

Novel XMC Biopolymer to Improve Iron Ore Reverse Cationic Flotation Performance

Marcelo Moreira da Costa¹
Robisnéa Adriana Ribeiro²
Thalita Mendonça de Resende²
Julia de Cristo Figueiredo³ 

¹ Universidade Federal de Viçosa (UFV), Engenharia Florestal, Viçosa, MG, Brasil.

² Universidade Federal de Viçosa (UFV), Viçosa, MG, Brasil.

³ Universidade Federal Rural do Rio de Janeiro (UFRRJ), Seropédica, RJ, Brasil.

Abstract

Iron ore pellets are raw materials used by the iron and steel industries. In these applications, flotation process has been used for increasing the iron content. In this process, starch is normally used as a depressant and amine as a collector. The main objective of this study was to compare the starch with different alternatives of biopolymers. Such depressant was developed in the US Patent granted at number 9,421,556 named XMC. The best XMC produced in this work (XMC SB) shown iron content at tails fraction (RJ) and at concentrate fraction (CO) of 39.4% and 67.2%, respectively while starch shows 36.5% and 67.3%, respectively, at the same SiO₂ level. Additionally, mass recovery was 63.3% and 65.0%, respectively for XMC SB and starch, and metallic recovery were 75.2% and 79.0%, respectively for XMC SB and starch. Therefore, the major advantage of XMC as iron ore depressant will be regard its sustainability.

Keywords: Selectivity, flotation process, sustainable depressant, iron ore products.

1. INTRODUCTION AND OBJECTIVES

Iron ore pellet feed is an important upgraded product, agglomerated as a pellet material, which is used as raw material in steel manufacturing. In order to meet the specifications of the blast furnace process for steel production regarding trace elements content, upgrading steps are required (Souza Pinto et al., 2021). Among others steps, flotation has been essential for intermediate and low-grade iron ore upgrading prior to agglomeration.

In over half a century's practice in the iron ore industry, froth flotation has been established as an efficient method to remove impurities from iron ore. Most of the Brazilian pellets feed production sites use the reverse cationic froth flotation as the benchmark process to deal with the iron ore quality variation and to efficiently remove the main contaminants named gangue (Aguiar et al., 2017). The flotation process can be direct, when iron oxides are floated, or reverse, when the silica gangue is floated (Stapelfeldt and Lima, 2001; Nascimento, 2010).

According to Rabockai (1979), flotation consists of making a material of a hydrophobic nature float on a liquid phase, while the material of a hydrophilic nature is deposited at the bottom of the container. The suspension is stirred or air bubbled through it. The hydrophobic particles adhere to the bubbles which transport them to the surface of the suspension. It is necessary to form a stable foam, which is obtained through the action of reagents known as foaming agents, which reduce the surface tension at the liquid/air interface, among other characteristics.

The flotation system includes many interrelated parameters, for example, chemical components (collectors, frothers, activators, depressants and chemicals for pH control), equipment components (cell design, agitation, air flow, cell bank configuration, cell bank control) and operation components (feed rate, mineralogy, particle size, pulp density, temperature). Because of the interrelationship between these factors, the study of each parameter in an isolated manner is very difficult, since the variation of one component can alter the conditions of the others (Kawatra, 2012).

Corn starch is widely used as depressant in reverse cationic flotation system of hematite/quartz (Pearse, 2005). But, the size of the polymer chain to be used as depressant in the iron ore flotation process may be an important parameter for the functionality of the polymer. The use of corn starch in reverse flotation may, in the future, harm the food chain of the world population, therefore, a substitute for this material, which is as efficient as starch, is of great interest XMC can be extracted from lignocellulosic material, that is a waste of industry, offering for this a prime destination, besides it is possible to remove the starch of industrial process partially or totally, preserving it for human and animal food chain.

XMC basically consists of xylan, and it is proven that this type of carbohydrate is extracted from lignocellulosic material through alkaline extractions (Boonchuay et al, 2018; Chen et al, 2017; Huang et al., 2008). In US patent 9,421,556 the depressant agent is produced by alkaline extraction. By the way, alkali pretreatment has also been proposed as promising to treat lignocelluloses without impact to the environment (Peng et al., 2009). The use of enzymes such as lipase and xylanase can improve the extraction of hemicelluloses.

The present investigation deals with the goal of increasing metallic recovery values through the improvement of reverse cationic flotation process selectivity at a competitive cost. Several alternatives were evaluated to refine the XMC material, in order to make it more selective, *via* removal of lipophilic substances, lignin and other impurities.

