

# Effect of the Relative Humidity on Formaldehyde Emission from Tackifier-Coated HVAC Filters

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## SUMMARY

Tackifiers and adhesive additives in commercially available HVAC filters help retain particles that impinge upon the filter media. A previous report has shown that the hydrolysis of such additives can be a formaldehyde emission source. The objective of this study is to investigate formaldehyde emissions from tackifier-coated filters and to evaluate its dependence with relative humidity (RH) and air velocity. Experiments were performed with 47 mm diameter filter samples at face velocities of ~0.0022 m/s and ~0.5 m/s, and under relative humidity of ~20%, ~50% and ~80%. The higher velocity is typical of conditions in HVAC systems. Three different types of filters were used with varying tackifier loading. Formaldehyde was quantified upstream and downstream of each sample to determine emission rates. Higher formaldehyde emissions were observed under high humidity levels in all cases, suggesting an important role of hydrolysis reactions. Surprisingly, formaldehyde emission rate increased approximately in proportion to air velocity. No significant differences in formaldehyde emissions were observed for filters with different tackifier loading. The results suggest that these filters could contribute substantially to indoor formaldehyde levels, when the humidity is high.

**KEYWORDS:** Filter, Emission Studies, Formaldehyde, HVAC Systems, Tackifier

## 1 INTRODUCTION

Formaldehyde is a sensory irritant at levels well below the odor threshold of approximately 500 ppb (OEHHA, 2001), has been designated as a human carcinogen by the WHO (Cogliano et al., 2005; WHO, 2006), and can be found in residential and commercial buildings due to emissions by many sources (Kelly et al., 1999; Salthammer et al., 2010). Given that the general US population spends more than 80% of time indoors and that the concentrations of formaldehyde

are generally higher indoors than outdoors, the indoor environment is the primary location where people are exposed to formaldehyde (Liu et al., 2006). It was suggested that air filters and coils are among the stronger sources of sensory pollutants in the new HVAC systems (Seppanen et al., 2002), and that the hydrolysis of filter binder or tackifier additives may be a significant formaldehyde source (Destailats et al., 2011). However, there is little evidence confirming these findings or exploring what are the key factors that influence the chemical emission rates from filters with such additives. The objective of this study is to investigate the links between formaldehyde emissions, humidity, and air velocity for filters with tackifiers.

## 2 MATERIALS/METHODS

### Tests performed at low face velocity

The experimental setup is shown in Figure 1-A. Clean supply air was split into two streams, one as dry air and the other passing through a water bubbler. The humidity was controlled by adjusting the ratio of air passing through the bubbler to that of dry air. The two streams were mixed thoroughly inside a 20-L environmental chamber. A temperature and relative humidity sensor (HMD-70, Vaisala, Finland) measured the conditions within the mixing chamber. The air flow was then passed through the flow tube reactor containing the filter coupon at a rate of approximately 1.3 L/min. With this flow rate, the velocity of the air entering the filter sample was approximately 0.022 m/s which is 4% of the typical 0.5 m/s velocity of air entering the filter media of a deployed pleated air filter. The experimental setup was operated under room temperature in the range of 22-27 °C. Three different RH settings of  $(20 \pm 5)\%$ ,  $(50 \pm 5)\%$ , and  $(80 \pm 5)\%$  were studied.

Three types of new filters were used. According to product specification, the same base filter media (fiberglass) and filter dimensions were used for these three filters. The difference between the three filters was the amount of tackifier coating, ranging from heavily coated (F1), medium-coated (F2), and lightly-coated (F3). Also F1 was a high density fiber filter, while F2 and F3 were medium density. All filters were 2-inches thick. Sample coupons of 47-mm diameter disks were cut from representative sections of each filter. The exposed area of each filter sample was 10 cm<sup>2</sup>. For all experiments, the background concentration in the supply air was checked first by collecting gas-phase samples through the ports before placing the filter coupon. The filter coupon was then quickly installed in the flow reactor tube and three sequential 24-hr integrated samples were collected through ports located downstream of the exposed filters at the end of 24 hours.

### Tests performed at high face velocity

Separate tests were performed at a higher flow rate of approximately 30 L/min, resulting in a face velocity of 0.5 m/s. The experimental setup is shown in Figure 1-B. Clean air was circulated through a bubbler and the flows were adjusted using a dilution stream to achieve the desired RH. The temperature and RH were monitored downstream of the filter using a logging system (Automated Performance Testing, TEC; Minneapolis). Samples were collected through sample ports located upstream and downstream of the filter holder. Experiments were conducted on F1

filter samples as these samples have the maximum tackifier loading. The exposed area of the filter sample was again 10-cm<sup>2</sup>. Three different RH settings of (20 ± 2)%, (55 ± 5)% and (84 ± 10)% were studied. Samples were collected at the end of 12 hours for experiments conducted at 20% and 84% RH. Samples were collected at the end of 24 hours for experiment conducted at 55% RH.

