AERAULIC BEHAVIOUR OF A BIOTRICKLING FILTER PILOT PLANT: EXPERIMENTS AND SIMULATIONS

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ABSTRACT: Trickling bed biofilters (or biotrickling filters, BTFs) are biological systems for polluted air treatment. Hydrodynamics of BTFs, and reactors in general, is of paramount importance for obtaining good performances. In fact, a non-uniform distribution of the pollutant into the bed brings to dead zones or bypass which reduce the bed working volume and, therefore, cause low removal efficiencies. The paper presents the preliminary results obtained regarding the aeraulic behavior of a BTF pilot plant with seashells as packing material. Experimental results of bed void fraction and pressure drop at several flow rates were used to obtain Ergun equation coefficients for dry bed. A numerical simulation of the reactor flow field carried out with a commercial CFD (Computational Fluid Dynamics) code, validated by the means of velocity measurements made with a Hot Wire Anemometer (HWA) completed the analysis of the reactor hydrodynamics.

KEY WORDS: biotrickling filter, computational fluid dynamics, hydrodynamics, packing material, pressure drops.

1. INTRODUCTION

Uniform distribution of fluids into chemical and biological reactors plays a key-role in the processes optimization. In fact, the presence of non-uniform fluid or reactant distribution causes dead zones, or bypass, which bring to both an underexploiting of reactor volumes and a reducing of expected process performances. In particular, for polluted fluids treatment, reduced performances regard removal efficiencies. For such reasons the fluid dynamic behavior of reactors is of great importance.

Trickling bed biofilter, or biotrickling filter (BTF), is an emerging and attractive technology for the removal of pollutant (e.g. H_2S, NH_3, VOCs and other odorous compounds) present at low concentrations (Copelli et al., 2012). In BTFs (Shareefdeen and Singh, 2004), as the polluted air is passed through a bed of media, the contaminants and oxygen are first transferred to the biofilm formed on the surface of the particles and, then, metabolized by bacteria. The media within a BTF are normally inert natural (e.g. lava rock) or synthetically manufactured (e.g. foams, propylene) materials. The trickling liquid provides moisture, salts, metabolites and supplemental nutrients to the process culture; moreover it is a convenient mean to control pH and temperature. Some experiences concerning the hydrodynamic characterization of BTFs filled with regular packing materials (propylene) are present in literature (Trejo-Aguilar et al., 2005; Sharvelle et al., 2008).

The paper shows a series of experimental and numerical results regarding the aeraulic behavior of a BTF pilot plant filled with M*ytilus edulis* shells. Dry bed pressure drops at different flow rates were measured in order to obtain the *ad-hoc* coefficients for Ergun equation. Such coefficients were employed in a commercial finite volume method code in order to obtain the solution of Reynolds Averaged Navier-Stokes (RANS) equations on a Cartesian grid and to obtain the characteristic quantities of the air flow field with an Eulerian approach (Ferziger and Peric, 2002). Flow field numerical results in steady-state conditions were validated by the means of local velocity measurements and, finally, discussed.

2. MATERIALS AND METHODS

2.1. Experimental setup

The experiments were carried out in a pilot plant BTF 0.50 m wide (W), 1.00 m long (L) and 1.80 m high (H), filled with 1.10 m (*h*) of *Mytilus edulis* shells. Shells are principally composed of $CaCO_3$ (Cubillas et al., 2005): such a composition gives them a high buffering power, useful for neutralizing acidic by-products of biological degradation. An axial fan blew atmospheric air into the 0.30 m high reactor plenum, placed at the bottom of the system, through a horizontal circular (D_{in}=0.100 m) feeding duct (figure 1). Fan speed was regulated by the means of an inverter.