2. MATERIALS AND METHODS

2.1. Material

The biopolymer used throughout this study was extracted from the lignocellulosic material, that is a waste of industry, named CL, the samples are differentiated, among other features, by the particle size and moisture content. Thus, the preparation of samples was carried out differently, according to the interest of the study. The iron ore used in experiments was obtained from a mine in the Iron Quadrilateral in Minas Gerais, Brazil (V), then it was grounded and quartered.

2.2. Methods

2.2.1. Characterization of lignocellulosic material and iron ore

Agro-industrial residue (CL) was characterized in terms of extractive content, carbohydrate content (Wallis et al., 1996), soluble lignin (Goldschmid, 1971), insoluble lignin

(T222 om-98), total uronic acids (Scott, 1979), acetyl group (Solár et al., 1987) and ash content (Tappi 211 om-93). Raw ore were characterization by hematite, that was determined by titration, quartz and trace elements (Al_2O_3 , P, Mn, TiO_2 , CaO, MgO), that were obtained by hematite subtraction ($Fe_2 \times 1.43$) and iron loss ($100\% - Fe_2O_3 - PPC$). Iron ore density was determined by the pycnometer method.

2.2.2. Characterization of lignocellulosic material lipophilic fraction by GC-MS

2.2.2.1. Extraction

Air-dried lignocellulosic material samples were extracted with acetone for 6 hours using a Soxhlet apparatus following the Tappi standard process (T 204 cm-97). The solvent was removed under reduced pressure in a rotary evaporator, and the extracts were weighed.

To isolate the lipophilic fraction, the acetone extract was redissolved in dichloromethane (3 x 2 mL) and filtered off, as described by del Rio et al. (1998). The derivatized dichloromethane soluble (lipophilic) residues were analyzed by CG-MS, as described below.

2.2.2.2. Derivatization

Aliquots of lipophilic extracts were dissolved in pyridine in capped vials followed by the addition of 100 μ L bis(trimethylsilyl)-trifluoroacetamide (BSTFA) containing 1% chlorotrimethylsilane (TMSCI). The reaction mixture was heated at 70 °C for 30 min. It was then cooled down to room temperature before GC-MS analysis.

2.2.2.3. GC-MS analysis

GC-MS analysis was performed on a Shimadzu PQ5050A GC-MS equipped with an AOC-5000 auto injector and a DB-1 J&W capillary column (30 m x 0.25 mm i.d., 0.25 μ m film thickness), using helium as carrier gas (35 cm/s). The chromatographic conditions were as follows: injector temperature 290 °C; oven initial temperature 80 °C held for 5 min; temperature rate 4 °C /min; final temperature 285 °C held for 40 min. The interface temperature was 290 °C and a split ratio of 1:10 was applied. The mass detector was operated in the electron impact mode (70 eV) with a scan range of 30 to 600 m/z.

For semi-quantitative analysis, the GC-MS equipment was calibrated with pure reference compounds, representative of the major extractives' components, relative to hexanedioic acid and tetracosane used as internal standards, as already described by Freire et al. (2002). The corresponding response factors need to obtain correct quantifications calculated as an average of GC-MS runs.

2.2.3. Optimization of alkaline extraction consistency

The consistency was optimized in order to harmonize with the industrial conditions related to reactor feed; storage tank and final XMC concentration. The extraction was performed with 25 g of absolutely dry lignocellulosic material under the following conditions: 70 °C; 4 hours, 160 kg of NaOH per ton of over dry lignocellulosic material and 10, 15 and 20% of over dry biomass consistency. It was done on a thermostatic bath.

At the end of the extraction, the solubilized mass was centrifuged (Thermo/IEC CL10) for 5 min and 4000 rpm. The XMC extracted was separated from the solid residue, and the solid residue was washed with an equivalent of 5 m³ of distilled water per ton of dry material and it was centrifuged again under the same conditions. The XMCs were evaluated by their performance in the flotation test.

2.2.4. Talc in situ removal of XMC lipophilic fraction

The extraction with addition of talc (Mg₃Si₄O₁₀(OH)₂) was performed with 25g of absolutely dry lignocellulosic material under the following conditions: 70 °C; 4 hours, 160 kg of NaOH per ton of lignocellulosic material, 10% of consistency and 0, 3, 6 and 9 kg of talc per ton of lignocellulosic material. Then all the proceedings described in the end of consistency optimization were done. The lipophilic content removed by the talc was measured by liquid-liquid extraction of the XMC applying nonpolar solvent dichloromethane.

2.2.5. XMC extracts treatment with Lipase

Different charges of lipase (Lipozyme® CALB) were tested (3; 5 and 8 kU/g) for 2, 4 and 6 hours of reaction. The temperature and pH were kept constant at 45 °C and 7, respectively. The enzymatic treatment was performed with 50 g of absolutely dry lignocellulosic material, under the following conditions: 10% of consistency and NaOH charge sufficient to maintain pH of 7.

