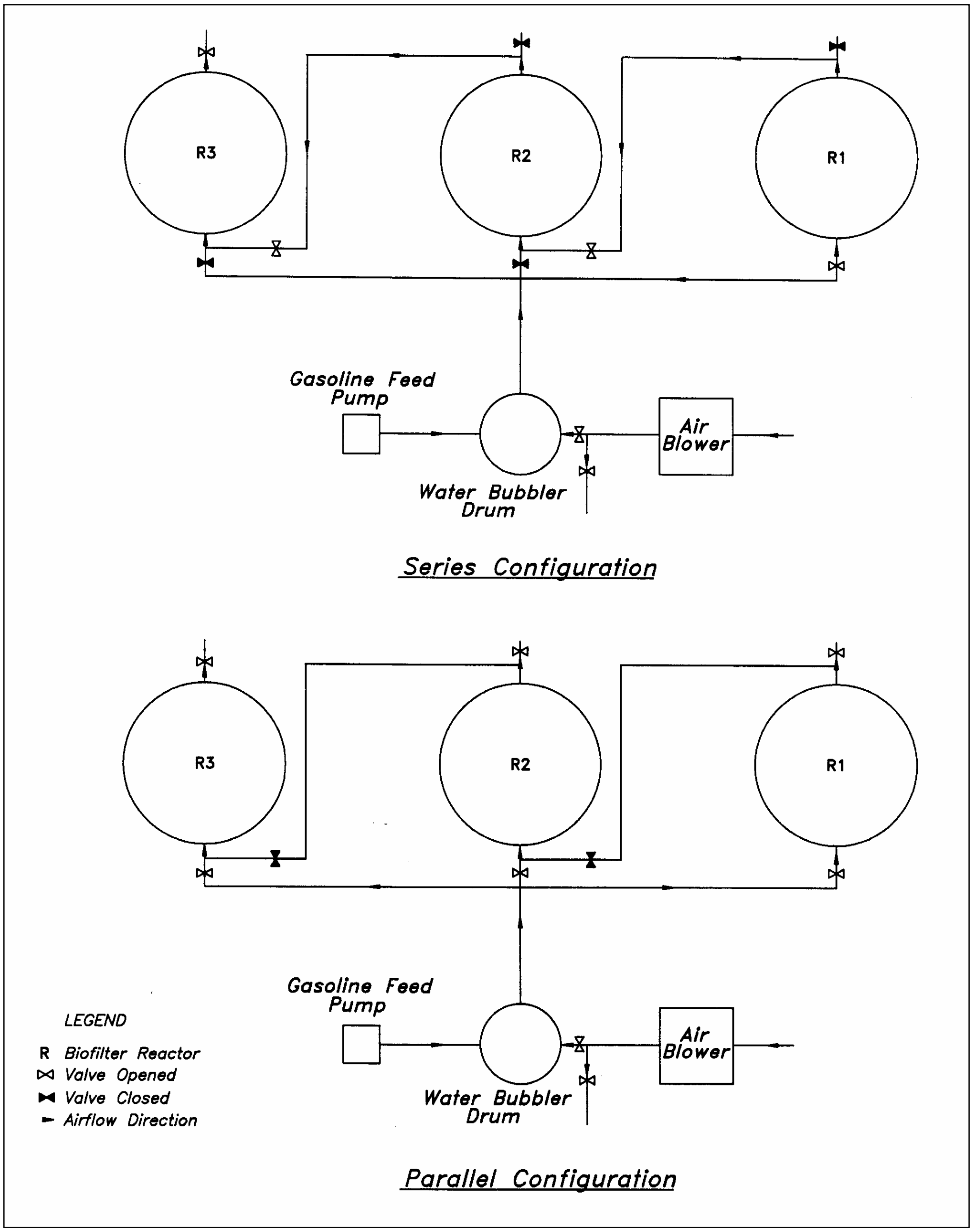


Figure 2. Experiment Configurations for Biolfilters

In May 1998, Reactor R1 was excavated. Then, all three reactors were moved to a different location within the same job site and installed above ground in the open air. In July and August, experiments were carried out to determine biofilter efficiencies both in series and in parallel using simulated off-gas. Each experiment typically lasted three hours.

