

Integrated production of furfural and silica from rice husk

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Abstract

The main purpose of this work is to study the integrated process of the production of furfural and silica from agricultural wastes as raw material, particularly rice husk, and other substrates such vine leaves, grass and pine sawdust.

In order to maximize furfural production, several parameters were studied, namely concentration, mode of acid addition, and the use of metal chlorides as catalyst. The best result obtained corresponds to using as a catalyst, 25 g of NaCl, 5.4 M of hydrochloric acid (HCl), added drop by drop, with an yield equal to 9,1 %.

On the other hand, silica extraction always involves a basic attack step with sodium chloride (NaOH), of the substrate with or without furnace treatment. From the experiments carried out, it was possible to conclude that the best result was obtained when the raw material, rice husk or solid residue after furfural production, was previously taken to the furnace.

This study allows concluding that it is possible to produce both silica and furfural in an integrated process where the residue obtained from the organic process is used in the silica extraction process.

Keyword: rice husk, furfural, amorphous silica, hemicellulose

1 Introduction

Nowadays, there is great concern about the responsible management of available resources and the reduction of environmental impacts caused by the production of solid, liquid and gaseous effluents.

Thus, in recent years, it has become necessary to use new raw materials to replace the use of fossil fuels, being this change important in environmental and economic level. These new materials can be agricultural residues, since they are one of the largest areas of solid waste production in the world, coming, for example, from the production of rice, oats, corn, among others.

There is a wide variety of forest materials, vegetable and agricultural residues that allow the furfural production at a low cost, such a rice straw [1], corn cob, cotton husks, bagasse, beech bark, sunflower hull [2], larch-tree needles [3], oat husk [4]. In addition, it is also possible to produce furfural by xylose solutions [5].

The work developed focused on the use of rice husk as raw material for the furfural production and subsequent silica extraction, since it is a

material whose composition encompasses not only the pentosans present in hemicelluloses, which allow the furfural production, but also silica.

The composition of the rice husk is shown in Table 1 [6]. The figures given in the table depend on various factors such as the type of soil where the plant is planted, the type of products used, such as pesticides, insecticides and fertilizers, the environmental and geographical conditions of production, as well as the type of rice produced. Regardless of all the factors presented, the cellulose and hemicelluloses corresponds between 55 to 60 % and lignin corresponds to 22 % [7]. In addition, this agricultural residue contains minority compounds, such as ash consisting essentially of silica, more than 90 % [8], calcium, iron, manganese and potassium.

If biomass is used as the raw material for the furfural production in an acid medium, two reactions occurs in series, i.e., the lignocellulosic part of the hemicelluloses is transformed into pentoses, which reaction is designated by acid hydrolysis, and subsequently the pentoses are transformed into furfural, this reaction is called dehydration.

Table 1- Rice husk composition.

Composition	Percentage
Cellulose	31.12
Hemicellulose	22.48
Lignin	22.34
Mineral ash	13.87
Water	7.86
Extractives	2.33

Table 2 shows some experimental conditions present in the literature for the furfural production from biomass as raw material.

Table 2- Operating conditions for furfural production.

Acid	C _{acid}	T (°C)	T _{reaction} (min)	η	
H ₂ SO ₄	0.05-0.25 M	220-240	-	50-65 %	[9]
H ₂ SO ₄	6 w%	120	15	0.87 g _{furfural} /L	[10]
H ₂ SO ₄ /HCl	0.25-8 w%	80-220	10-2000	15 %	[11]
HCl	6 w%	122	70	2.0 g _{furfural} /L	[12]
HNO ₃	6 w%	122	9,3	1.32 g _{furfural} /L	[13]
H ₃ PO ₄	6 w%	134	300	0.13 g _{furfural} /g	[14]
HCl	6 M	110	≅120	6-7 %	[15]

In all of above cases the solvent used was water. However, there are some experiments in the literature that use organic solvents [16], thus avoiding the production of acidic effluent, ionic liquid [17], or biphasic systems [18] [19].