2.2.6. Activation with xylanase enzymes and hydrogen peroxide for XMC molecular weight control

For activation with the enzymes (Buckman PE-xx72), a charge of 3.5 kU xylanase per gram of XMC was evaluated for a reaction period of 8 hours at 60 °C temperature and pH 6. The enzymatic treatment was performed with 50 g absolutely dry of lignocellulosic material at 10% of consistency.

The extraction with hydrogen peroxide addition was performed with 50 g of absolutely dry lignocellulosic material

under the following conditions: 70 °C; 4 hours, 10% of consistency, 160 kg of NaOH and 45 kg of H₂O₂ per ton of lignocellulosic material.

At the end of the extractions, the XMC was extracted by filtering. Then the XMC was stored and the residue was washed twice with an equivalent of 4.5 m³ of distilled water per ton of dry lignocellulosic material. The fractions of XMC (initial XMC and after the wash) were mixed, and the generated sample of XMC were centrifuged again and directed to the organic solids content and viscosity analysis.

The viscosity of the XMCs was measured by a Brookfield viscometer, model DV-II + Pro LV - Spindle SC4-18 - 25 °C - 100RPM. The principle of the method is based on measuring the torque caused by the rotational movement of a Spindle in the fluid for testing. The viscosity is proportional to the outflow resistance according with Equation 1:

$$T = n \times dG/dT \quad (\text{Equation 1})$$

where

T = Shear stress needed to produce the outflow

n = Viscosity coefficient

dG/dT = Shear rate

The result is expressed in cP viscosity and torque percentage

2.2.7. XMC mass balance

The extraction to obtain XMC Mass Balance was performed under the following conditions: 70 °C, 4 hours, 10% of consistency and 160 kg of NaOH per ton of lignocellulosic material. At the end of the extraction the XMC was diluted to 5% consistency and centrifuged for one hour, 4000 rpm (2647 x g). Three phases were obtained, F1, F2 and F3.

The F1 phase is the supernatant of the centrifugation and, therefore, the soluble fraction named XMC SB. The F2 is the solid phase which is suspended with the XMC when the centrifugation step is not performed. The F3 phase is the unreacted residue with NaOH, which, therefore, was not solubilized. The three phases, F1, F2 and F3 were directed to the organic solids content analysis.

2.2.8. Cationic reverse flotation performance test

The flotation tests were performed in the laboratory using a flotation cell: model CFB-1000-E, brand CDC. The flotation was performed in a cuba of 1.250 L with addition of water which added to the volume of reagents results in the consistency predetermined. Following, the depressant agent prepared to 1% was added. The conditioning time was 5 min; after this time the collector (EDA Amine-C Clariant) to 1% conditioned 1 min was added.

The flotation was carried out by adding a replenishment solution with the same pH of the flotation trying to keep the pulp level constant. Then, the procedure for drying the residue and the concentrate in an oven at 105 °C for 12 hours was carried out. After complete drying, the mass recovery was determined.

Iron ore conditions were 60% of conditioning solids; 40% of flotation solids; 1200 rpm conditioning rotations; 1200 rpm of flotation rotation; and final pH of 10.5. The aliquots of the products were sent for XRF chemical analysis.

3. RESULTS AND DISCUSSION

3.1. Raw material chemical characterization

3.1.1. Lignocellulosic material

In regard to lignocellulosic CL feedstock, besides the major biomass components, such as cellulose, hemicellulose, and lignin, there are also minor components, which may include protein, starch, ash, organic acids, and other non-structural materials. Although, individually, these components represent only a small raw material fraction, their presence may develop a significant pattern in a bio-refinery industrial-scale operation. The characterization of the lignocellulosic CL is described in Table 1.

Table 2. Iron ore characterization by XRF.

Iron ore	Fe ₂ O ₃ (Fe), %	SiO ₂ , %	Al ₂ O ₃ , %	P, %	Mn, %	TiO ₂ , %	CaO, %	MgO, %	Mass loss (1000 °C), %	Total, %
V	81.8 (57.2)	16.5	0.7	0.04	0.06	0.11	0.02	<0.1	1.0	100.1

Note that iron ore impurities content is mostly composed of quartz (SiO₂). The other compounds represent less than 1% of the impurities.

3.2. Optimization of alkaline extraction consistency

To determine the best consistency, it was varied in 10, 15 and 20% of biomass over dry, named XMC 1, XMC 2 and XMC 3, respectively. After the treatments, the three tests yield were 84.4, 70.6 and 69.7% for XMC 1, XMC 2 and XMC 3, respectively, and the organic solids content were 6.0, 6.6 and 7.7% for XMC 1, XMC 2 and XMC 3, respectively.