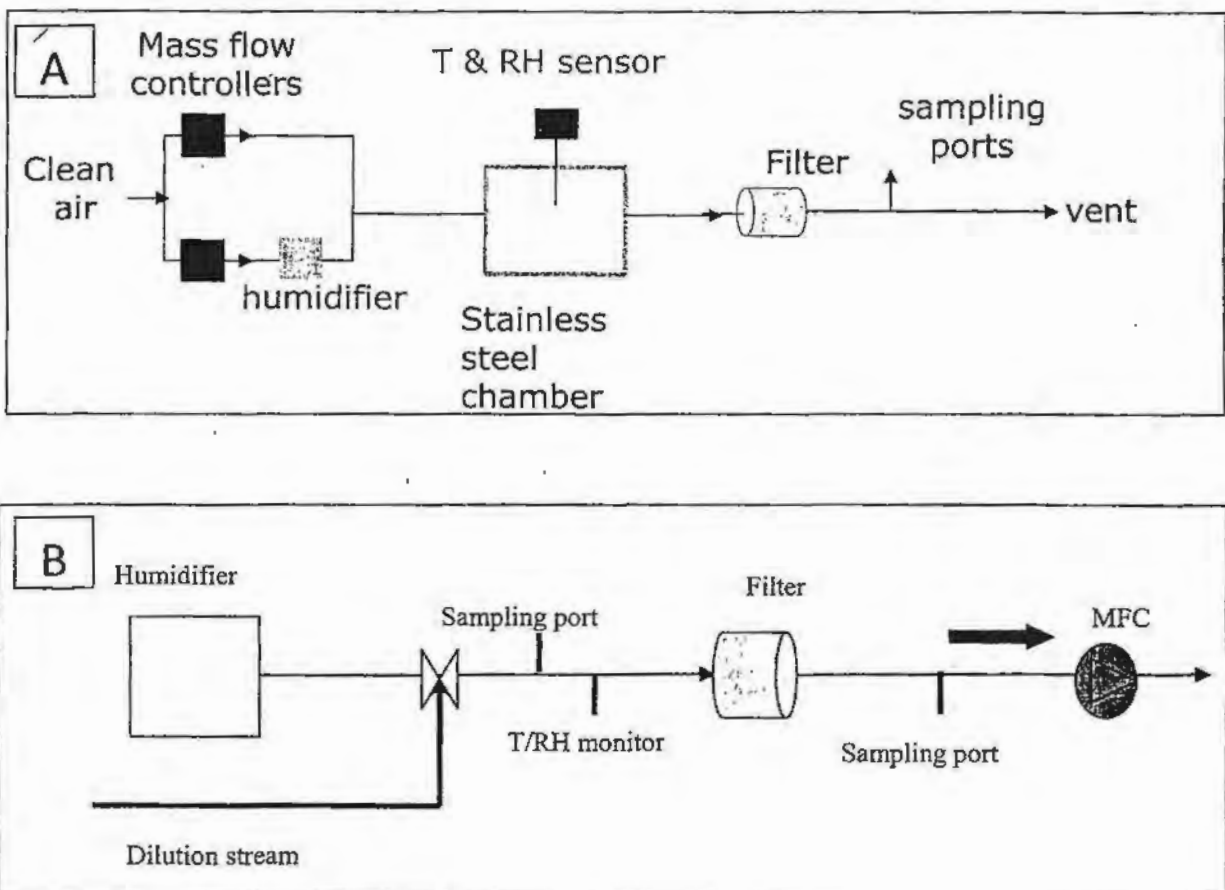


Figure 1. Experimental setup used in (A) low face-velocity and (B) high face-velocity tests.

#### Gas-phase sample collection and analysis

2,4-Dinitrophenylhydrazine (DNPH)- impregnated silica gel cartridges (XpoSure, #WAT047205, Waters Corporation, USA) were used to collect aldehyde samples. The cartridges were extracted with acetonitrile, and analyze by HPLC with UV detection (1200, Agilent Technologies, USA). Formaldehyde and acetaldehyde were quantified with a calibration curve prepared with authentic standards of the DNPH hydrazone derivatives (Sigma-Aldrich, USA).

### 3 RESULTS

#### Tests performed at low face velocity

Table 1 shows the test conditions and results obtained at different relative humidity levels of 20%, 50% and 80% when the face velocity was approximate 0.022 m/s. Upstream (background)

concentrations were in all cases below  $0.9 \mu\text{g}/\text{m}^3$ . It was observed that the formaldehyde concentration, which is approximately proportional to formaldehyde emission rate, increased with relative humidity and was independent of filter sample type or tackifier concentration. The measured formaldehyde concentrations were close to upstream (background) concentrations and can be regarded as negligible at 20% RH, while they were quite significant at 80% RH for all filter samples tested.