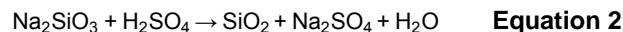
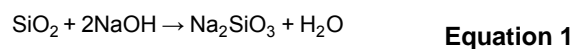
In the furfural production various substances can be used as catalysts, such oxides [20], organic acids [21] [22] [23], metal chlorides [24] [25] [26] or even solid catalysts [27] [28].

In the present study, the experimental conditions explained in the previous table were used, namely, 200 mL of a 6 M aqueous solution of HCl, working at 110 °C, boiling temperature of the mixture, and atmospheric pressure [15]. It should be noted that the conditions mentioned above were those used as the starting point for the present work, and the use of different metal chlorides as catalysts was also studied.

Furfural has several applications, such as solvent, fuel, gasoline additive and lubricant [29], and can also be used as an intermediary in the synthesis of pharmaceuticals, chemicals, plastics and agricultural products, such fertilizers and fungicides. In addition, it is also used in the food industry, in particular to enhance the taste of different foods, such wines and juices [24].

On the other hand, there are several methods in the literature, Table 3, which allow the extraction of the silica either in the amorphous form or in the crystalline form or even a mixture of both, starting from either the rice husk or rice husk ash. Thus,

the method chosen in the present study consists of the extraction of silica through a basic attack (Equation 1) to the residue obtained after the furfural production followed by an acid neutralization where a silica gel is formed (Equation 2).



Silica is used in different applications, depending on its degree of purity, namely, in silicon nanostructures [30], such nanoelectronics [31], photonics [32], biotechnology (e.g. biosensors) [33] and photovoltaic cells [34]. This compound can also be used in the production of catalysts, namely, in supported catalysts [35], in ceramics and in composite materials [36].

Table 3- Operating conditions for silica extraction.

Raw material	Procedure
Rice husk [37]	-Treatment with HCl; -Burn or furnace;
Rice husk [37]	- Treatment with HCl; -Burn at 1000 °C;
Rice husk [37]	- Treatment with NaOH; -Filtration; -Precipitation with HCl;
Rice husk [38]	-Combustion of rice husk; -Acid leaching; -Incineration under atmospheric conditions;
Rice husk [38]	-Washing with H ₂ O; - Treatment with HCl; -Incineration; -Extraction with NaOH; -Precipitation;
Rice husk ash [38]	-Acid leaching; -Extraction with NH ₄ F; -Acid precipitation;
Rice husk ash [38]	- Acid leaching; -Extraction with NaOH; -Precipitation with HCl; - Washing with H ₂ O;

2 Experimental

2.1 Furfural production

To quantify the obtained furfural, spectrophotometry was used. This method is based on the reaction between the aniline, acetic acid and furfural, in acidic medium, according to the Stenhouse reaction [39], where a pink compound is formed which absorbs in the visible light zone of the spectrum.

This method is affected by several factors, for example, the pH of the solution, the temperature and the presence of interfering species in solution. Thus, the pH of the samples for analysis was kept equal to 1 and these were prepared at a

temperature equal to 25 °C and then placed in the dark for 15 minutes.

Each sample for analysis has a total volume of 10 mL and consists of: 4 mL of X solution, 1 mL of ethanol and depending on the pH value of the distillate so the quantity that pipette, making the remaining volume up to 10 mL with water.

Solution X is composed of aniline, acetic acid and ethanol in a volume ratio of 0.24:0.49:3.27, based on the values expressed in the literature [40].

2.2 Silica extraction

In order to proceed with the silica extraction, two types of substrates were used as the raw material, namely the rice husk and the solid residue remained in the reactor after the furfural production. These were used with and without furnace treatment.

The experimental procedure followed is described in the literature [41]. However, some changes were made, namely, during the reaction with NaOH, 5 mL of water were added every 20 min so that the reactor does not stay dry. After silica was obtained and partially dried it was milled and finally, after drying, it was washed to remove the salts formed and dried again.

The temperature program used in the furnace is described in Figure 1, which has been chosen based on the literature [42], making some pertinent changes.

