Effect of Hydrophobic Fumed Silica Addition on a Biofilter for Pentane Removal

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INTRODUCTION

The emission of airstreams containing volatile organic compounds (VOCs) has been recognized as a major environmental problem, resulting in a reduced air quality and provides a danger to public health (Salthammer et al., 2009). Pentane is a highly hydrophobic compound (Henry's law coefficient i.e. 40 (-)) and is frequently found in industrial contaminated gas streams. Pentane serves as a model compound for the hydrophobic compounds and its removal from waste gas streams gained considerable attention in the last decade. Biofiltration has been proven to be an efficient and cost-effective technology to treat VOCs contaminated airstreams (Bruneel et al. 2018). However, the main drawback of biofilters is the low mass transfer of the pollutant to the biomass (biofilm), which reduces its bio-availability and inhibits their metabolic activity. In most cases, the limiting step for the pollutant removal is a complex combination of kinetic reaction limitation and mass transfer limitation. In order to enhance the VOCs transfer to the biofilm, the addition of substances like surfactants has been investigated (Cheng et al., 2016). However, the addition of high hydrophobic substances with low moisture adsorption has not been tested. The **aim** of this work was to investigate the effect of the addition of **hydrophobic fumed silica (HFS) to the BF**. This HFS contains octamethylcyclotetrasiloxane groups on its structure (See Fig. 3.) and was added in particulate form to the original BF material in order to evaluate pentane removal.