In September 1998, the reactors were moved from the job site to the parking area of OAK Environmental Equipment Ltd. in NE Calgary. The three reactors were placed in an insulated wooden shed. Reactor R1 was now provided with three heat-tracing wires and was insulated with Reflextix™ insulation. Each of the heat-tracing wire was 50 ft. long supplying 8 W/ft. Reactor R2 remained to be foam insulated, however, its heat-tracing was not operated. The foam insulation around Reactor R3 was stripped and maintained uninsulated. Prior to the start of experiments, the relative humidity (R.H.) of the outflow from each reactor was monitored. The R.H. of Reactor R1 was below 90%. As a result, the biofilter material of R1 was sampled and its moisture content determined, and 1200 L of water was added to the reactor to maintain a moisture content of 144 %. From November 1998 to December 1999, experiments for the Cold Period were carried out by pumping simulated off-gas through the biofilters for three hours. Hydrocarbon removal efficiency was determined at the end of the three-hour period.

RESULTS

Air Temperatures in the Atmosphere and Reactors:

Air temperatures measured during the experiments in the Warm Period (April, July and August 1998) are presented in Figure 3. In April, Reactor R1 was buried just below the ground surface and the heat tracing for Reactor R2 was operated. As shown in Figure 3, similar air temperatures were recorded in Reactor R1 and the insulated reactor, R3. The heat-traced and insulated reactor, R2, was slightly warmer than the other two reactors. It was concluded that the amount of heat tracing installed on R2 was not adequate to maintain sufficiently high temperatures. In late May, the uninsulated Reactor R1 was excavated and was then installed above ground. In the July/August 1998 experiments Reactor R1 was considerably warmer than the two insulated reactors showing the heating effect of sunshine.