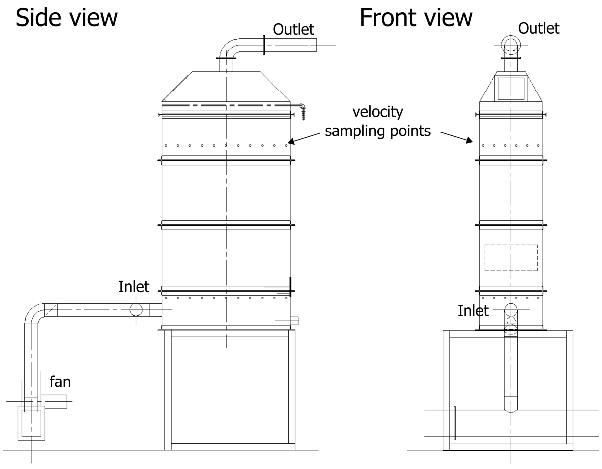

Figure 1. Pilot plant layout.

2.2. Experimental measurements

Pressure drops (*Δp*) across the bed were measured with a Sensirion SDP1000 pressure probe. Sampling and A/D conversion was performed through a Microchip PIC16F87XA connected with a Laptop. A *ad-hoc* C++-based software managed both acquirement and data storage.

The inlet flow rate (*Q*) was measured by the means of a Delta Ohm HD 2303.0 Hot Wire Anemometer (HWA; Arts et al., 1994) with a AP471 S1 probe. The HWA was also employed to measure 126 local vertical velocities ($|w|$, m s^{-1}) in two planes placed, respectively, 0.05 m below and above the bed (z=0.250 m and z=1.450 m) during a reactor hydraulic loading rate of 267 m³ h^{-1} m^{-3} reactor. Because of the HWA characteristics, velocity measurements near the vertical walls were carried out with a Pitot tube (Arts et al., 1994) connected to the pressure probe. Velocities were sampled for 60 s: average results were employed for the comparison with the numerical results. Bed porosity, or void fraction (ε, dimensionless), was determined by measuring bulk volume (V_{ss}) and shell mass (m_{ss}):

$$\varepsilon = \frac{m\,\rho_{ss}}{V_b} \qquad (1)$$

where ρ_{ss} is the seashell density.

2.3. Numerical model

The steady-state velocity field simulation was obtained with the CFD code CD-Adapco STAR-CD 3.26 (Cd-Adapco, 2005), which solves the RANS equations using a finite volume scheme with a 2nd-order upwind differentiation for convective terms. Solutions were obtained iteratively by the use of the predictor-corrector SIMPLE (Semi-Implicit Pressure Linked Equations) algorithm (Cd-Adapco, 2005). The sensitivity with respect to different turbulence models was tested (*k-ε* standard, *k-ε* RNG). The computational mesh consisted in 561’600 hexahedral cells 0.01 m × 0.01 m × 0.02 m in the outer region and in a more refined one near the boundaries and into the plenum. The inlet velocity (V_{in} = 5.2 m s^{-1}) was assumed to be constant and uniform. Near the solid boundaries, the velocity was assumed to follow the standard logarithmic law for a turbulent boundary layer close to a smooth wall; a zero pressure condition was imposed at the outlet. A view of the resulting computational mesh is shown in figure 2, where the boundary surfaces are colored according to the relative boundary condition (white: inlet; dark grey: pressure).

The seashell bed was modeled as a porous media with an isotropic behavior which follows the Ergun equation (Ergun, 1952):

$$\Delta p / h = \alpha U + \beta U^2 \qquad (2)$$

where, in the Moreno et al. (2009) version rewritten for non-spherical particles, α and β are:

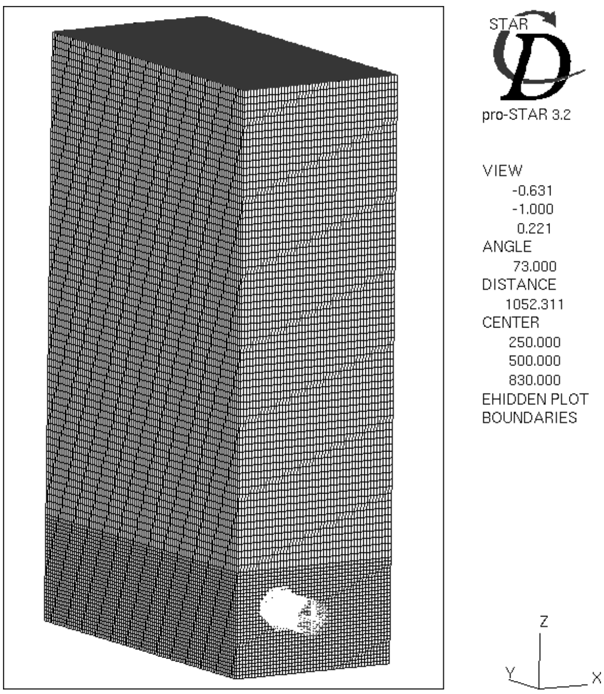

Figure 2. Computational grid and boundary conditions.

$$\alpha = 150 \frac{(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu_g}{36} S_p^2 \tag{3}$$

$$\beta = 1.75 \frac{1-\varepsilon}{\varepsilon^3} \frac{\mu_g \rho_g}{6} S_p \tag{4}$$

where μ_g and ρ_g are, respectively, the molecular viscosity and the density of the gas, while S_p is the specific surface area of a non-spherical particle (Perry and Green, 1999).

3. RESULTS AND DISCUSSION

3.1. Pressure drop

Results of pressure drop to bed height ratio measurements for dry bed as a function of the mean reactor velocity ($V_{BTF}= Q\ W^{-1}\ L^{-1}$) are shown in figure 3.

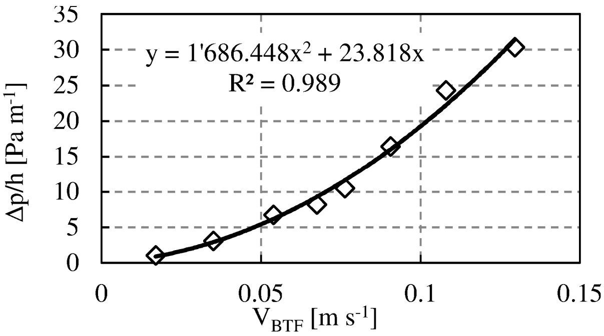

Figure 3. Bed pressure drops at different air velocities.

Experimental data were fit very well by a 2nd order polynomial curve, from which it is possible to obtain α and β values for shells (table 1). Rewriting equation (3) or (4), the equivalent specific surface area (S_p) for modified Ergun equation was found. Results are reported in table 1.

Table 1. Experimental results regarding shells.

Characteristics	Unit	Value
Density, ρ_{ss}	kg m^{-3}	2688
Bed porosity, ε	-	0.90
Ergun equation α	Pa s m^{-2}	1686
Ergun equation β	Pa s^{-2} m^{-3}	23.82
Specific surface area, S_p	m^2 m^{-3}	9147

Regarding bed porosity, shells guaranteed a high value (0.90) which indicates both a good biofilm surface to volume ratio and low pressure drops for air.

3.2. Reactor aeraulics

3.2.1. Numerical results

The two considered turbulence model did not show any particular difference. Due to reactor geometry, the velocity field shows the classic symmetry considering *yz* plane at *x*=0.25 m. Figure 4 showed that vertical velocities (*w*) before

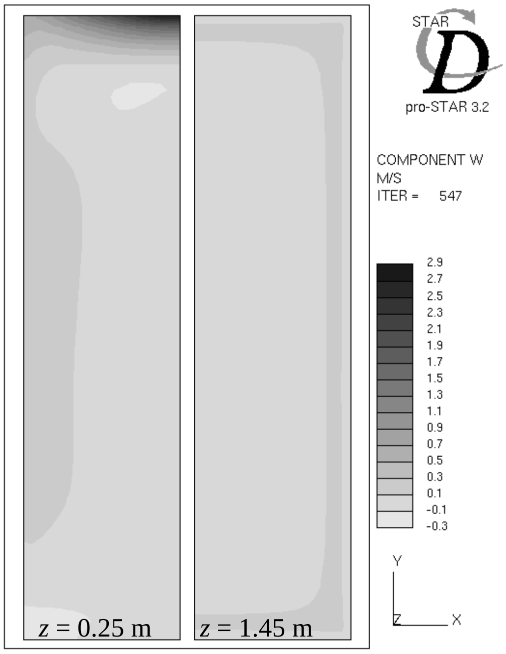

Figure 4. Numerical simulation velocity field.