EXPERIMENTAL SET-UP

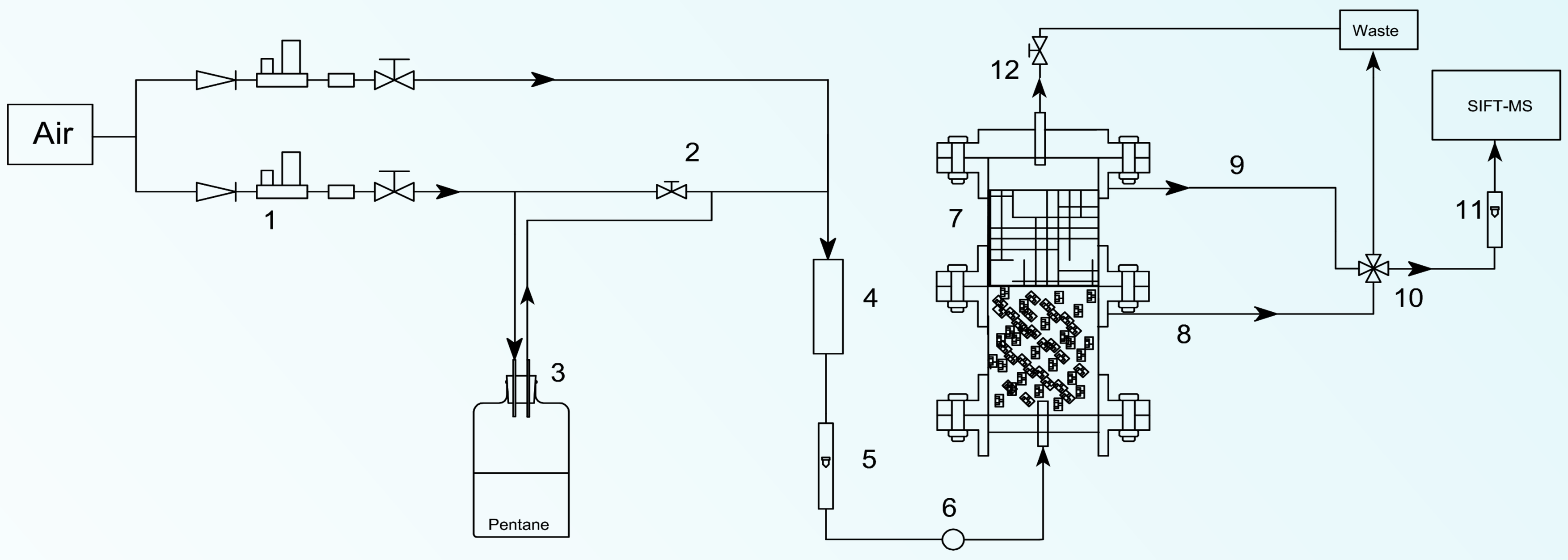

Fig. 1. Experimental set-up with (1) mass-flow controllers, (2) valve, (3) stainless-steel bottle with pure VOC liquid, (4) humidification bottle, (5) rotameter, (6) injection port, (7) biofilter (1.33 L working volume) (8) inlet stream, (9) outlet stream, (10) four-way valve, (11) rotameter and (12) valve.

RESULTS

§1 Performance

The BF was operated during 95 days at a constant empy bed residence time (EBRT) of 120 s. The BF packing material was pre-adapted to a pentane loading in another BF (with 80% removal efficiency (RE) with an inlet load (IL) of 40 g m^{-3} h^{-1}). After two days of no pentane loading, the BF was started at day 1 with an IL of 14 ± 3 g m^{-3} h^{-1} during 10 days (Fig. 1). During this start-up phase, the BF took 4 days to increase its RE from 54 to 98% at IL of 14 g m^{-3} h^{-1} ± 3 g m^{-3} h^{-1} . From day 11, the IL was increased to 40 ± 7 g m^{-3} h^{-1} followed by a drop in RE to 76%. In order to increase the BF performance, 15 mL nutrient solution (Table 1.) was mixed completely with the packing material at day 22 corresponding to an average C/N molar ratio of 11 until day 63. At day 36, the packing material was completely mixed with 0.25% HFS leading to a slight increase in the RE from 61 to 83% after 4 days. At day 50, when RE dropped to 50%, 15 mL extra nutrient solution was added to the BF resulting in a RE increase to 81%. After 13 days, RE declined to 63% and was followed by addition of 150 mL nutrient solution to the BF. This larger nutrient pulse probably led to an enhancement of biomass growth and an increase of RE resulting in an average C/N molar ratio of 2 until the end of the operation time. At day 77, 1.5% HFS was mixed with the packing material obtaining an average RE of 96% afterwards, demonstrating an enhancement of the BF performance in the last stage.

