OPTIMIZATION OF ACQ-, CA-, MCQ-TREATED WOOD WASTES RECYCLING USING THE BOX BEHNKEN RESPONSE SURFACE METHODOLOGY

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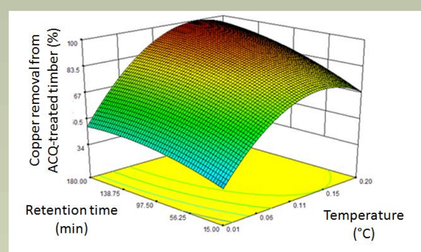
1. INTRODUCTION

CCA*-treated wood has been replaced for most residential uses by alternative copper-based preservative-treated wood such ACQ*-, CA- and MCQ-treated wood. Treated wood wastes disposal is becoming a challenge because of increasing fees and stringent regulations regarding solid waste landfill. Technologies have been applied to CCA-treated wood wastes based on metals solubilization by leaching[1-3]. Previous studies identified an efficient chemical leaching process for CCA-, ACQ-, CA- and MCQ-treated wood recycling[4].

2. OBJECTIVES



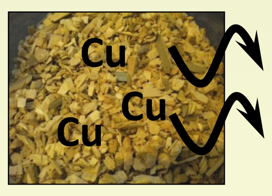
- **To model copper solubilization from ACQ-, CA- and MCQ-treated wood (influence of leaching parameters) using a Response Surface Methodology (Box Behnken Design, BBD**).**
- **To define optimal leaching conditions in terms of copper removal efficiencies from ACQ-, CA- and MCQ-treated wood and operational costs.**

3. METHODS

Experimental conditions:

- 30 g of ACQ- , CA-, and MCQ-treated timbers (0-12mm particle size).
- 200 mL of leaching (H_2SO_4) and rinsing solution.
- 1, 2 or 3x2h leaching steps and 3x7min rinsing steps.
- Solid/liquid separation by filtration (1.5 µm).

Determination of response factors:

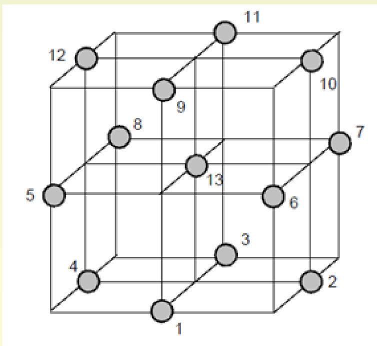


- Y_1 : Cu removal (%) from ACQ-treated wood.
- Y_2 : Cu removal (%) from CA-treated wood.
- Y_3 : Cu removal (%) from MCQ-treated wood.
- Y_4 : Operational costs ($/ttw***)

Box Behnken Design:

- Factor responses (Y_1.....Y_n) are defined.
- Independent factors (X_1, …., X_n : which affect copper solubilisation from treated wood)
- Levels of each parameters (Min and Max values) are chosen.
- Experimental assays (41 assays per treated wood) are carried.
- Significance of mathematical models established using Expert Design 8.0 software is checked.
- Optimized copper removal efficiencies and operational costs are identified.

Experimental region and levels of each independent factor:



BBD matrix representation

Parameters	Units	Coded values (Xi)	Experimental field		
			Min value (-1)	Middle value 0	Max value (+1)
Temperature	°C	X_1	20.0	47.5	75.0
Acid concentration	N	X_2	0.010	0.105	0.200
Retention time	min	X_3	15	97	180
No. of leaching steps	-	X_4	1	2	3

4. RESULTS

Copper-based preservative-treated wood characterization :

Preservative	ACQ	CA	MCQ
Provider	Home Depot	Drop-off eco-center	U. Toronto
Service time (yr)	0	Unknown	3
MC (%)	12	11	20
Cu content (mg/kg)	1723 ± 143	3906 ± 557	3730 ± 516

- **ACQ-treated wood** had a **low copper content** (intended use of timber).
- **Larger amounts of copper** were found on **CA- and MCQ-treated wood**.
- Moisture contents range from 11 to 20%.

Evaluation of mathematical model adequacy with Design Expert software :

Wood sample	Source	ACQ-		CA-		MCQ-	
		Pr > F	Conclusion	Pr > F	Conclusion	Pr > F	Conclusion
Analysis of variance (ANOVA)	Model	< 0.0001	significant	< 0.0001	significant	< 0.0001	significant
	Lack of fit	0.0017	significant	0.3833	not significant	0.1569	not significant
		R^2 = 0.97		R^2 = 0.98		R^2 = 0.98	

- Pr > F values are lower than 0.05 => **mathematical models established to predict copper solubilization from ACQ-, CA- and MCQ-treated wood are significant**.
- A **satisfactory correlation** (R^2 > 0.97) between measured and predicted values.