entering in the bed (z = 0.25 m) are not uniform: the zone opposite to the inlet has high velocities due to the impinging air jet. Moreover, few zones show even negative velocities caused by recirculation into the plenum. Such a situation demonstrated that the current inlet configuration did not guarantee an uniform distribution of polluted air into the reactor. Instead, *w* field outgoing the bed (z = 1.45 m; figure 4) is quite uniform thanks to the porous media.

3.2.2. Experimental results

The HWA measurements confirmed the non-uniform velocity distribution below the bed (at z = 0.25 m): figure 5 shows a non-symmetric velocity profile near the wall opposite to the inlet (y = 0.95 m). The same results were obtained in other positions.

Air velocities above the bed near the wall opposite to the inlet (figure 6) were higher than the average velocity (0.82 m s^{-1}); such phenomena demonstrated that an air bypass along the wall existed.

The bypass could defeat the removal efficiencies of the BTF, even if in the remaining part of the field measured air velocities agreed quite well with the numerical results, as demonstrated by the velocity profile at y = 0.235 m shown in figure 6.

4. CONCLUSIONS AND INTENTIONS

The paper describes the preliminary results obtained with both aeraulic measurements (i.e. pressure drop, local velocities) and numerical simulations on a pilot plant biotrickling filter.

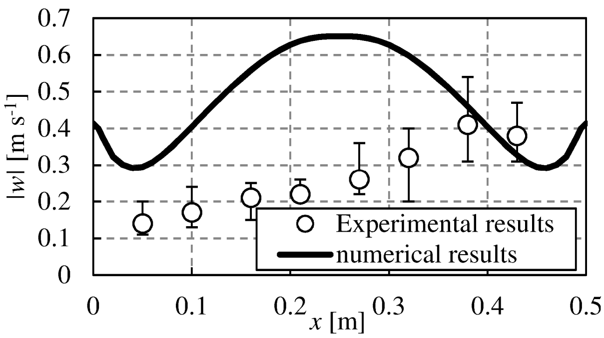

Figure 5. Vertical velocity profiles at z = 0.25 m.

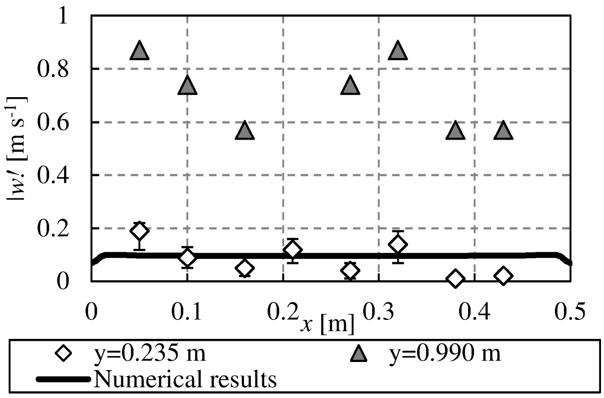

Figure 6. Vertical velocity profiles at z = 1.45 m.

Experiments allowed to calculate Ergun equation coefficients and equivalent specific surface area for *Mytilus edulis* shells, a packing material used in biotrickling filters. Such data can be useful for the correct fan sizing and, as consequence, for reducing construction and management costs.

Numerical simulation of the velocity field into the biofilter plenum demonstrated that a simplified geometrical configuration of the inlet brings to a non-uniform flow distribution which is also confirmed by velocity measurements.

Further developments in the research will be focused on (i) testing new inflow geometries and baffles with experiments and numerical simulations in order to achieve a more uniform air flow distribution and avoid near wall by-pass; (ii) improving numerical simulations, considering also differential packed bed permeability able to simulate the near wall by-pass effects; analyzing pressure drop behavior (iii) of other packing materials (iv) in presence of varying trickling liquid flow rate.

5. ACKNOWLEDGEMENTS

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