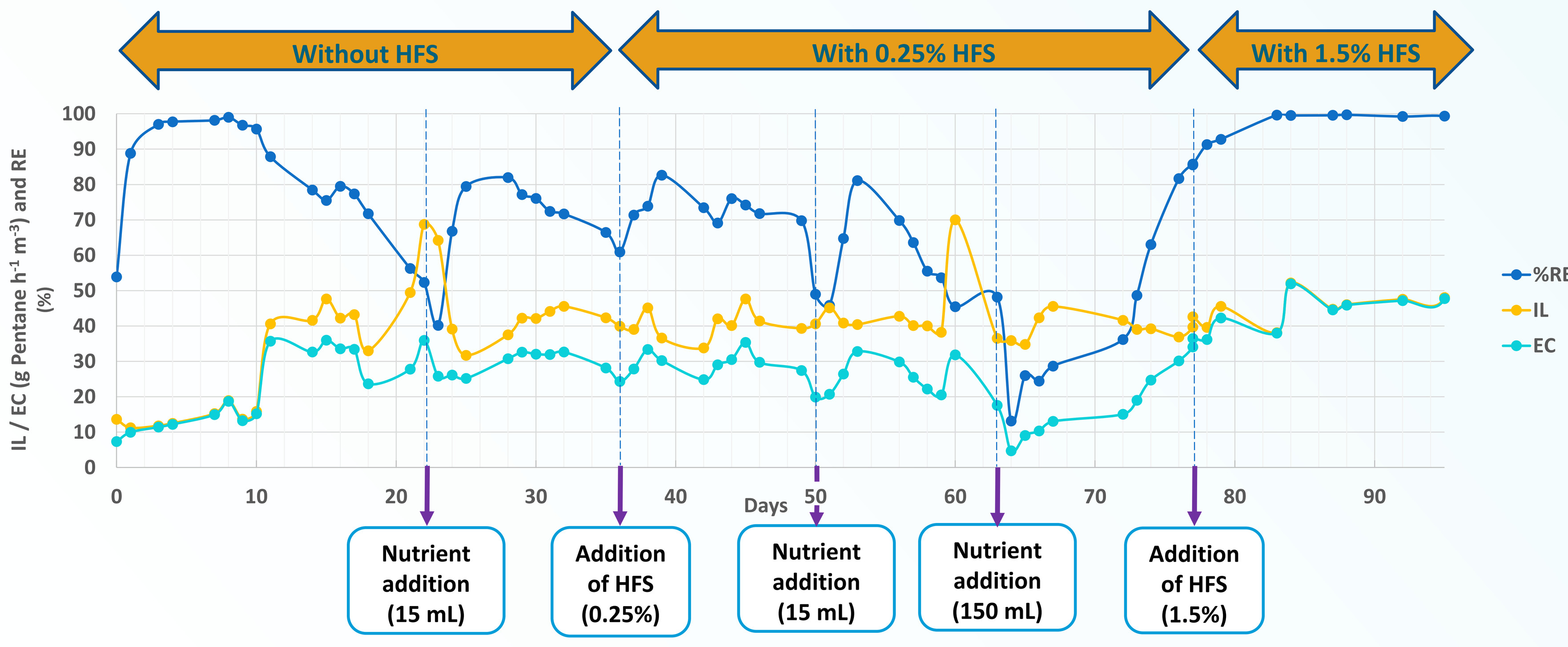

Fig. 2. Inlet load (g m^{-3} h^{-1}), elimination capacity (g m^{-3} h^{-1}) and removal efficiency in function of time.

Table 1. Nutrient solution composition.

Nutrient Solution	
Component	Concentration (g L^{-1})
KNO_3	95.3
$Na_2HPO_4 \cdot 2H_2O$	12.7
KH_2PO_4	3.2
$MgSO_4$	0.8
$CaSO_4$	1.5
Stabilox	2.1

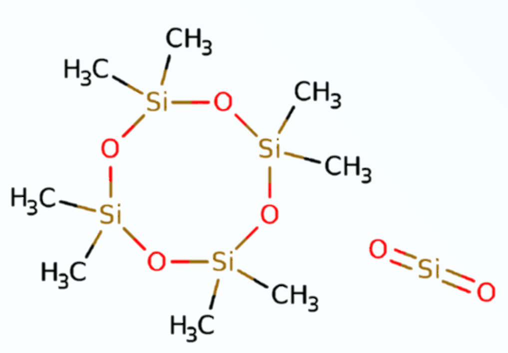

Fig. 3. Structure of octamethylcyclotetrasiloxane groups with silica.

§2 Pentane behaviour study

The net residence time (NRT) of a compound in a BF packing material is an important parameter to evaluate the behaviour of pollutants inside a BF. The NRT measurement requires an online monitoring system such as Selected Ion Flow Tube Mass Spectrometry (SIFT-MS), able to measure the concentration at second time resolution. Peak injections of the compound at an injection port (Fig. 1, (6)) can be followed-up at the inlet and outlet port. The longer the time difference between the inlet and outlet peak, the larger the interaction of the compound with the BF material. In order to compare the interactions between the packing material with 1.5% HFS and pentane/methane, a pulse containing these two different gases was injected to the BF at day 78 at an EBRT of 120s. The NRTs of methane and pentane were different (Fig. 4a.), resulting in 194 and 249 s, respectively. The higher NRT of pentane can be explained because of its higher interaction with the BF when compared to methane. Next, the evolution of pentane NRT on the three different stages of the BF (no HFS and 0.25 and 1.5% HFS) was determined at a constant EBRT of 30 s. Fig. 4b. shows the evolution of the average NRT and HFS amount. This is an indication that HFS increased the hydrophobicity of the BF.