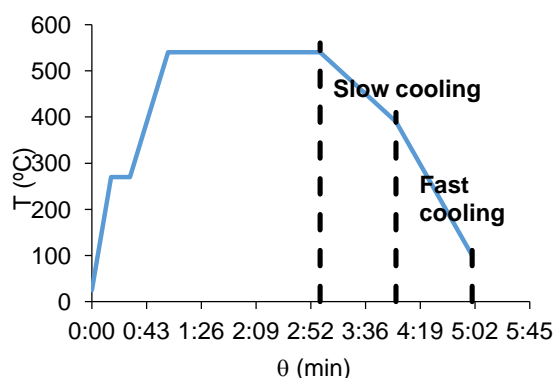


Figure 1- Temperature program used in the present study for the heat treatment of rice husk and solid residue after furfural production.

To characterize the obtained silica, the X-ray diffraction was used.

3 Results and discussion

3.1 Furfural production

As described previously, the furfural production in an acid medium starting from the rice husk, was carried out at the boiling temperature, at atmospheric pressure and the raw material mass was 25 g. The concentration of the aqueous acid

solution, the way it was added to the reaction medium and the possible use of catalyst were varied.

As mentioned, in some tests metal chlorides were used as catalyst, in particular sodium chloride (NaCl), aluminium chloride (AlCl₃) and magnesium chloride (MgCl₂). When the metal chloride used as catalyst was altered it was intended that the number of equivalent would remain unchanged.

The yield was obtained using Equation 3.

$$\text{Yield (\%)} = \frac{m_{\text{furfural}} \text{ (g)}}{m_{\text{rice husk}} \text{ (g)}} \times 100 \quad \text{Equation 3}$$

3.1.1 Effect of concentration and mode of acid addition

The furfural production study was started by evaluating the acid concentration that maximized this process and how it was added to the reaction medium, i.e. whether it would be added before the heating was started to initiate the reaction (beginning of the test) or if part would be added before the reaction was started and the remainder would be placed in a dropping funnel and added drop by drop to the reaction medium (drop by drop). The results obtained are shown in Table 4.

Table 4- Variation of furfural yield and furfural concentration with the HCl concentration and without catalyst.

	Test	C _{ácido} (M)	C _{furfural} (g/L)	η (%)
Beginning of the test	18	4.5	8.6	3.8
	4	5.4	13	7.3
	3	6.0	4.8	2.9
	5	6.3	0.5	0.3
Drop by drop	17	4.5	10	4.4
	63	5.4	8.3	5.0
	6A	6.0	2.9	1.7

Considering the results presented, it can be seen that in both methods, i.e. either where the addition of the acid was done drop by drop or in the case where the addition was made at the beginning of the test, the total acid concentration which maximized the furfural production corresponding to 5.4 M. For the experiments carried out drop by drop this discrepancy is not so obvious.

The choice of the way to add the acid to the reaction medium is very difficult, since there are cases where drop by drop is more favourable and others where the opposite is true. However, taking into account only the experiments using 5.4 M acid, that maximizes the furfural production, it can be concluded that the best way to add the acid to the reaction medium is at the beginning of the reaction.

3.1.2 Effect of the presence of the catalyst/NaCl

According to the literature [24] the metal chlorides could be used as catalyst. Thus, sodium chloride was chosen for the first studies on the influence of the catalyst on the production of furfural. The results obtained are shown in Table 5.

Table 5- Variation of furfural yield with the NaCl mass when HCl (5.4 M) was used as acid.

	Test	m_{NaCl} (g)	C_{furfural} (g/L)	η (%)
Beginning of the test	43	0	9.2	5.5
	53	25	7.8	4.8
	63	0	8.3	5.0
Drop by drop	21	12.5	2.7	1.6
	24	25	5.7	3.0

Based on the results in Table 6, it is possible to verify that in both whatever the way of adding the acid, the best results were obtained when no catalyst was used. Comparing the tests whose acid addition was done drop by drop and where NaCl was used it is verified that for 25 g of this salt the result obtained is higher than the result obtained for 12.5 g.

