Mathematical Modeling of Olive Mill Wastewater (OMW) Rhizodegradation with the Halophyte *Juncus Acutus* for Water Reuse

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Introduction

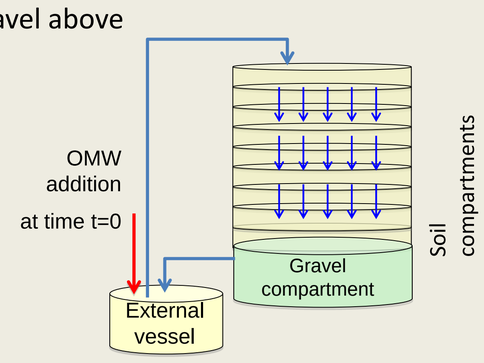
In this work we consider the treatment of OMW through a phytoremediation process using the halophyte *Juncus Acutus*. Rhizodegradation i.e., the microbial degradation in the rhizosphere is considered as the dominant process for the reduction of the COD as the OMW is recycled through the soil. The COD removal process is also linked to evapotranspiration, whereby the COD entering the roots and moving to leaves is degraded by plant's oxidative enzymes or by endophytic bacteria. In general, the soil absorbs organic compounds from the recycled OMW, which are subsequently desorbed as the COD in the OMW is reduced according to the thermodynamic equilibrium. *Juncus acutus* was selected as a candidate plant, because it is a perennial wetland plant, widespread in the Mediterranean region and has an extensive root system that provides it with great capacity for extracting contaminants from the aqueous phase.

Experimental set-up

A pilot unit containing two grown-up *Juncus Acutus* plants has been operated over a period of two months treating OMW through recirculation from an external storage tank.

•**Experimental process characteristics**
•OMW inlet: top of the unit
•OMW output: bottom of the unit (**sampling point**)
•Tap water addition to the external vessel whenever necessary to account for water losses.

Rhizodegradation unit characteristics
•Total soil mass: 1040 kg
•Gravel layer compartment: 110L small-sized gravel at the bottom and 55L medium-sized gravel above



Experimental information	Run#1	Run#2
Duration (days)	27	23
Initial OMW strength (mg/L COD)	5500	8500
Total COD inserted to the system (g)	454	727
Pumping rate (L/h)	4-6	2,5-4,5
Pumping duration (h/d)	24	5
COD removed (%)*	99,1%	99,6%
Final COD concentration (mg/L) (exit point)*	10	120

* Measured experimentally

Mathematical modeling

A mathematical model has been developed in MATLAB® to describe the dynamics of the overall OMW removal process.
The pilot unit has been conceptually divided into **12 equal volume soil** compartments + **1 gravel** compartment in order to adequately describe the plug flow of the OMW in the unsaturated zone.

Basic model considerations

COD removal processes

- **Rhizodegradation**: Monod Kinetics microbial degradation in the rhizosphere zone (main COD removal mechanism)
- **Phytodegradation**: First order COD removal through plant up-take during evapotranspiration
- **COD adsorption to soil**

COD mass balance equation

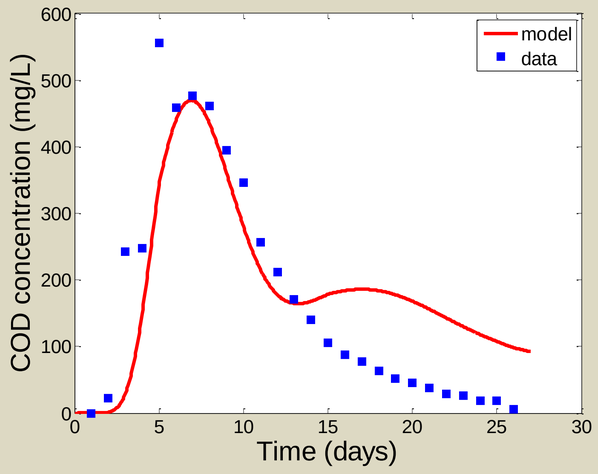
$$\frac{dC_{COD,i}}{dt} = \frac{Q_{in,i}C_{COD,i} - Q_{out,i}C_{COD,i} - q_{ev}C_{COD,i} - \mu_{max}\left(\frac{C_{COD,i}}{k_s + C_{COD,i}}\right)}{V_{aq,comp,i} + K_{SD}M_{soil,comp}}$$