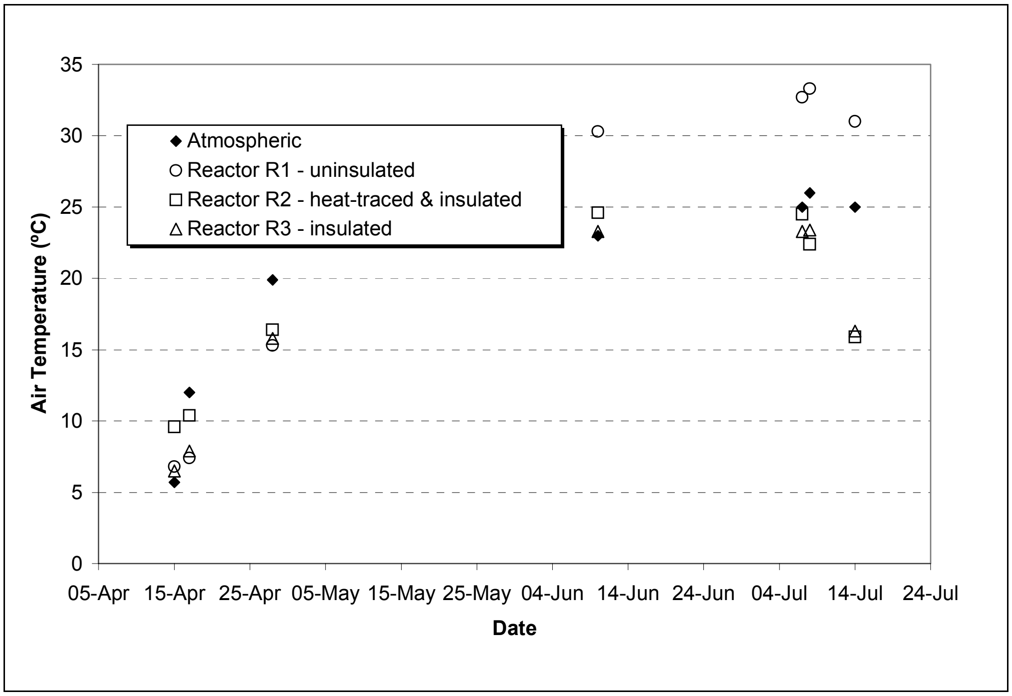


Figure 3. Air Temperatures in Reactors, Warm Period

As described in the previous sections, Reactor R1 was heat-traced and insulated, Reactor R3 was uninsulated, and Reactor R2 remained foam insulated for the Cold Period experiments. Figure 4 shows the variation of air temperatures in the reactors, the atmosphere and inside the shed. From 18 to 23 Dec, two heat-tracing wires were plugged in while only one heat-tracing wire was used for the remainder of the period shown in the graph. The temperature in the shed changed with the atmospheric temperature but was about 10 ºC warmer. With the heat-tracing operational, Reactor R1 was the warmest with temperatures ranging from 8 to 19 ºC. The records showed that with one heat-tracing wire (400 W total) the reactor temperature was about 12 ºC higher than the shed temperature and with two heat-tracing wires (800 W total), the temperature was about 18 ºC higher. During this period of 12 days, both the insulated reactor, R2, and the uninsulated reactor, R3, gradually cooled off. The temperature in R2 dropped from 9 to 2 ºC, while R3 cooled from 4 to 0 ºC.

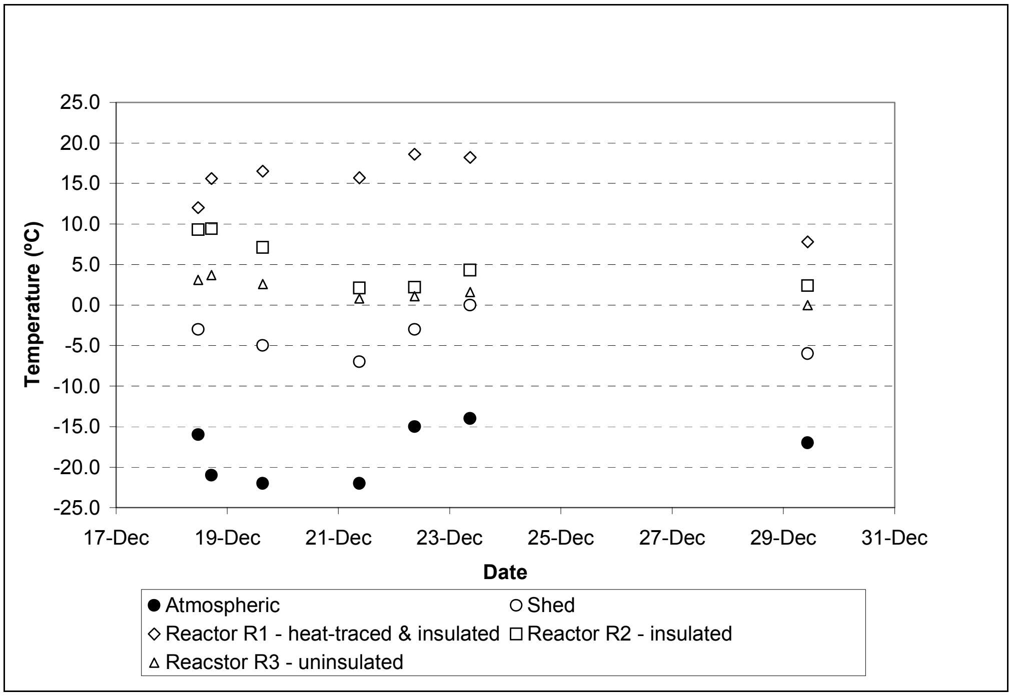


Figure 4. Air Temperatures in Reactors, Cold Period

Hydrocarbon Removal Efficiencies:

Hydrocarbon removal efficiency of a biofilter is expressed as the percentage reduction in the concentrations of the inflow vapours as they pass through the biofilter. A hundred percent efficiency indicates clean air coming out of the biofilter. Table 3 presents the biofilter efficiencies determined during the April 1998 experiments when off-gas from a vapour extraction system was treated using the three biofilters connected in a series configuration. In this paper, retention time in minutes was calculated by dividing the air pore volume of the biofilter by the vapour flow rate. The results indicate higher removal efficiencies for BTEX vapour than total petroleum hydrocarbons (TPH). Rapid variations in the flow rates and the concentrations of the inflow vapours did not permit more experiments to establish definite trends in the treatment of in situ vapours. The vapour flow rate, ambient temperature and air temperatures recorded for the biofilter reactors are reported in Table 4.

Table 3. Biofilter Efficiencies during April 1998 Experiments.

Date	**Inflow Concen-tration (ppm)**	**Reactor R1**		**Reactors R1+R2**		**Reactors R1+R2+R3**	
		Retention Time (min)	**Removal Efficiency (%)**	**Retention Time (min)**	**Removal Efficiency (%)**	**Retention Time (min)**	**Removal Efficiency (%)**
Apr. 28 12:30	275	0.36	18.2 (TPH) 57.0 (BTEX)	0.74	27.3 (TPH) 57.1 (BTEX)	1.11	36.4 (TPH) 72.1 (BTEX)
Apr. 28 15:30	325	0.22	23.1 (TPH) 52.4 (BTEX)	0.46	30.8 (TPH) 67.0 (BTEX)	0.65	38.5 (TPH) 81.3 (BTEX)
Apr. 28 17:00	375	0.17	26.7 (TPH) 53.5 (BTEX)	0.34	40.0 (TPH) 53.1 (BTEX)	0.51	52.0 (TPH) 62.4 (BTEX)

Note: Reactor R1 was not insulated and installed underground.
Reactor R2 was heat-traced and insulated.
Reactor R3 was insulated.

Table 4. Atmospheric and Biofilter Temperature during April 1998 Experiments.

Date	**Atmospheric Temperature (ºC)**	**Inflow Rate (cfm)**	**Air Temperature (ºC)**		
			Reactor R1	**Reactor R2**	**Reactor R3**
Apr. 28 12:30	19.7	39.1	15.2	16.3	15.7
Apr. 28 15:30	21.5	63.2	15.3	16.4	15.8
Apr. 28 17:00	22.0	85.1	15.3	15.8	15.3

All experiments in July/August 1998 were performed by feeding the biofilters with moist gasoline vapours generated by bubbling air through gasoline-mixed water in a bubbler drum (Figure 2). Although tests were conducted both in parallel and series configurations, due to space limitations, only results from the parallel configuration will be discussed in this paper. Tables 5 and 6 present, respectively, the removal efficiencies and temperatures recorded for these experiments. Gasoline vapours were fed into the biofilters at a nominal flow rate of 25 cfm (11.8 L/s) and various concentrations. The retention time was between 0.5 and 0.6 min. In general, the removal efficiencies for TPH of each biofilter reactor decreased with higher vapour concentrations. The range of efficiencies observed was between 30 and 57%. The BTEX removal efficiencies also showed trends similar to those observed for TPH but at much higher efficiencies ranging between 80 and 98%. Similarity observed in the performance of the three reactors indicates uniformity in the construction of the biofilters.

Tables 7 and 8 summarize the biofilter efficiencies and temperature records for experiments carried out in December 1998. Only tests carried out in parallel configuration are presented in this paper. As discussed previously, for this period, Reactor R1 was insulated and heat-traced, Reactor R2 remained insulated while Reactor R3 was not insulated. All three reactors were located in an insulated wooden shed. In Table 8, the ambient temperature was the air temperature inside the wooden shed.

