Full Scale Test Method for Gas Contaminant Removal Device

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ABSTRACT

Activated carbon filters have been used for purification of air and water in industrial applications. However these technologies have not been applied to the non-industrial built environment in general and there is no standard to quantify or to classify the performance of these systems for in-duct mechanical system application. The development of a standard testing procedure and design tool are a very timely effort, since it would create a benchmark for evaluating the contaminant reduction and energy savings of these systems.

This paper first describes the experimental set-up for testing for in-duct air cleaner system applications, and then presents the experimental results of three different kinds of activated carbon filters.

Keywords: ventilation system, air purification, air filtration, activated carbon filters, filter efficiency, dynamic test

1. INTRODUCTION

Current research demonstrates that the operation of non-industrial buildings substantially contributes to global energy consumption, and raises many energy–related environmental issues. This information indicates the presence of opportunities and areas for improvement, and urges a broader effort to promote energy effective measures during the design and operation stage of office buildings. Ventilation systems, in the very nature of their design, are a means to bring in outdoor air and trap and dilute contaminants such as particulates, microorganisms and chemicals, and exhaust them to the outdoor. These typical contaminants have been recognized explicitly in the ASHRAE ventilation standard which requires that the ventilation rate specification be based on the contribution from occupants as well as other indoor/outdoor sources, implying that an increased ventilation rate is needed. Increased ventilation rates and outdoor air supply rates enhance indoor air quality (IAQ); however, they can also result in a large increase of global energy consumption. Filtration and air purification can provide key strategies to improve IAQ while reducing outdoor air supply with concomitant energy savings. This methodology is categorized in the ANSI/ASHRAE Standard 62.1 as an IAQ Procedure which offers the design professionals the opportunity to choose an alternative to the prescriptive method, the *Ventilation Rate Procedure*. Air cleaner (gas phase filtration) is an established technology and shown to be extremely useful for such applications. This device can play a significant role in reducing building energy consumption, and removing chemical contaminants, hence improving the well-being of occupants and building energy efficiency. Section M-1603.1.1 of the Building Official and Code Administrators (BOCA) permits up to 85% of the air to be re-circulated when the HVAC system is equipped with air cleaners capable of effectively removing gaseous pollutants. Nevertheless, there are no current standards to quantify or classify the performance of these new technologies.

Most air cleaners for gaseous contaminants act on the basis of adsorption phenomenon. For this purpose, activated carbon media are commonly used, since they have a high capacity in adsorbing gas-phase pollutants due to highly developed porous structure and huge specific surface area. The activated carbon filters are available in several forms: activated carbon retained in fibrous or foam filter media (cloths) or granular activated carbon packed in various shapes for area enlargements. The performances of activated carbon filters have been investigated mostly in small-scale test systems (Lee et al., 2006, Haghighat et al., 2008). Limited study has been carried out in full-scale testing.

This paper first describes the experimental set-up for testing activated carbon filters for in-duct mechanical system application, and then presents the experimental results of three different kinds of activated carbon filters.

2. EXPERIMENTAL METHODS

A full-scale system was designed on the basis of an air delivery of up to 1 m^3/s airflow rate and incorporates an air-cleaning device in a manner similar to its actual use in the practice. The duct is 610 mm x 610 mm made of stainless steel with smooth interior finishes to reduce absorption. Air supplied to the apparatus could be dehumidified, filtered through HEPA and charcoal filters. The exhaust air from the chamber is then passed through an air-cleaning device and is either returned to the system (closed loop) or exhausted outside (open looped). The total length of system is over 12 m (see Figure 1). This design draws on experience by the applicants and from the proposed draft of ASHRAE 145.2P.

A contaminant generation system has been developed to provide constant concentrations from low ppb levels to hundreds of ppm levels. A gas analyzer was used to monitor the air contaminant concentration in real time upstream and downstream of the filter. A photoacoustic infrared spectroscopy (Innova, Type 1312) was used for routine and quick tests and a GC/MS was used for detail analysis. The upstream and downstream contaminant concentrations were measured simultaneously using a single gas analyzer combined with an automatic multi-channel sampler (CAI Intelligent Sampling System MK2). Experimental data was analyzed to determine the performance of these devices in terms of breakthrough time, efficiency and total absorbed of contaminant mass.


Figure 1: Test facility

For GAC, four V-shape modules filled with virgin activated carbon cylindrical pellets were tested to verify the applicability of the test procedure. Test tested GAC is a coal based activated carbon with pellet diameter of 3 mm. Two different RCF were tested: one with the thickness of 305 mm (RCF-12”) and the other of 102 mm (RCF-4”). Both RCF contains 60% carbon tetrachloride activity GAC Carbonweb media. According to product information, RCF-12” has 5.45 m^2 of the media area and 3.5 kg of GAC per filter. RCF-4” has 3.23 kg/m^2 of carbon density, hence the total carbon mass is about 1.2 kg.