Table 1. Chemical characterization of lignocellulosic material.

Components	Lignocellulosic Material Composition (%)
Arabinan	11.18
Galactan	2.95
Glucan	30.19
Xylan	16.43
Mannan	0.68
Soluble Lignin	6.80
Insoluble Lignin	3.58
Uronic acid	0.89
Acetyl Groups	1.74
Total Extractives	14.04
Ash	0.89

In general, the lignocellulosic material chemical composition obtained in this study is similar to other reported characterization (Chanliaud, et al., 1995; Schell, et al., 2004; Kálmán, et al., 2006). Hemicelluloses, total lignin, and ash contents are in accordance with the range usually experienced.

3.1.2. Iron ore

To evaluate the efficiency of flotation it is necessary to know the iron content (Fe₂O₃) and impurities (SiO₃, Al₂O₃, P, Mn, TiO₂, CaO, MgO) that composes the iron ore. This characterization of the iron ore is described in Table 2.

An increase of the organic solids with increasing extraction consistency was observed. However, as the yield of extraction is a relation of organic solids content with the consistency (liquid volume in extraction), the yield decreases as consistency increases. Thus, despite the increase in organic solids, this increase is not enough to maintain or increase the extraction yield. Because of this, the XMC production was done at 10% of dry biomass consistency.

3.3. Characterization of lignocellulosic material lipophilic fraction by GC-MS

A typical GC-MS chromatogram obtained for lignocellulosic material CL is shown in Figure 1.

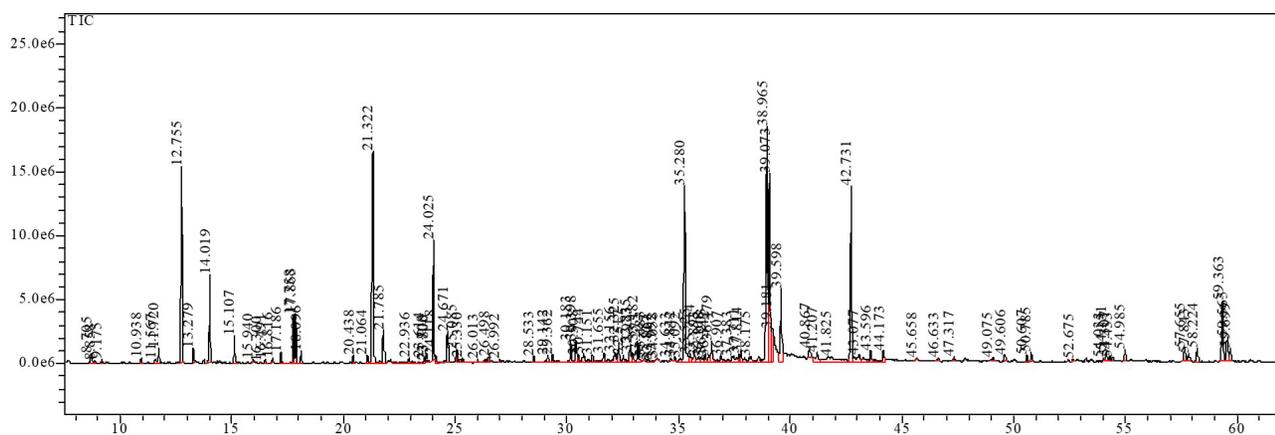


Figure 1. chromatogram obtained for lignocellulosic material by gas chromatography coupled to mass.

Approximately, about 80 compounds were detected, of which alcohols, fatty acids, aromatics, steroids, hydrocarbons and carbohydrates stand out. As expected, quantitatively, the fatty acids represent 55% of the resulting concentration of these compounds present in the sample.

Under the conditions described for the chromatography in the gaseous phase method, the Hexadecanoic acid (627.95 mg/kg) was the first to be identified. Then, the chromatogram showed the cis, cis-9,12-octadecadienoic acid (801.32 mg/kg), trans-9-Octadecenoic acid (590.64 mg/kg), Octadecanoic

acid (215.86 mg/kg) and finally the cis-9-Octadecenoic acid (138.86 mg/kg), that are similar to the compounds found by Pastor et al. (2020) in corn. These results demonstrate that the size of the chain fatty acids exerts a greater influence on the elution order than the number of unsaturation, ie, lower chain, lower chromatographic retention time.

Figure 2 shows the total concentration of all components that compose each identified class, alcohols, fatty acids, aromatics, steroids, hydrocarbons, carbohydrates and also compounds which were not identified by the library (UD).