Table 5. Biofilter Efficiencies for Biofilters in Parallel Configuration, June - July 1998

Date	***Inflow Concen-tration (ppm)***	***Reactor R1***		***Reactor R2***		***Reactor R3***	
		Retention Time (min)	***Removal Efficiency (%)***	***Retention Time (min)***	***Removal Efficiency (%)***	***Retention Time (min)***	***Removal Efficiency (%)***
Jun. 10	750	0.58	30.0 (TPH) 80.4(BTEX)	0.61	30.0 (TPH) 88.0(BTEX)	0.58	32.0 (TPH) 89.5(BTEX)
Jul. 7	225	0.57	51.1 (TPH) 98.4(BTEX)	0.59	55.6 (TPH) 97.8(BTEX)	0.58	55.6 (TPH) 96.6 (BTEX)
Jul. 7	375	0.57	44.0 (TPH) 81.5(BTEX)	0.59	52.0 (TPH) 93.6(BTEX)	0.57	57.3 (TPH) 95.5(BTEX)
Jul. 8	500	0.57	45.0 (TPH) 85.1(BTEX)	0.60	52.0 (TPH) 93.6(BTEX)	0.57	55.0 (TPH) 95.4(BTEX)

Note: Reactor R1 was not insulated and installed above ground.
Reactor R2 and R3 were insulated and were installed above ground.

Table 6. Atmospheric and Biofilter Temperature, June - July 1998.

Date	***Atmospheric Temperature (ºC)***	***Inflow Rate (cfm)***	***Air Temperature (ºC)***		
			Reactor R1	***Reactor R2***	***Reactor R3***
Jun. 10	23.0	24.4	30.3	24.6	23.3
Jul. 7	25.0	25.0	32.7	24.5	23.3
Jul. 7	25.0	25.0	32.1	25.2	23.6
Jul. 8	26.0	25.0	33.3	22.4	23.4

Starting on Dec. 17, R1 was heated with at least one heat-tracing wire; between Dec. 18 and Dec. 29, two heat-tracing wires were used. For this Cold Period, the TPH removal efficiency ranged from 30 to 51% while the BTEX removal efficiency was between 68 to 98%. Although Reactor R1 was kept at about 10 to 15ºC warmer than the other two reactors, its efficiency was almost the same as the other two reactors. This insignificant change in efficiency can be attributed to the short duration of the cold spell experienced (between December 21 and 23, see Table 8). However, it is also possible that the microorganisms and filtration media in each biofilter developed differently while they were installed at the job site during the summer when Reactor R1 was not insulated and R2 and R3 were insulated with foam insulation. An indicator to support this hypothesis is that, prior to the start of the Cold Period experiments, R1 was found to be much drier than the others were. Figures 5, 6 and 7 show respectively the efficiency versus temperature for Reactors R1, R2 and R3. These graphs show that, in general, hydrocarbon removal efficiency is directly proportional to temperatures. The most marked change is seen in Reactor R3 (uninsulated) where efficiency is increased by approximately 20% with a 20 ºC rise in temperature. In Reactor R1 (heated and insulated), efficiency is changed by less than 10% with a 30 ºC change in temperature. Figures 5 and 6 also show that significant increase in efficiency only occurs when the biofilter material is warmer than approximately 10 ºC.

Table 7. Biofilter Efficiencies for Biofilters in Parallel Configuration, November - December 1998

Date	**Inflow Concen-tration (ppm)**	**Reactor R1**		**Reactor R2**		**Reactor R3**	
		Retention Time (min)	**Removal Efficiency (%)**	**Retention Time (min)**	**Removal Efficiency (%)**	**Retention Time (min)**	**Removal Efficiency (%)**
Dec. 15	200	0.56	45.0 (TPH) 82.9(BTEX)	0.58	45.0 (TPH) 85.5(BTEX)	0.56	40.0 (TPH) 82.8(BTEX)
Dec. 16	225	0.58	42.0 (TPH) 75.2(BTEX)	0.57	35.7 (TPH) 83.7(BTEX)	0.56	32.9 (TPH) 80.2 (BTEX)
Dec. 17	500	0.56	30.0 (TPH) 68.2(BTEX)	0.57	33.0 (TPH) 77.0(BTEX)	0.57	31.0 (TPH) 70.4(BTEX)
Dec. 21	225	0.57	35.6 (TPH) 87.2(BTEX)	0.53	33.3 (TPH) 83.5(BTEX)	0.58	33.3 (TPH) 77.9(BTEX)
Dec. 22	350	0.59	40.0 (TPH) 83.1(BTEX)	0.58	40.0 (TPH) 82.2(BTEX)	0.59	35.7 (TPH) 74.9(BTEX)
Dec. 23	500	0.56	39.0 (TPH) 74.3(BTEX)	0.57	37.0 (TPH) 75.3(BTEX)	0.57	36.0 (TPH) 72.2(BTEX)