Toluene was selected as a representative compound for VOC. It was generated using the bubbling method. A constant flow of compressed air from the lab was introduced to the HPLC grade liquid toluene containers via PTFE tubes connected to porous diffusing stones (Fisher Scientific, average pore size 60 μm). Each test was conducted in two stages: adsorption followed by desorption. In the adsorption period, air with a constant toluene level was challenging the test filter. The adsorption period lasted until the removal efficiency dropped to 10%. Then the toluene generation system was stopped and cleaned air was introduced for the desorption period.

3. RESULTS

Table 1: Summary of test conditions

		GAC	RCF 12”	RCF 4”
Average flow rate [cfm]		1948	1964	1968
Average flow resistance [inch of H_2O]		0.895	0.339	0.347
Adsorption test	Upstream toluene concentration [ppm]	3.57±0.01	3.13±0.04	3.21±0.03
	Temperature [°C]	27.0±0.01	26.7±0.01	26.4±0.03
	Relative humidity [%]	28.0±0.06	25.8±0.09	33.3±0.29
Desorption test	Upstream toluene concentration [ppb]	148±5.53	141±19.1	75±28
	Temperature [°C]	27.0±0.03	26.7±0.01	26.5±0.05
	Relative humidity [%]	28.4±0.07	26.4±0.09	33.7±0.29

Table 1 presents test conditions and toluene concentration, temperature and relative humidity data as the average ± 95% confidence interval’, and Figure 2 shows the upstream and downstream concentration profiles of GAC for both adsorption and desorption periods. From the upstream and downstream concentrations, the breakthrough and removal efficiency were obtained:

Breakthrough, $$BT(t) = \frac{C_{down}(t)}{C_{up}(t)} \quad (1)$$

Efficiency [%], $$E(t) = \{1 - BT(t)\} \times 100 \quad (2)$$

where, C_{up} and C_{down} are upstream and downstream toluene concentrations at time, t. The breakthrough time and the efficiency profiles of GAC are presented in Figure 3. The initial efficiency of GAC was about 95% and it stayed above 90% for about first 25 hours and gradually decreased. The 50% breakthrough time was about 65 hours, and 10% of the efficiency was reached after more than 97 hours of continuous adsorption process.

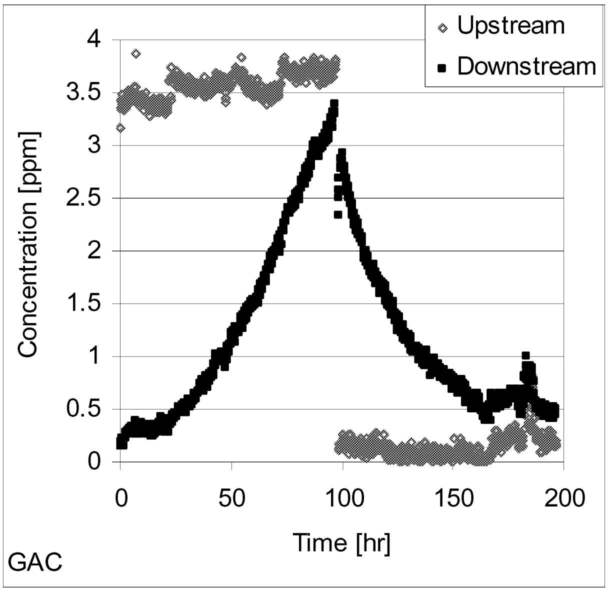

Figure 2: Upstream and downstream concentration profiles of GAC

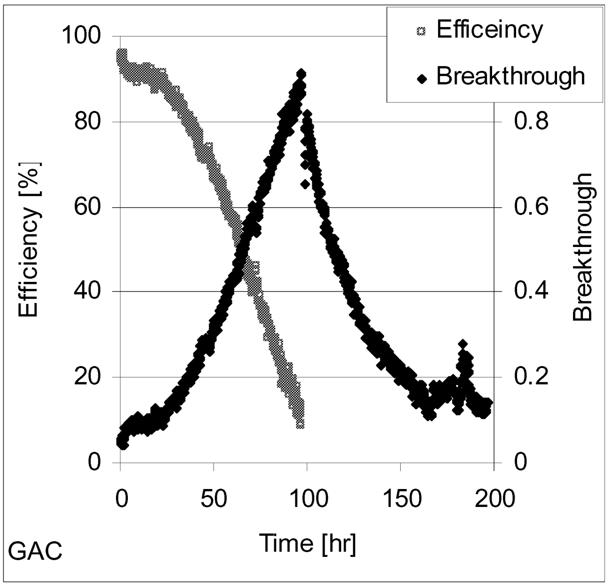

Figure 3: Breakthrough and efficiency profiles of GAC

Figures 4 and 5 present the RCF-12” and RCF-4” test results, respectively. The efficiency of RCF-12” started from less than 75% and dropped rather quickly: 50% breakthrough time was about 2.5 hours, and 10% of the efficiency was reached only after about 12 hours. The efficiency of RCF-4” was around 50% initially, and decreased to 10% in 3.5 hours.