3.1.3 Effect of NaCl and HCl

Although the furfural production is maximized when the NaCl is not used, it was decided to study the joint effect of this salt with the variation of the total concentration of HCl, and if the previous dissolution of the salt (NaCl) before it was added to the reactor had an influence on the furfural formation. The results obtained are shown in Table 6.

Considering the results presented in the table, it can be seen that in the presence of NaCl and for different modes of acid addition the total concentration of acid that maximizes furfural production is 5.4 M.

If one considers only the results whose acid addition was made drop by drop it is possible to verify that in the case in which NaCl was added to the reactor in solid form the total acid concentration that maximizes the furfural production corresponds to 4.5 M, whereas when NaCl is previously dissolved in water the total acid concentration that maximizes the production corresponds to 5.4 M.

However, this result can be explained by the fact that the values obtained when the acid addition was made drop by drop were less reliable. Due to the strong boiling or even pressure variations within the reactor the dripping of the aqueous acid solution was not uniform in all tests, leading in some experiments to a zero drop addition to the reaction medium.

Table 6- Variation of furfural yield with the HCl concentration when was used 25 g of NaCl.

	Test	$C_{\text{ácido}}$ (M)	C_{furfural} (g/L)	η (%)
w/NaCl	53	5.4	7.8	4.8
Undissolved	10	6.0	7.3	4.4
Beginning of the test	11	6.3	9.5	5.7
w/NaCl	13	4.5	16	8.5
Undissolved	24	5.4	5.7	3.0
Drop by drop	16	3.5	5.2	4.7
dissolved	19	4.2	5.8	4.6
Drop by drop	20	5.4	15	9.1
	15	6.0	9.6	5.8

3.1.4 Effect of other salts as catalyst

At the later stage, the influence of other metal chlorides that could play the function of catalyst was studied: $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$. The results obtained are shown in Table 7.

Considering the results presented it is verified that the test in which a higher value of yield was obtained, in other words, a greater production of furfural corresponds to the test whose added catalyst was the NaCl, this for when the acid was added to the reaction medium in the beginning of the test. Thus, and since the number of equivalents has remained unchanged it can be affirmed that the Cl^- ion had no influence on the reaction, and therefore, the cation (Na^+ , Mg^{2+} and Al^{3+}) influences the formation of furfural. Therefore, due to the above mentioned ratio, the cation which most adversely affected the reaction was Al^{3+} .

Table 7- Variation of furfural yield with the catalyst used, when HCl (5.4 M) was used.

	Test	Catalyst	C_{furfural} (g/L)	η (%)
Beginning of the test	53	NaCl	7.8	4.8
	48	$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	6.6	4.0
	54	$\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$	2.2	1.3
Drop by drop	30	NaCl	5.3	3.2
	25	$\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$	7.7	4.6

3.1.5 Furfural production throughout the test period

In order to study the furfural formation throughout the test, new tests were carried out in which the distillate was collected in separate fractions, i.e. distillate samples of 25 in 25 mL were collected until a final volume of 150 mL was obtained. The results obtained are shown in Figure 2.

It is to be noted that in these tests the acid addition to the reactor was made at the beginning

of the reaction and the catalyst, when used, was added to the reaction medium in solid form.

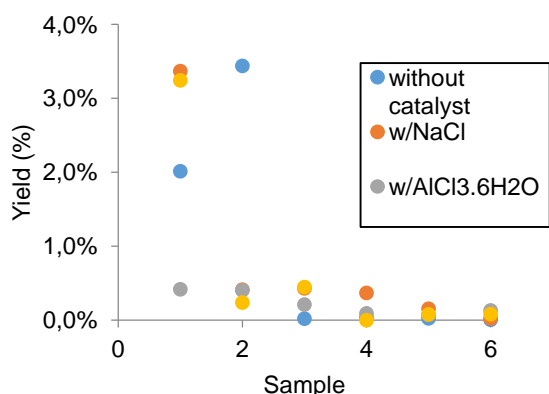


Figure 2- Variation of furfural yield with the catalyst used, when the distillate was collected in samples and the acid used was HCl (5.4 M).