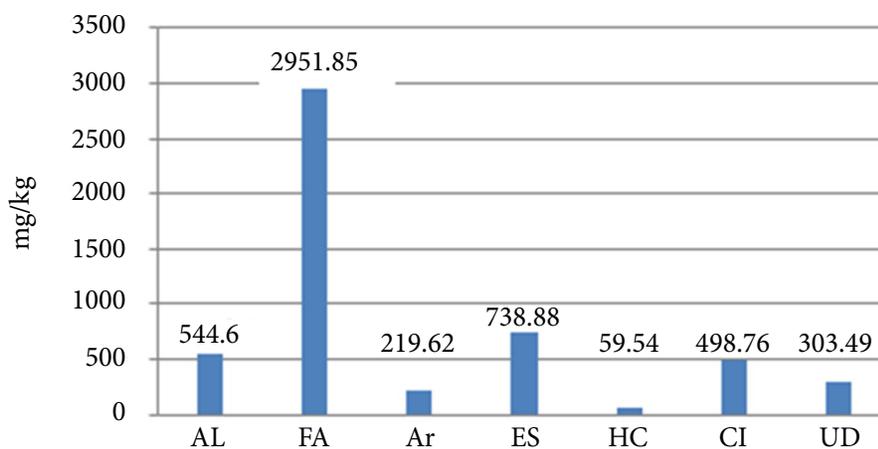


Figure 2. Distribution of chemical compound classes in corn leaf extracts as determined by GC-MS. AL = alcohols, FA = fatty acids, Ar = aromatic, Es = esteroids, HC = Hydrocarbons, CI = carbohydrates, UD = unidentified.

3.4. *In situ* removal of XMC lipophilic fraction with talc

The addition of talc in the alkaline extraction step is an alternative to decrease the content of the lipophilic materials in the XMC. The samples were named as 4, 5 and 6, respectively,

XMC SB + 3 kg/t of talc, XMC SB + 6 kg/t of talc + XMC SB and 9 kg/t of talc. The solids content and yield results were about 4.0 % of solids content for all the samples, and the sample with 9 kg/t of talc (6) had the less solid content, about 3.8 % and yield was about 74.3 % for the control sample (1), 73.6, 70.2 and 68.4 % for 4, 5 and 6, respectively.

It was no surprise that the addition of talc slightly decreased the organic solids content, since the lipophilic fraction was being removed. However, the talc charge of 9 kg per ton of lignocellulosic material reduces the yield considerably. This observation indicates a need for further studies aimed at understanding this behavior.

A way of evaluating the lipophilic removal is by quantifying the content of such materials in the lignocellulosic raw material, and also in the components of the alkaline extraction. The lipophilic substances percentage were 21.5, 16.2, 12.8, 10.2 % for samples 1, 4, 5 and 6, respectively, and the wastes for these same samples were, respectively, 78.2, 82.5, 89.4 and 92.8 %, with a total around 100 %, showing a close mass balance.

The content of lipophilic substances in XMC decreased from 21.5%, in the reference, to 10.2% in the XMC with talc

addition of 9 kg per ton of lignocellulosic material (6). This decrease was accompanied by the increase in the lipophilic material concentration present in the waste. With the purpose of certifying the influence of lipophilic substances present in the XMC, the flotation with XMC 1 and XMCs 4 through 6 was performed. The results are presented on Table 3. The results concerning iron and silica content in the residue (RJ) and in the concentrate (CO), mass recovery, and metallic recovery.

The results of Table 3 indicate that the addition of talc hindered the flotation performance, which leads to the conclusion that the lipophilic fraction removed by the talc, was not being prejudicial to the process and that a new method of lipophilic removal must be evaluated. Hence, a lipase enzyme was evaluated in order to decrease XMC lipophilic content.

Table 3. Effect of lipophilic substances content on XMC flotation performance.

XMC	Depressant dosage (g/t)	EDA dosage (g/t)	pH	Fe CO (%)	Fe RJ (%)	SiO ₂ CO (%)	SiO ₂ RJ (%)	Massic Rec. (%)	Metallic Rec. (%)
1				67.2	39.4	2.5	41.4	63.3	75.2
4	400	60	10.5	66.6	43.8	3.0	35.3	57.2	68.5
5				66.7	42.7	2.7	36.7	58.8	70.4
6				66.9	43.3	2.6	35.6	56.8	68.9
Starch	800	60	10.5	67.3	36.5	2.4	44.4	65.0	79.0
Original Material (Costumer V)				57.2		16.5		-	-

XMC 1: XMC SB; XMC 4: XMC SB + 3 kg/t talc; XMC 5: XMC SB + 6 kg/t talc; XMC 6: XMC SB + 9 kg/t talc

3.5. XMC extracts treatment with Lipase for lipophilic materials removal

The lipase enzyme acts as a pre-treatment before the alkaline extraction phase and has the same role as talc, which is to remove the lipophilic fraction present in the XMC. The percentages of the lipophilic substances present in the XMC without any treatment (test 1) and with lipase action (tests 7 - 15) are presented in Table 4.

