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REMOVAL OF VINYL ACETATE FROM WASTE GASES IN THE PILOT-SCALE BIOLOGICAL TRICKLE - BED REACTOR*

OCZYSZCZANIE GAZÓW ODLOTOWYCH Z OCTANU WINYLU W PILOTOWEJ INSTALACJI BIOREAKTORA STRUŻKOWEGO

Abstract: The removal of vinyl acetate from air streams in a pilot-scale trickle-bed bioreactor (TBB) inoculated with *Pseudomonas* sp. PCM 2123 strain was studied experimentally. For various gas and liquid flow rates and inlet vinyl acetate concentration ranging from 0.25 to 1.5 g · m^{-3} the efficiency of the process was tested. For all the operating conditions high elimination capacity was obtained.

Keywords: vinyl acetate, air purification, trickle-bed bioreactor

Introduction

Vinyl acetate belongs to a group of compounds known under the common name of Volatile Organic Compounds (VOCs). In normal/standard conditions it is a colourless liquid with a characteristic sweetish odour, forming flammable and explosive mixtures with air. This chemical compound is commonly used in industry to produce polyvinyl acetate which is a component of masses bonding glues, water based paints, foils, inter-layers of chilled glass, paper impregnates and many copolymers [1]. Vinyl acetate was listed by US EPA among the 189 pollutants most noxious for the environment [2].

The emission of vinyl acetate into the atmosphere is significant. According to EPA report from 2002 concerning the emission of pollutants in the organic chemistry industry, the amount of vinyl acetate emitted into the atmosphere was 235,542 Mg per year [3].

This compound has a great influence on the functioning of living organisms. In case of human beings vinyl acetate in the concentration of more than 21.6 ppm irritates breathing tracts. The negative influence of this pollutant on a human body is confirmed by tests; 17 chromosome aberrations and the phenomena of sister chromatid exchanges (SCE), and DNA cross-linking were observed, while incubating in vitro human lymphocytes and leukocytes in the presence of vinyl acetate [4]. The mechanism of metabolism of vinyl acetate in the tissues of mammals was described in the work [5] where the negative influence of the products of vinyl acetate decomposition (acetic aldehyde and acetic acid) on tissues exposed to the action of this compound was emphasized. Clinical testes proved its effect as a carcinogenic factor inducing nose cancer (papillomas and squamous cell carcinomas) among rodents, which gives a good view on the hazard that is posed by the presence of vinyl acetate in the environment. The application of microbiological processes to eliminate vinyl acetate does not increase the risk of uncontrolled genetic modifications in case of micro-organisms since this compound is not mutagen for bacteria [6]. Thanks to it,

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it is possible to use bacteria in the process of biological purification of air from vinyl acetate.

There is very little information about microbiological decomposition of vinyl acetate in literature. They are only the works of Nieder et al [7] who studied the rate of degradation of the compound by an environmental strain marked V2 and works [8-10] where the efficiency of vinyl acetate biodegradation by a group of environmental and laboratory strains was compared, the most effective strain was selected and the kinetics of its growth on a biodegraded substrate was determined.

The basic criterion to choose the technology of air purification should be the concentration of pollutant in the stream of the purified gas and the rate of that stream. Figure 1 shows the ranges of the concentrations of pollution and the gas flow rate in which the use of proper technologies can give measurable effects. As it can be seen, biological methods can be used for very big air streams, however, the concentration of the pollutant cannot exceed 10 g · m^{-3}. Here biological methods are more advantageous in comparison with the other technologies that are used such as catalytic oxidation, combustion, adsorption, absorption or concentrations on membranes [11].