OMW flow and other considerations

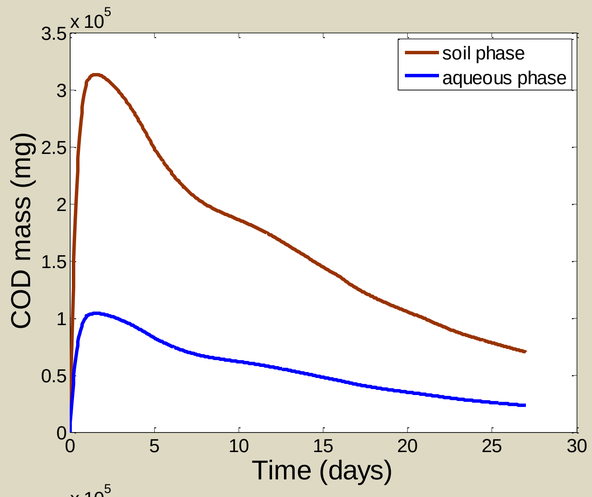
- Water loss from the system: **evapotranspiration** in soil compartments with roots plus **evaporation** in the top compartment (constant rates during the two experimental runs).
- **Rhizodegradation** takes place across all unit (highly developed root system of the plants)
- **Biomass** concentration: **same** across all unit and **constant** with respect to time (due to minimal growth of root system during the experimental runs)
- **Thermodynamic equilibrium:** reached at all times as COD is slowly reduced
- **Only 80% of the soil** is assumed to be watered by the pump (excluding the soil near to the perimeter of the unit)

Modeling results and experimental data

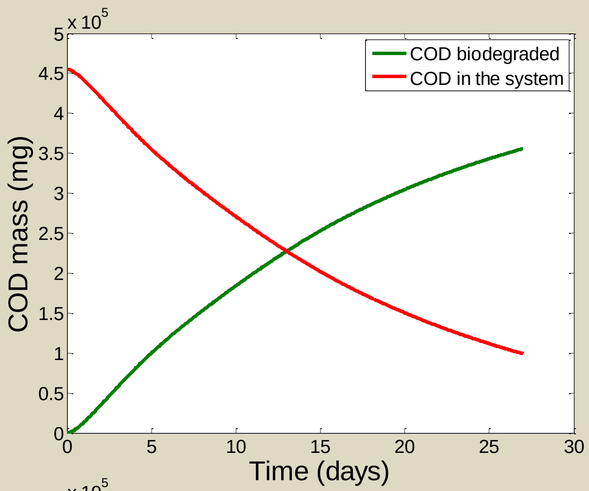
Output COD concentration



Total COD distribution in the unit



Remaining total COD in the system and total COD biodegraded vs. time



• total COD biodegraded by rhizodegradation and phytodegradation: **78,23%** (1st run) **89,24%** (2nd run)

• total COD adsorbed to soil at the end of the run: **15,42**% (1st run) **5,39%** (2nd run)

• total COD remaining in the liquid phase at the end of the run:**5,12**% (1st run) and **4,75%** (2nd run)

Conclusions

- According to the experimental results, the phytoremediation process has been proven to be very effective in reducing the COD of the OMW. About 99,6% of the initial COD has been reduced within a period of 23 days when the initial COD is 8500 mg/L.
- The model calibration has been performed with raw data from two experimental runs of the pilot unit and the simulations match the experimental data for both runs satisfactorily.
- The Ksd factor has been proven a sensitive parameter of the model.
- The treated OMW has a sufficiently low COD that enables its use for the irrigation of crops (e.g., corn) or trees (e.g., olive trees, vineyards, etc).

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