The pretreatment that provided greater lipophilic reduction was when a lipase charge equal to 8 kU/g and 6 hours of reaction was used. Therefore, the flotation tests were done in XMC samples in all enzyme charge for 6 hours reaction time. The results are shown in Table 5. The results concerning iron and silica content in the residue (RJ) and in the concentrate (CO), mass recovery, and metallic recovery.

The results of Table 5 indicate that the addition of lipase did not influence the performance of flotation, which leads to

the conclusion that the lipophilic fraction, which had lipase removed, was not detrimental to the process and that a new lipophilic removal method must be evaluated.

Table 4. Lipophilic fraction present in the XMC before and after pre-treatment with lipase.

ID	Samples	Lipophilic XMC, %
1	SB	21.5
7	L3 - 2	11.6
8	L3 - 4	9.9
9	L3 - 6	9.3
10	L5 - 2	7.8
11	L5 - 4	7.2
12	L5 - 6	6.1
13	L8 - 2	7.5
14	L8 - 4	5.8
15	L8 - 6	4.9

Lx - y, where x is Lipase charge in kU/g and y is the lipase reaction time.

Table 5. Effect of the Lipase dosage associated to its performance in flotation.

XMC	Depressant dosage (g/t)	EDA dosage (g/t)	pH	Fe CO (%)	Fe RJ (%)	SiO ₂ CO (%)	SiO ₂ RJ (%)	Massic Rec. (%)	Metallic Rec. (%)
1				67.2	39.4	2.5	41.4	63.3	75.2
9	400	60	10.5	66.9	42.0	2.7	37.9	59.8	71.4
12				66.8	40.6	2.4	39.5	61.7	74.0
15				66.5	39.3	2.8	41.4	62.7	76.4
Starch	800	60	10.5	67.3	36.5	2.4	44.4	65.0	79.0
Original Material (Costumer V)				57.2		16.5		-	-

XMC 1: XMC SB; XMC 9: XMC SB + Lipase 3 kg/t; XMC 12: XMC SB + Lipase 5 kg/t; XMC 15: XMC SB + Lipase 8 kg/t

3.6. Lignocellulosic material activation with xylanase enzymes and hydrogen peroxide

The xylanase enzyme applied as a pre-treatment before the alkaline extraction phase has the same goal as hydrogen peroxide treatment, which is decreasing XMC molecular weight. The decrease in the molecular weight was measured by following the XMC viscosity behavior.

According to the results it was possible to affirm that the hydrogen peroxide (test 17: 6.3 cP) was more effective in reducing the viscosity, or molecular weight, than the xylanase enzyme (test 16: 10.2 cP), and both showed an efficient reduction comparing with the sample control (test 1: 11.8 cP). The flotation performance is shown in Table 6. The results concerning iron and silica content in the residue (RJ) and in the concentrate (CO), mass recovery, and metallic recovery.

Table 6. Effect of adding the xylanase and hydrogen peroxide on XMC flotation performance.

XMC	Depressant dosage (g/t)	EDA dosage (g/t)	pH	Fe CO (%)	Fe RJ (%)	SiO ₂ CO (%)	SiO ₂ RJ (%)	Massic Rec. (%)	Metallic Rec. (%)
1				67.2	39.4	2.5	41.4	63.3	75.2
16	400	60	10.5	65.7	36.1	4.7	46.1	70.9	81.9
17				65.7	34.4	4.2	48.5	71.7	83.5
Starch	800	60	10.5	67.3	36.5	2.4	44.4	65.0	79.0
Original Material (Costumer V)				57.2		16.5		-	-

XMC 1: XMC SB; XMC 16: Pre-treatment with xylanase – XMC SB; XMC 17: XMC SB + 45 kg/t of H₂O₂

The use of the xylanase as a pretreatment to the alkaline extraction and XMC production led to a reduction of the iron content in the concentrate and also an increase in the concentrated silica. However, the weight and metal recovery were higher when compared to the reference (XMC 1) and the starch. The behavior of XMC with added hydrogen peroxide was similar to the xylanase.

Both parameters reached XMC's produced above the starch. However, further studies are required to complete more clearly the performance of these XMC's.

3.7. XMC mass balance

The mass balance was performed to determine the percentage of fractions (F1, F2 and F3) present in the lignocellulosic material CL. Also, to evaluate each one of the fractions regarding

their flotation performances. According to the results it is interesting to observe that the mass balance reached 100.1% of mass recovery. Fraction F1 (49.7 %) is the soluble part (supernatant), which is the XMC SB. The fractions F2 (27.1 %) and F3 (23.3%) are the precipitate of the centrifugation. The F2 was characterized as the XMC part in suspension that can be separated using centrifugation. The F3 is the material that was not made soluble during the alkaline extraction.