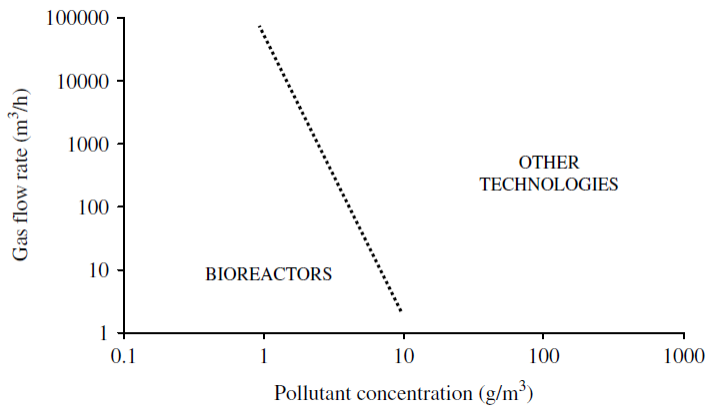

Fig. 1. Ranges of the use of various technologies of eliminating organic pollutants depending on gas flow rate and concentration of pollutants [12]

VOCs biodegradation in trickle-bed reactors is a process carried out in pressure and temperature conditions slightly different from standard conditions, which is its important advantage in comparison with other technologies of waste gases purification. Biotechnological methods require the lowest expenditures connected with VOCs utilization calculated for 1 $m^3 \cdot h^{-1}$ of the polluted air.

In comparison, depending on the used method, expenses are in the range of: $ 13-90 - biotechnological methods, $ 25-155 - adsorption, $ 30-600 - combustion, $ 40-190 - absorption, $30-200 condensation. As it has been mentioned above, chemical and physical methods can be used only at the determined operational conditions at proper ranges of concentration of the pollution [13].

The aim of the study was to check the efficiency of the pilot-scale trickle-bed bioreactor (TBB) installation designed to purify ~200 $m^3 \cdot h^{-1}$ of air polluted by a volatile

organic compound. The carried out studies are to provide directions making it possible to scale up bioprocesses and determine the range of changes in operational biodegradation process parameters for which high conversion of the pollutant will be ensured.

Materials and methods

The pilot installation was made up of three basic systems: a system feeding the bioreactor with a given stream of air containing enough volatile organic compound vapour, a system recycling liquid in which the composition of the solution feeding the bioreactor was controlled and adjusted, and the trickle-bed bioreactor system provided with ports to sample liquid and gas, to measure pressure drop etc. The scheme of the installation was shown in Figure 2.