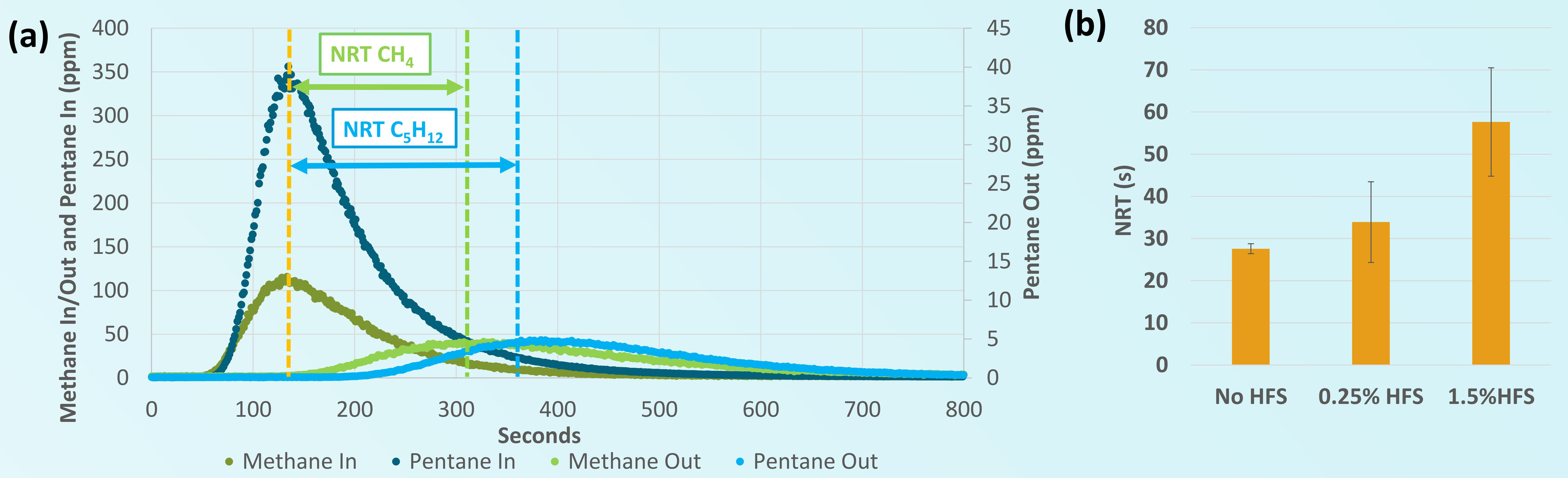

Fig. 4. (a) NRT variation of methane and pentane at EBRT of 120 s at day 78. (b) Average pentane NRT at different HFS concentrations. The measurements were made at days 17, 28, 39, 49, 67, 71, 74, 77, 78 and 84 (Fig. 2)

§3 Pentane peak perturbations experiments

Among all parameters affecting BF efficiency, the flow rate, that determines EBRT, showed to be one of the most important design parameters to optimise, because of its strong correlation with BF dimensions design, costs of construction, maintenance and operation. A decrease in the EBRT means an increase in the pollutant loading which can be potentially removed by the BF. So, in order to study the effect of the EBRT on pentane removal, peak perturbations experiments were carried out. Herewith, 500 µL of headspace gas of pentane pulses (884 µg) were injected at several EBRTs (240 to 8 s). Fig. 5. gives an overview of the effect of the EBRT on pentane removal before and after HFS addition. The data was collected on the same days mentioned above Fig. 3b. An increase in pentane removal was achieved at the third stage of the study, when 1.5% of HFS was added to the packing material. On this stage, a RE>97% was obtained at an EBRT of 45 s. compared to a RE of 74 and 63% when none or 0.25% HFS was added, respectively.