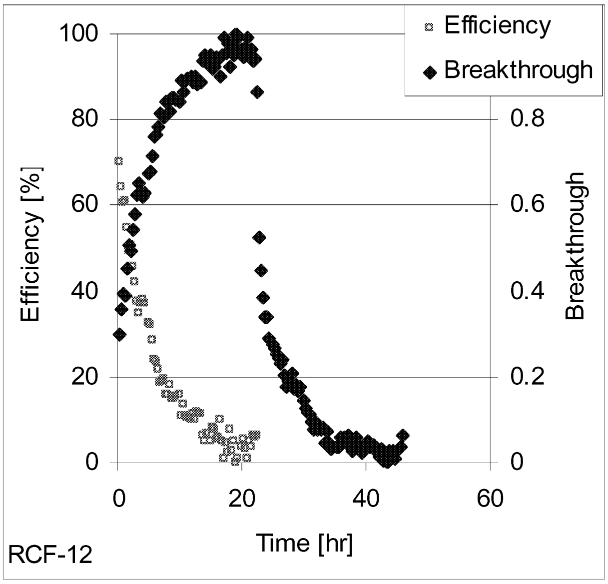

Figure 4: Breakthrough and efficiency profiles of RCF-12”

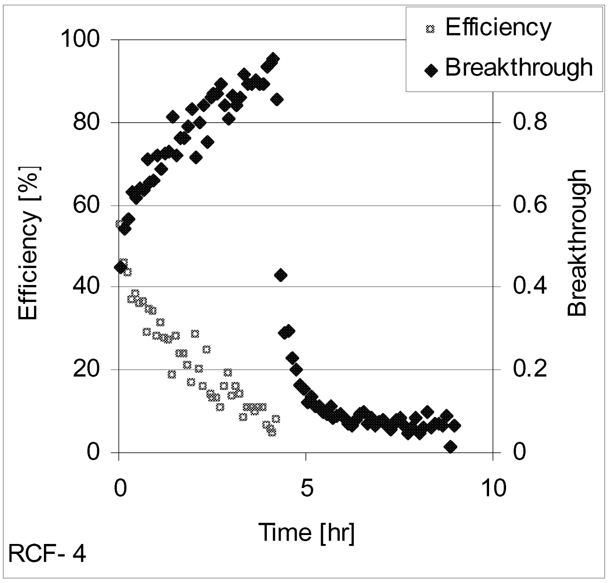

Figure 5: Breakthrough and efficiency profiles of RCF- 4”

Figure 6 clearly demonstrates the performance differences between GAC and RCFs. The toluene removal efficiency of GAC is much better than those of the tested RCF. The 50% breakthrough time of GAC is approximately 26 times longer than RCF-12”, and as much as 1300 times longer than RCF-4”. Even when RCF cannot remove toluene any more, the GAC has 90% more removal efficiency. Considering the fact that the tests were conducted at only moderately elevated concentration levels, the air cleaning performance of RCF is questionable especially when RCF is applied for the enhancement of building security and safety.

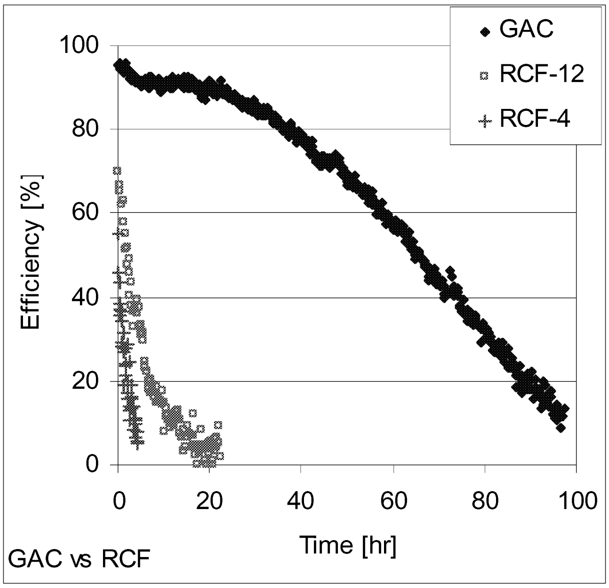

Figure 6: Efficiency profiles of GAC and RCF

Figure 7 presents the total adsorbed masses of toluene by GAC and RCF-12” as a function of time. Since the total adsorbed mass by RCF-4” was too small relative to GAC, it is presented in Figure 8 along with RCF-12”. The total adsorbed toluene mass (m_{total}) was calculated by the following mass balance equation:

$$m_{total} = Q\int_0^t \left\{C_{up}(t) - C_{down}(t)\right\} dt \qquad (3)$$

where, Q is the flow rate in [m^3/sec]; C_{up} and C_{down} are upstream and downstream concentrations respectively in [g/m^3]; and t is the time in [sec]. The maximum m_{total} is found at the end of adsorption test. The maximum m_{total} was 38 g for RCF-4”; 165 g for RCF-12”; and 2656 grams for the GAC. At a 50% breakthrough time, the m_{total} of GAC was more than 45 times larger than that of RCF-12” and more than 1700 times larger that of RCF-4” (i.e., 1.3 g for RCF-4”, 48.5 g for RCF and 2224 g for GAC).

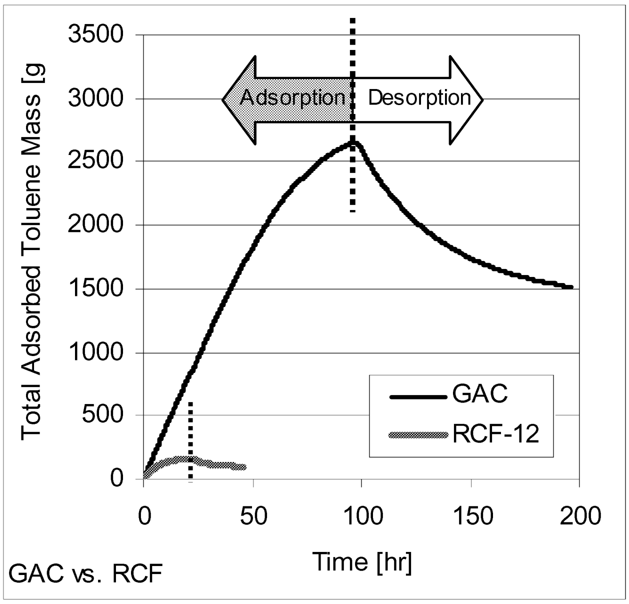

Figure 7: Total adsorbed toluene masses of GAC and RCF-12”

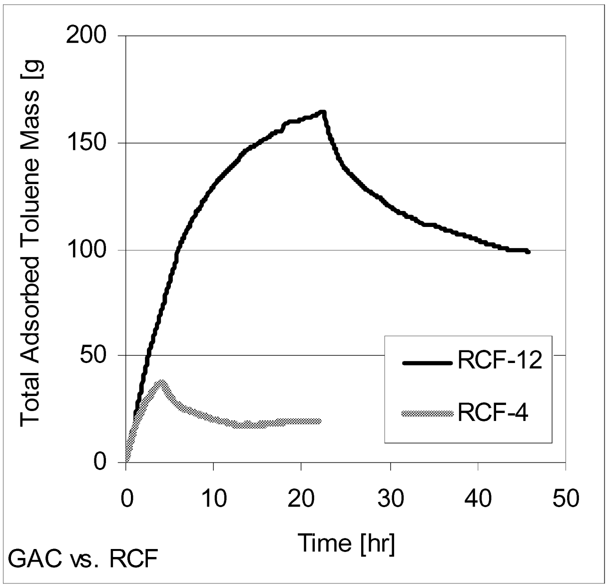

Figure 8: Total adsorbed toluene masses of RCF: 12” and 4”

The capacity was obtained by dividing m_{total} by the mass of activated carbon media. The mass of GAC was measured (i.e., 31.7 kg), and the carbon masses of RCF were 3.6 kg for RCF-12” and 1.2 kg for RCF-4”, respectively. The maximum capacity was 8.4% for GAC, 4.7% for RCF-12”, and 3.2% for RCF-4”. The capacity at 50% breakthrough time was 7.0% for GAC, 1.4% for RCF-12”, and 0.1% for RCF-4”.

4. CONCLUSIONS

The performances of pleated rigid carbon filters (RCF) were investigated and compared with granular activated carbon (GAC) filled in V-shape modules. Toluene removal efficiency tests were conducted at about 2000 cfm of flow rates in the full-scale test system in the Indoor Air Quality Laboratory at Concordia University. Unlike the common claims of RCF manufacturers, the performances of the tested RCF were poor. The initial efficiency of RCF was less than 75% for RCF-12” and about 50% for RCF-4”, while that of GAC was 95%. The RCF was decreasing fast: 50% efficiency after 2.5 hours for RCF-12” in contrast to 65 hours for GAC. While the efficiency of RCF is free falling, GAC sustained about 90% of efficiency. GAC removed 70 times more toluene than RCF-4”, and 16 times more than RCF-12”. This study indicates that RCF may be ineffective: however, more studies are required.

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