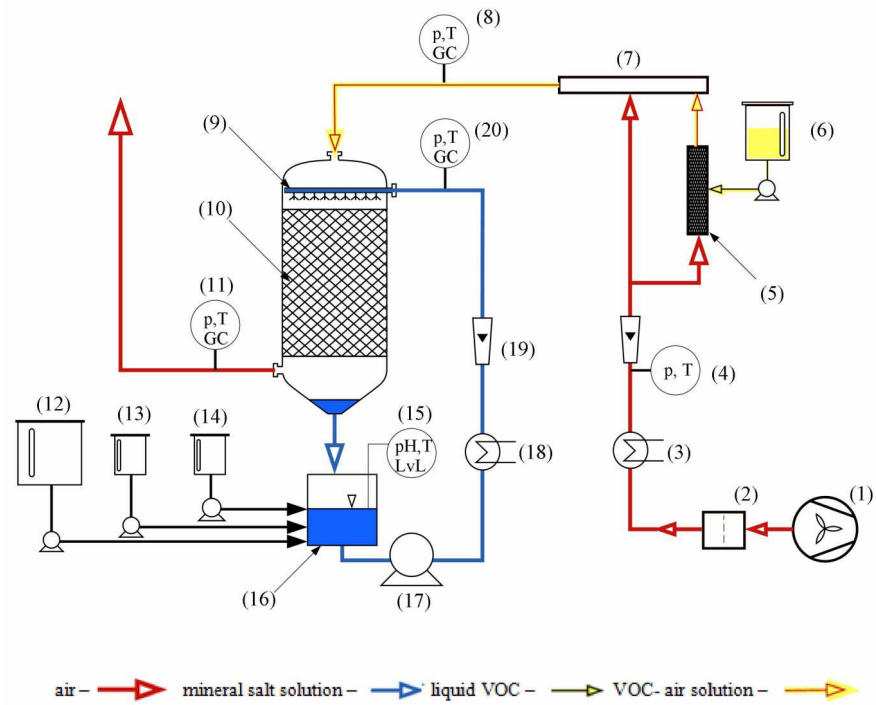

Fig. 2. Schematic diagram of the experimental setup: 1 - compressor, 2 - air filter, 3 - air heater, 4 - gas flow meter, pressure and temperature meter, 5 - VOC evaporation chamber, 6 - VOC container integrated with dosing pump, 7 - gas mixing chamber, 8 - concentration, pressure and temperature measurement in gas inlet, 9 - sprinkler, 10 - packed column, 11 - concentration, pressure and temperature measurement in gas outlet, 12 - mineral salt solution container with dosing pump, 13 - KOH solution container with dosing pump, 14 - KH_2PO_4 solution container with dosing pump, 15 - level, temperature and pH measurement, 16 - solution container, 17 - liquid pump, 18 - liquid heater, 19 - liquid flow meter, 20 - VOC concentration, temperature and pressure measurement

The air and liquid phases flowed concurrently downward through the column packed with polypropylene Ralu Rings ($\varepsilon = 0.94$), covered with a thin layer of microorganisms

(*Pseudomans fluorescens* PCM 2123). During experiments the gas flow rate was changed from 50 to 200 $m^3 \cdot h^{-1}$, liquid flow rate was changed from 5 to 10 $m^3 \cdot h^{-1}$, whereas concentration of vinyl acetate was changed in the range 0.25 to 1.5 $g \cdot m^{-3}$.

All experiments were carried out under steady-state and optimal for used microorganism conditions (pH = 6.9-7.0, $t = 30.0 \pm 0.5$ºC).

During experiments the concentration of vinyl acetate and carbon dioxide in the gas phase and concentration of vinyl acetate and intermediate products of biodegradation in the liquid phase, at the inlet and outlet of the bioreactor were controlled every day (gas chromatograph Varian Star 3800 (USA)).

Results and discussion

The performance of the bioreactor was evaluated by the following performance parameters: vinyl acetate (pollutant) load (*PL*), elimination capacity (*EC*) and removal efficiency (*RE*). The definitions of these parameters are set out below:

$$PL = \frac{C_g}{\tau} \tag{1}$$

where:

$$\tau = \frac{V_{bed}}{V_g} \tag{2}$$

$$EC = PL^0 - PL^H \tag{3}$$

$$RE = \frac{\left(C_g^0 - C_g^H\right)}{C_g^0} \tag{4}$$

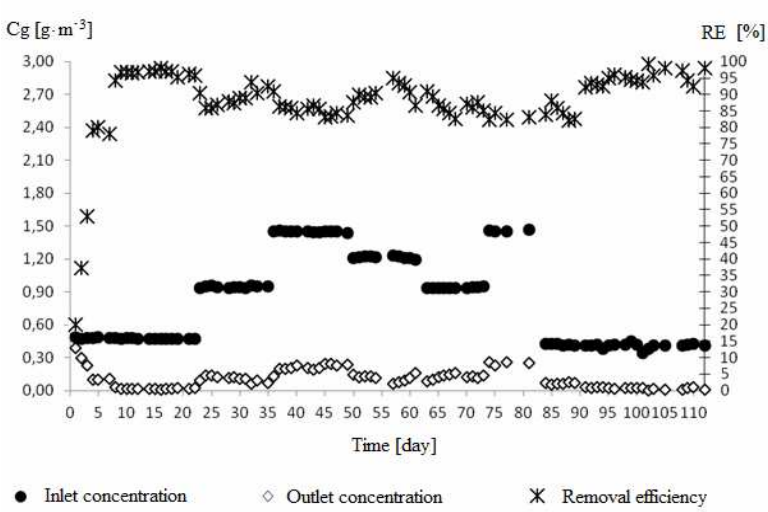

Fig. 3. Inlet and outlet concentrations and removal efficiency of vinyl acetate versus operation time

The pilot-scale trickle-bed bioreactor was operated for five months and no clogging of the column, due to excess growth of biomass on the packing material, was observed. The changes of inlet and outlet concentration of vinyl acetate and removing efficiency during experimental period was shown in Figure 3.

It has to be emphasized that the efficiency of the bioreactor was not lower than 85% even at the highest concentration of the pollutant in the purified gas. Figure 4 shows the results of the experiments in the form of *EC* vs. *PL* dependence. The presented comparison shows that if the inlet pollutant load of the bed (PL^0) does not exceed ~40 g · m^{-3} · h^{-1} then the pollutant conversion is close to 100%. The *EC* value decreases slightly for higher loads of bed with pollutant.