The next step was to evaluate the impact of each of these fractions on the flotation performance. The results are presented in Table 7. The results concerning iron and silica content in the residue (RJ) and in the concentrate (CO), mass recovery, and metallic recovery.

According to Table 7, the flotation performance for fractions F2, F3 and F2 added to F1 were inferior to the XMC SB suggesting that these tests are not significant.

Table 7. Flotation performance of the Mass Balance different fractions.

ID	Depressant dosage (g/t)	EDA dosage (g/t)	pH	Fe CO (%)	Fe RJ (%)	SiO ₂ CO (%)	SiO ₂ RJ (%)	Massic Rec. (%)	Metallic Rec. (%)
XMC SB				67.2	39.4	2.5	41.4	63.3	75.2
F1				66.8	39.9	2.6	40.7	63.1	75.2
F2	400	60	10.5	66.4	46.3	3.0	32.2	52.6	63.0
F3				66.1	45.2	2.9	33.7	54.6	66.1
F1+F2				66.6	43.2	2.8	36.3	58.9	69.6
Starch	800	60	10.5	67.3	36.5	2.4	44.4	65.0	79.0
Original Material (Costumer V)				57.2		16.5		-	-

Condition: Rotation per minute equal to 1200

4. CONCLUSIONS

Iron ore materials have different chemical compositions. Because of this variety, it was concluded that there would always be a need for optimization for each ore working provided by the mining company. According to this work, it was possible to identify some of the points needed to produce a XMC, with high performance depressant for iron ore flotation. The addition of talc as an additive to the alkaline extraction step or the performance of a pretreatment with lipase in order to remove fatty acids from XMC SB, did not improve the performance of XMC as depressant for iron ore flotation process. The use of the xylanase as a pretreatment to the alkaline extraction, at the XMC production led to a reduction of the iron content in the concentrate and also a silica increases in the concentrated. However, the massic and metallic recovery were higher when compared to XMC SB and to starch. The behavior of XMC treated with hydrogen peroxide was similar to the XMC treated with xylanase.

SUBMISSION STATUS

Received: 13 Dec. 2021

Accepted: 31 Aug. 2022

Associate editor: Fernando Gomes 

CORRESPONDENCE TO

Julia de Cristo Figueiredo

Universidade Federal Rural do Rio de Janeiro/Instituto de Florestas/
Departamento de Produtos Florestais BR 465 Km 7, CEP 23897-
000, Seropédica, RJ, Brasil

e-mail: juliacristofigueiredo@gmail.com

AUTHORS' CONTRIBUTIONS

Marcelo Moreira da Costa: conceptualization (Equal), Project administration (Equal), Supervision (Equal), Writing – review & editing (Equal).

Robisnéa Adriana Ribeiro: conceptualization (Equal), Data curation (Equal), Formal analysis (Equal), Investigation (Equal), Methodology (Equal), Resources (Equal), Supervision (Equal), Writing – original draft (Equal).

Thalita Mendonça de Resende: conceptualization (Equal), Formal analysis (Equal), Methodology (Equal).

Julia de Cristo Figueiredo: conceptualization (Equal), Data curation (Equal), Formal analysis (Equal), Investigation (Equal), Resources (Equal), Writing – review & editing (Equal).

REFERENCES

- Aguiar MAM, Furtado RM, Peres AEC. Seletividade na flotação catiônica reversa de minério de ferro. *Holos* 2017; 6: 126-135.
- Arantes RS, Lima RMF. Comparative Studies of Inverse and Direct Flotation of a Brazilian Low Grade Iron Ore. In: XIII International Mineral Processing Symposium. Bodrum, Turkey, 2012.
- Arenzon A, Neto TJP, Gerber W. Manual sobre toxicidade em efluentes industriais. Environment Council. Porto Alegre, Brazil, 2011.
- Boonchuay P, Techapun C, Leksawasdi N, Seesuriyachan P, Hanmoungjai P, Watanabe M, Takenaka S, Chaiyaso T. An integrated process for xylooligosaccharide and bioethanol production from corncob. *Bioresour Technol.* 2018; 256:399–407.
- Cassola MS, Bartalini NM. Comportamento de coletores para o tratamento dos minérios de ferro através da flotação reversa. *Tecnologia em Metalurgia e Materiais* 2010; 6: 215-219.
- Chanliaud E, Saulnier L, Thibault JF. Alkaline extraction and characterisation of heteroxylans from maize bran. *Journal of Cereal Science* 1995; 21(2): 195-203.
- Chen H, Liu J, Chang X, Chen D, Xue Y, Liu P, Lin H, Han S. A review on the pretreatment of lignocellulose for high-value chemicals. *Fuel Process Technol.* 2017; 160: 196–206.
- Costa MM, Lagsch JE, Morais PH, Moore L. Depressants for mineral ore flotation. US9421556B2. 2016 Aug. 23.
- Del Rio JC, Gutierrez A, Gonzalez-Vila FJ, Martin F, Romero J. Characterization of organic deposits produced in the kraft pulping of Eucalyptus globulus wood. *Journal of Chromatography A* 1998; 823: 457-465.