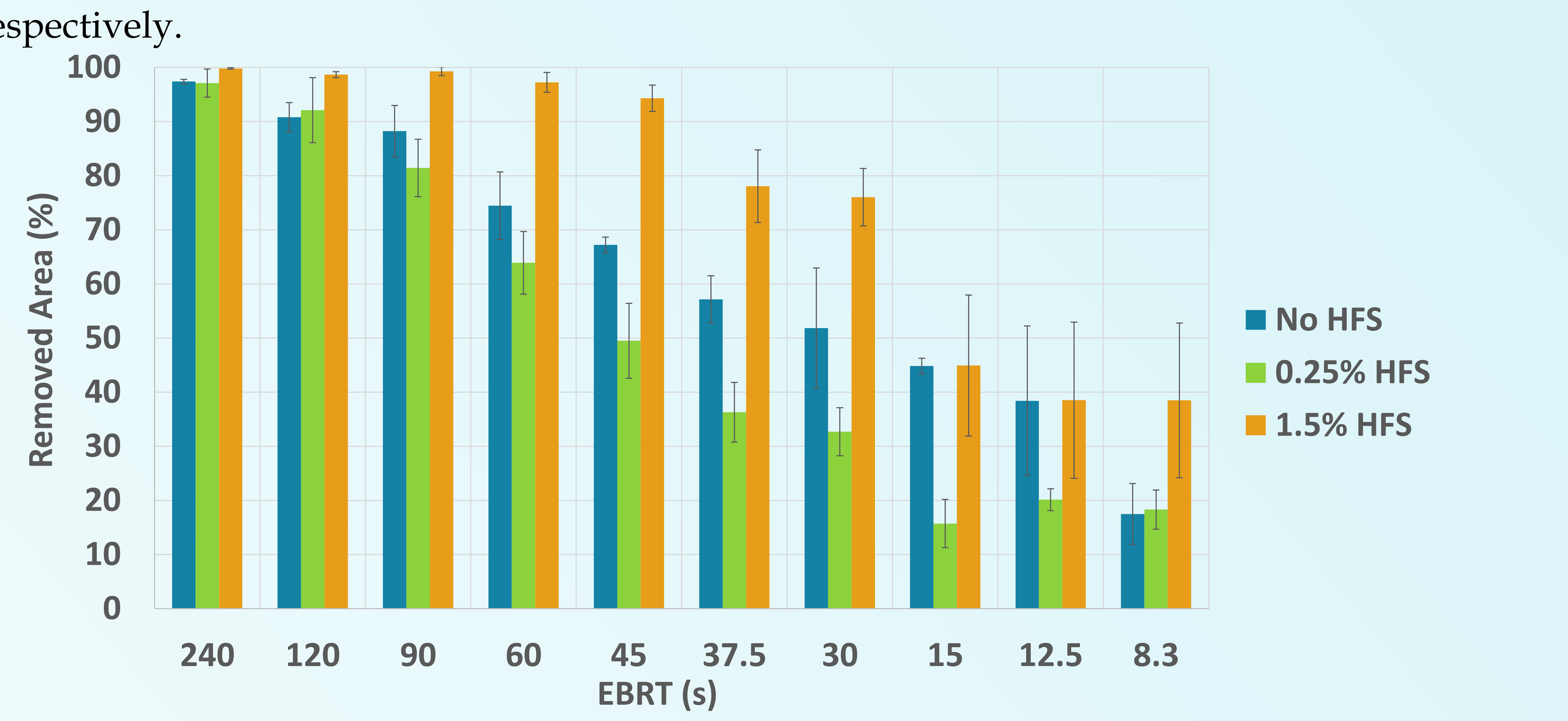

Fig. 5. Average pentane removed area versus EBRT at different HFS concentrations based on peak injections similar as showed in Fig .3. (a)

CONCLUSION

The use of a BF for pentane removal from an airstream represents an alternative technique to physico–chemical techniques. The BF showed robustness at high ILs before and after HFS addition. The packing material has a strong interaction with pentane caused by its high hydrophobicity – showed by larger NRT of pentane after HFS addition. Empty bed velocity is a parameter who plays a key-role on the BF performance. Moreover, peak perturbation experiments allow to evaluate the BF performance in a fast way and provide essential information for its design at pilot or industrial scale. On the last stage of the study, when larger amounts of HFS and nutrients were added to the BF, a RE increase at high IL was found. These findings would seem to suggest a possible link between this performance improvement and the addition of HFS and nutrients.

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