Note: Reactor R1 was insulated and heat-traced.
Reactor R2 was insulated and R3 was not insulated.

Table 8. Atmospheric and Biofilter Temperature, December 1998.

Date	**Ambient Temperature (ºC)**	**Inflow Rate (cfm)**	**Air Temperature (ºC)**		
			Reactor R1	**Reactor R2**	**Reactor R3**
Dec. 15	7.5	25.0	11.2	11.5	9.4
Dec. 16	6.0	25.0	10.0	11.3	9.1
Dec. 17	3.5	25.0	9.4	10.9	8.2
Dec. 21	0.0	25.0	17.0	2.9	2.3
Dec. 22	2.0	25.0	18.3	3.6	2.3
Dec. 23	0.0	25.0	18.2	4.3	1.6

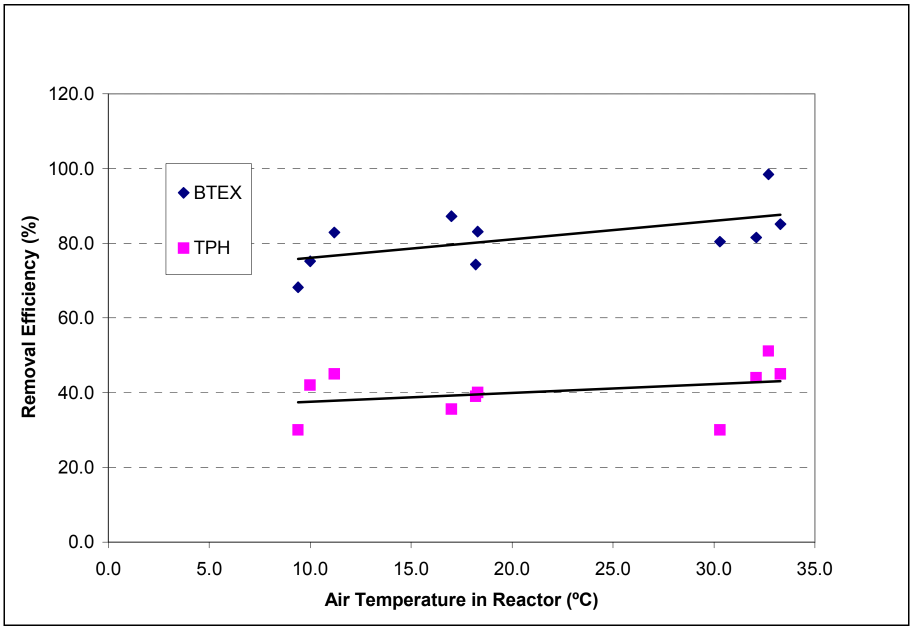
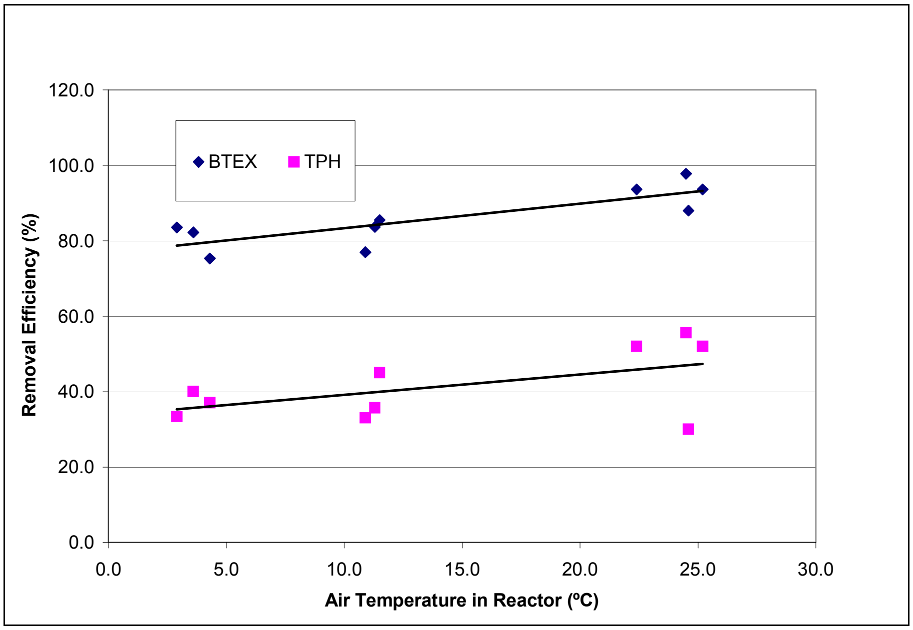