**Table 1. Formaldehyde emission in low face velocity experiments**

FILTER	F1			F2			F3		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Relative Humidity	20%	50%	80%	20%	50%	80%	20%	50%	80%
Average temperature ( $^{\circ}\text{C}$ )	23.1	24.2	22.9	23.3	22.9	23.1	22.7	24.2	23.3
Formaldehyde ( $\mu\text{g}/\text{m}^3$ ) <sup>1</sup>	0.86 $\pm 0.1$	1.3 $\pm 0.1$	7.5 $\pm 0.6$	0.69 $\pm 0.1$	1.4 $\pm 0.2$	7.8 $\pm 1.3$	0.82 $\pm 0.1$	1.5 $\pm 0.4$	8.5 $\pm 1.1$

Note: (1) Average  $\pm$  Standard Deviation for the three sequential 24-hr integrated samples taken during 24 – 96 hrs without subtracting the upstream concentration

#### Tests performed at high face velocity

Table 2 shows the formaldehyde concentration increases from filter F1 when the face velocity was approximately 0.5 m/s. Similar to low face velocity experiments, the formaldehyde concentrations increased with increase in relative humidity. The average formaldehyde concentrations upstream of the filter was  $< 0.4 \mu\text{g}/\text{m}^3$ , and were subtracted from downstream values to determine emission rates. Figure 2 illustrates emission rates calculated for experiments carried out under low and high flow conditions. Emission rates increased proportionally with the air flow rate, leading to downstream concentrations that were relatively similar under low and high airflow conditions.

**Table 2. Formaldehyde emission in high face velocity experiments**

FILTER	F1		
Experiment Time (min)	720	1440	720
Sampling Time (min)	55	60	60
Relative Humidity	20%	55%	84%
Average temperature ( $^{\circ}\text{C}$ )	25	26.1	24.3
$\Delta$ [Formaldehyde] ( $\mu\text{g}/\text{m}^3$ ) <sup>1</sup>	$0.75 \pm 0.2$	$4.5 \pm 0.6$	$10.4 \pm 0.4$

Note: (1) Average  $\pm$  Standard Deviation for duplicate samples after subtracting the upstream concentration

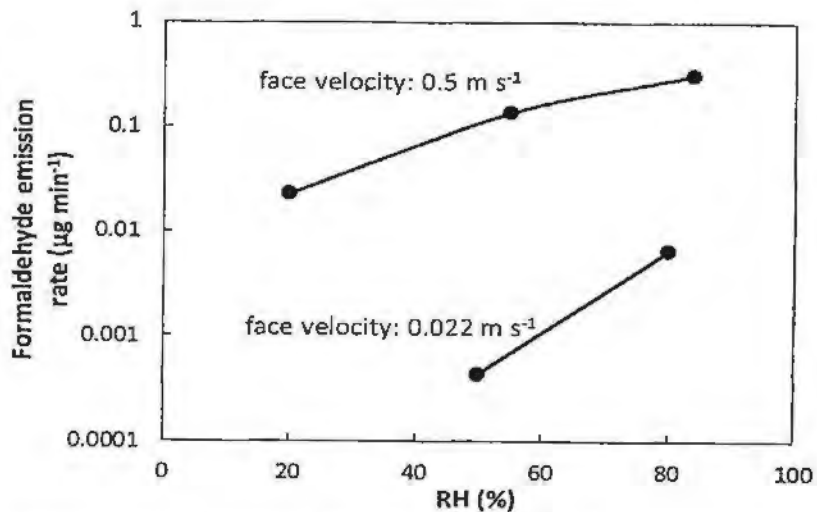


Figure 2. Formaldehyde Emission Rates at Different Levels of Relative Humidity

#### 4 DISCUSSION

When air was passed through the samples of unused fiberglass filters with tackifier, we observed an increase in formaldehyde emissions as air humidity increased. However, formaldehyde emissions were not significantly related to the amount of tackifier on the filter. These results suggest that water may be the limiting reactant, or that the formaldehyde emissions may be unrelated to the presence of tackifier. Additional tests are being conducted to better understand the role played by these additives. These findings are consistent with previous studies, which also found much lower formaldehyde emission rates from filters without tackifier (Destailats, 2011). The increase in emission rates with humidity suggests that a hydrolysis process may underlie the formaldehyde emissions. Comparison between low and high flow rate experiments suggests an increase in emission rates with increasing face velocity that is roughly proportional to the velocity, indicating that the reactants participating in hydrolysis process are not depleted significantly when the system operates at high face velocity.

These preliminary results suggest that certain HVAC filters may be potential substantial contributors to formaldehyde concentrations indoors in the presence of high humidity, because the expected increase in indoor formaldehyde concentration as a result of formaldehyde emissions from the filters is approximately equal to the increase in concentration reported from our experiments with a high air velocity. Additional experiments are required to confirm the dependence of emission rate on face velocities in order to predict more precisely the contribution of hydrolysis of tackifiers and/or other filter additives to indoor formaldehyde concentrations.

#### 5 CONCLUSIONS

Although our findings suggest that filters with tackifier coatings have significant formaldehyde emission at high relative humidity, we need to further analyze filter materials and tackifier used

to identify the chemical components and undergoing emission mechanism. We need data after extended periods of filter deployment. Most importantly, additional data is needed from experiments with realistic air velocities to determine if the formaldehyde emission from these filters are significant. If the preliminary results presented here were confirmed in follow-on studies, we could predict the contribution of these hydrolysis reactions to indoor formaldehyde levels. In a commercial building where these types of filters are used, increases in indoor air concentration of formaldehyde would be comparable to the concentration increase across the filters determined in our experiment.

## 6 ACKNOWLEDGEMENTS

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