Mathematical models (coded factors) of copper solubilization from ACQ-, CA- and MCQ-treated wood – Influence of leaching parameters :

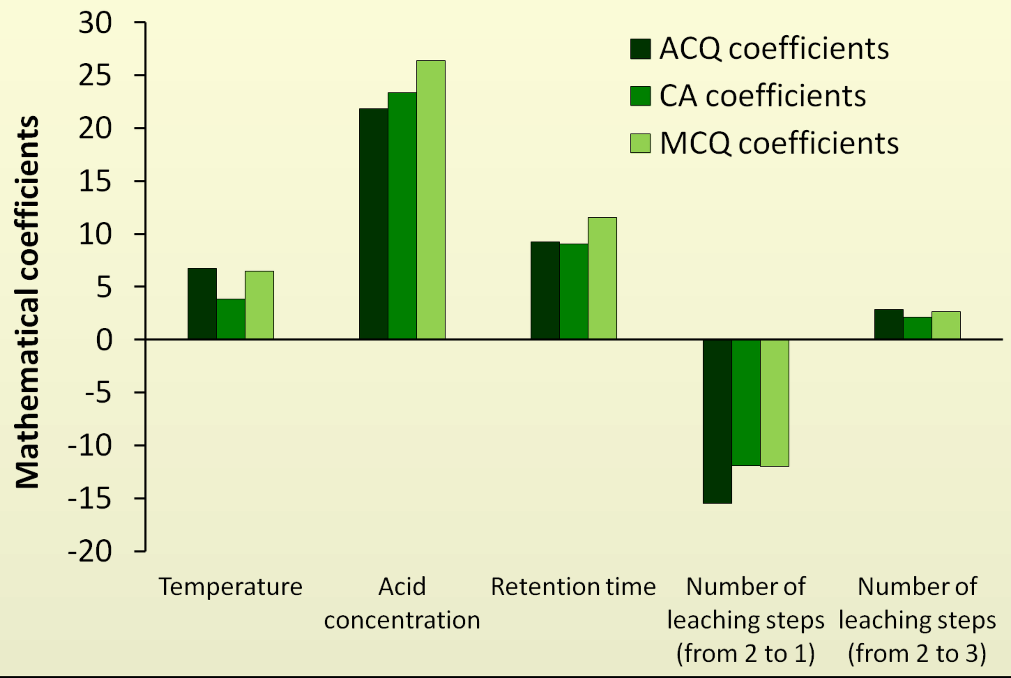
Design Expert 8.0 Software – Mathematical equations:

$$Y_1 = 84.55 + 6.75\ X_1 + 21.88\ X_2 + 9.22\ X_3 - 15.45\ X_4 + 2.84\ X_5$$

$$Y_2 = 81.25 + 3.84\ X_1 + 23.39\ X_2 + 9.05\ X_3 - 11.93\ X_4 + 2.10\ X_5$$

$$Y_3 = 82.72 + 6.49\ X_1 + 26.43\ X_2 + 11.55\ X_3 - 12.01\ X_4 + 2.63\ X_5$$

- **Similar mathematical models** are obtained to predict Cu solubilization from ACQ-, CA- and MCQ-treated wood.
- All leaching parameters had a **significant impact** on Cu solubilization from ACQ-, CA- and MCQ-treated wood.



- Temperature, acid concentration, retention time and No. of leaching steps (from 2 to 3) have a **positive impact** = increasing levels are required to allow Cu solubilization.
- No. of leaching steps (from 2 to 1) have a **negative influence** = reducing No. of leaching steps decrease amount of Cu solubilized.
- Influence of parameters : **Acid concentration > No. of leaching steps > Retention time ≈ Temperature.**

Determination of optimal leaching conditions using a Box Behnken Methodology :

Objectives :

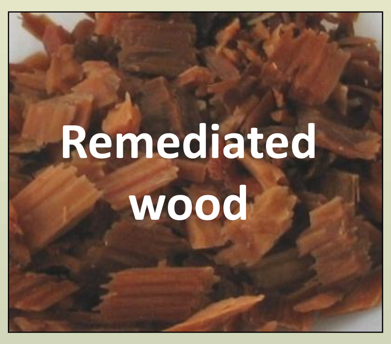
- **To maximize Cu solubilization from ACQ-, CA- and MCQ-treated wood and to minimize leaching costs.**

Optimal leaching conditions :

- N of leaching steps : 3.
- Retention time of each leaching steps : 2h 40.
- Acid concentration : 0.13 N
- Temperature : 20 C.

ACQ : [Cu] = 1723 mg/kg
CA : [Cu] = 3906 mg/kg
MCQ : [Cu] = 3730 mg/kg

ACQ- and CA- : 90%
MCQ- : 93%
Operational costs : $ 61/ttw



ACQ : [Cu] = 172 mg/kg
CA : [Cu] = 391 mg/kg
MCQ : [Cu] = 437 mg/kg

6 . CONCLUSION

According to the Response Surface Methodology Design, copper solubilization from ACQ-, CA- and MCQ-treated wood wastes was strongly influenced by sulfuric acid concentration and the number of leaching steps followed by temperature and retention time. The optimum leaching conditions were defined as three leaching steps of 2h 40min each at room temperature with an acid concentration fixed at 6.4 g/L. After leaching and rinsing steps carried out using optimal leaching conditions, more than 90% of copper was removed from ACQ-, CA- and MCQ-treated wood wastes for a total remediation cost of $121 per ton of treated wood (ttw) (total direct, indirect and general costs) and operating incomes (considering an energetic value of $ 13 per GJ) around $240/ttw. This compares favorably to landfilling or burning costs ranging from $40 to $150/ttw

7. REFERENCES

[1]Patent no 2.628.642 (2008) [2]Janin et al (2009) *J. Hazard. Mat. 169, 136-145* [3]*Gezer and Cooper (2009)* Proceedings IRG Annual Meeting Biarritz, France [4] Janin et al (2011) J. Hazard. Mat. 186(2), 1880-7 .

8. NOMENCLATURE

*CCA : Chromated Copper Arsenate; ACQ : Alkaline Copper Quaternary; CA : Copper Azole; MCQ- : Micronized copper
** BBD : Box Behnken Design
*** ttw : ton of treated wood