- Freire CSR, Silvestre AJD, Neto CP. Identification of new hydroxy fatty acids and ferulic acid ester in the wood of *Eucalyptus globulus*. *Holzforshung* 2002; 56(2): 143-149.
- Huang H-J, Ramaswamy S, Tschirner UW, Ramarao BV. A review of separation technologies in current and future biorefineries. *Sep Purif Technol.* 2008; 62: 1-2.
- Kálmán G, Recseg K, Gaspar M, Réczey K. Novel approach of corn fiber utilization. In *Twenty-Seventh Symposium on Biotechnology for Fuels and Chemicals* 2006; 738-750.
- Kawatra SK. *Froth Flotation – Fundamentals Principles*. Mining engineering handbook. 3rd ed. Edited by: Darling, Peter, U.S.; 2011.
- Marinelli PS, Frollini E, Bernardo AS, Bernardo L. Emprego de amidos de milho catiônico comum e híbrido como auxiliares de coagulação / floculação. XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental. Porto Alegre, Brazil, 2000.
- Nascimento DR. *Flotação aniônica do minério de ferro [dissertação]*. Ouro Preto: Universidade Federal de Ouro Preto, 2010.
- Norman AG. The determination of lignin: acid pretreatment and the effect of the presence of nitrogenous substances. *Biochemical Journal* 1937; 31(9): 1567.
- Norman AG, Jenkins SH. The determination of lignin: errors introduced by the presence of certain carbohydrates. *Biochemical Journal* 1934; 28(6): 2147.
- Pastor K, Ilić M, Vujić D, Jovanović D, Ačanski M. Characterization of Fatty Acids in Cereals and Oilseeds from the Republic of Serbia by Gas Chromatography–Mass Spectrometry (GC/MS) with Chemometrics. *Analytical Letters* 2020; 53(8): 1177-1189.
- Pearse MJ. An overview of the use of chemical reagents in mineral processing. *Minerals engineering* 2005; 18(2): 139-149.
- Peng F, Ren J-L, Xu F, Bian J, Peng P, Sun R-C. Comparative study of hemicelluloses obtained by graded ethanol precipitation from sugarcane bagasse. *J Agric Food Chem.* 2009; 57: 6305–17.
- Peterson CJ, Walde AW, Hixon RM. Effect of temperature on sulfuric acid method for lignin. *Industrial & Engineering Chemistry Analytical Edition* 1932; 4(2): 216-217.
- Rabockai T. *Físico-Química de superfícies*. São Paulo: Instituto de Química da Universidade de São Paulo: 128; 1979.
- Santos ID. *Utilização do ácido húmico como agente depressor da hematita na flotação de minério de ferro [dissertação]*. Rio de Janeiro: Universidade Federal do Rio de Janeiro; 2006.
- Schell DJ, Riley CJ, Dowe N, Farmer J, Ibsen KN, Ruth MF, et al. A bioethanol process development unit: initial operating experiences and results with a corn fiber feedstock. *Bioresource Technology* 2004; 91(2): 179-188.
- Skoog DA, Holler FJ, Nieman TA. *Princípios de análise instrumental*. 5th ed. São Paulo: Bookman; 2002.
- Sluiter JB, Ruiz RO, Scarlata CJ, Sluiter AD, Templeton DW. Compositional analysis of lignocellulosic feedstocks. Review and description of methods. *Journal of agricultural and food chemistry* 2010; 58(16): 9043-9053.
- Souza Pinto TC, Souza AS, Batista JNM, Sarkis AM, Leal Filho LDS, Pádua TFD, Béttega R. Characterization and drying kinetics of iron ore pellet feed and sinter feed. *Drying Technology* 2021; 39(10): 1359-1370.
- Stapelfeldt F, Lima RMF. Recycling of process water containing amines in the reverse flotation of iron ores. *International Mine Water Association Symposium* 2001; 1-10.
- Turrer HDG. *Polímeros depressores na flotação de minério de ferro [tese]*. Belo Horizonte: Universidade Federal de Minas Gerais, 2007.