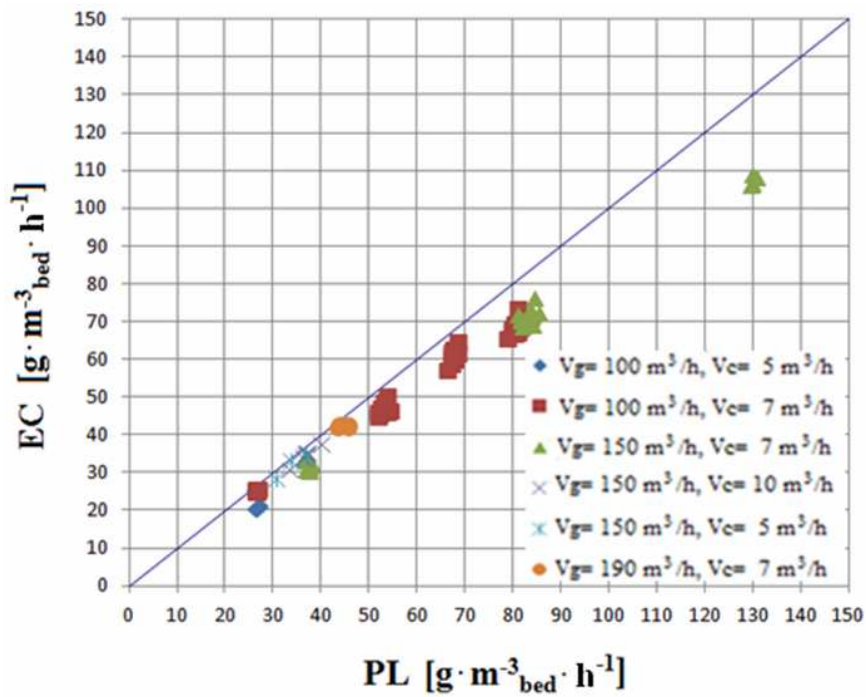

Fig. 4. Measured specific Elimination Capacity *EC* versus specific Pollutant Load *PL*

Conclusions

The experiments showed the significant potential applicability of TBB for the purification of large waste gas streams containing low concentrations of VOCs. More than 98-85% removal efficiency was achieved for influent vinyl acetate concentration ranging from 0.25 to 1.50 g · m^{-3}. The conducted experiments provided a lot of crucial information connected with scaling up of the process from laboratory to pilot-scale and made it possible to work out procedures ensuring the effective and long-term operation of the installation. The analysis of process parameters made it also possible to verify kinetic parameters of biodegradation processes determined in batch experiments.

Symbols

C - substrate concentration [g · m^{-3}]
EC - elimination capacity [g · m^{-3} · h^{-1}]
PL - pollutant load [g · m^{3} · h^{-1}]
RE - removal efficiency [%]
V - volumetric flow rate [m^{3} · h^{-1}]
V_{bed} - bed volume [m^{3}]
τ - empty bed residence time [h]

Subscripts

$_{g}$ - gas
$_{c}$ - liquid
$_{H}$ - outlet of reactor
$_{0}$ - inlet of reactor

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OCZYSZCZANIE GAZÓW ODLOTOWYCH Z OCTANU WINYLU W PILOTOWEJ INSTALACJI BIOREAKTORA STRUŻKOWEGO

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Abstrakt: Przeprowadzono badania usuwania octanu winylu z gazów odlotowych w instalacji pilotowej bioreaktora strużkowego zaszczepionego bakteriami *Pseudomonas sp.* PCM 2123. Badania przeprowadzono dla różnych wartości natężeń przepływu gazu i cieczy oraz przy stężeniach octanu winylu w zakresie od 0,25 do 1,5 g · m^{-3}. Dla wszystkich warunków operacyjnych uzyskano wysoką wydajność eliminacji zanieczyszczenia.

Słowa kluczowe: octan winylu, oczyszczanie powietrza, bioreaktor strużkowy