Figure 5. Variation of Efficiency with Temperature, Reactor R1



Figrue 6. Variation of Efficiency with Temperature, Reactor R2

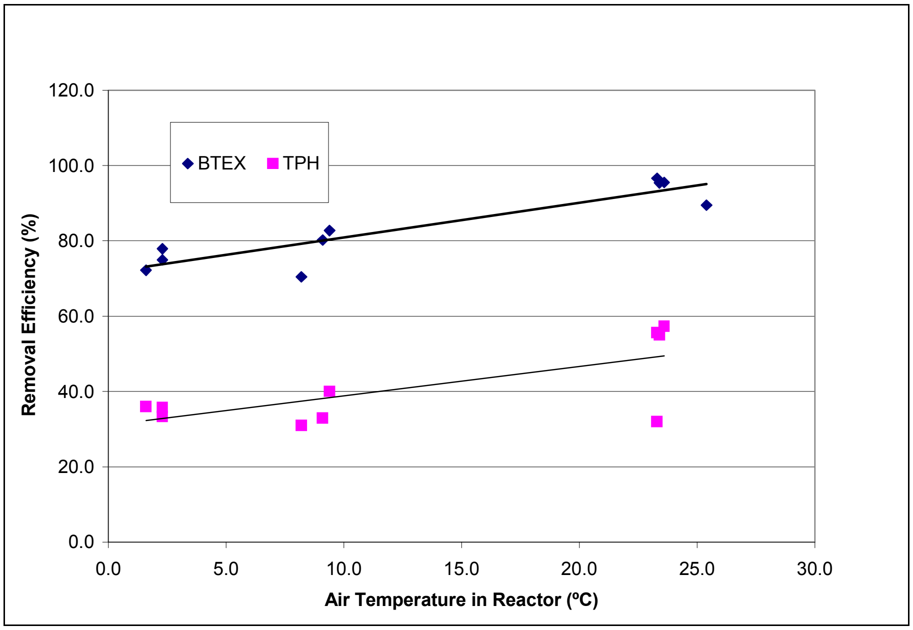


Figure 7. Variation of Efficiency with Temperature, Reactor R3

CONCLUSIONS:

From experiments carried out in three biofilter reactors between April and December 1998, the following observations can be made:

1) It appears that the biofilter material used works better at a temperature warmer than 10 ºC.
2) Significant changes in biofilter efficiencies can be expected in uninsulated biofilters under Calgary winter conditions. Biofilters need winter protection for efficient operation.
3) Heat-tracing can be used as a means to maintain a threshold temperature of 10 ºC in insulated biofilters during the occasional long cold periods.
4) Regardless of temperature, the removal efficiency for BTEX is significantly higher than that for TPH.

The results reported in this paper are from short-duration (3-hour) tests only. Tests are still on going to study the long-term behaviour of these biofilters.

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