Based on the results presented in the figure, it is possible to verify that in the absence of solid catalyst (test 43), the sample with the highest furfural concentration corresponds to the second sample collected, and in the following the furfural concentration is greatly reduced. However, in the tests in which the different metal chlorides were used as catalyst, it is verified that the highest furfural concentration appears in the first sample and the remaining ones have lower concentration values.

Taking into account only the tests where the catalysts were used it is still possible to verify that the test where a lower yield value was obtained corresponds to the test using AlCl₃.6H₂O, while the test with higher yield value corresponds to the test with NaCl.

The samples collected also had different colors. In the case of the test where no catalyst was used the first three samples had a pink color, while the others had a lighter color, with the last collected sample having a yellowish color. On the other hand, in the tests where the catalyst was used the first three samples collected were purple, the first sample collected being the one with a darker color.

3.1.6 Effect of other acids

As mentioned it was also possible to study the use of different acids in the furfural production, choosing a weak acid, H₃PO₄, and a strong acid, H₂SO₄, where two different concentrations were studied, 2 M and 6 M. The results obtained are shown in Figure 3 and Figure 4, respectively.

Observing the results explained in Figure 3, whose total concentration of acid used corresponds to 2 M, it is possible to verify that the results of three tests performed show the same behavior, since the concentration in furfural increases from the first to the last sample.

However, in the test where the acid used was the HCl or in the test where the acid used was the H₂SO₄ the values obtained are quite close to each other and higher than the values obtained in the test where H₃PO₄ was used, which is of according to the expected result, since the first two acids are strong whereas the last acid mentioned is weak acid.

Analyzing the results schematized in Figure 4, it is possible to verify that these do not present the same behavior among, since in the case of the test in which the acid used was HCl the furfural concentration increases from the first to the second sample, which is the highest furfural concentration, and decreases in the following samples, while in the test where the acid used was H₃PO₄ the furfural concentration increases from the first sample collected to the fourth and decreased in the following samples. In the test where H₃PO₄ with a total concentration of 6M was used, this was terminated before 150 mL of distillate was collected, since the reaction became very violent causing the solid to reach the condenser. Moreover, no test was performed where H₂SO₄ was used with a total concentration of 6 M, since the results obtained for a lower concentration, namely 2 M, present a behavior close the test in which HCl was used.

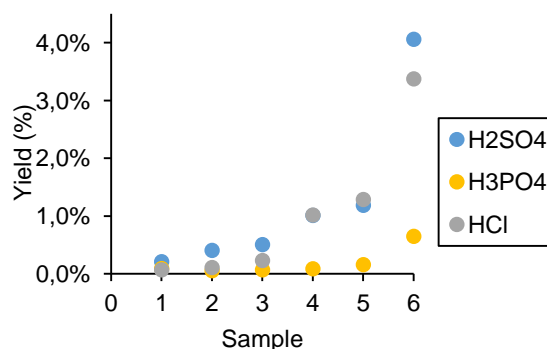


Figure 3- Variation of furfural yield with the acid used (H₃PO₄, H₂SO₄ e HCl (2 M)), without catalyst.

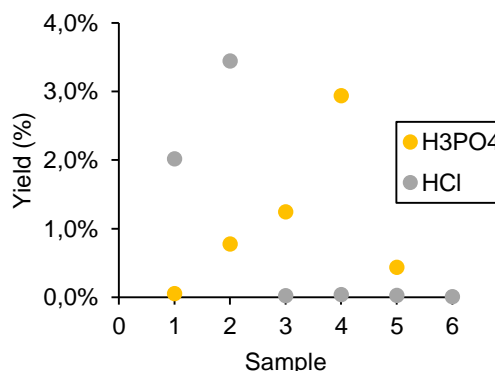


Figure 4- Variation of furfural yield with the acid used (H₃PO₄ e HCl (6 M)) without catalyst.

3.1.7 Other substrates

In the literature, there are several residues from which furfural can be produced. In this work we chose to use pine sawdust, the vine leaf and the grass in two forms, green and after drying, already showing a yellowish aspect. It should be noted that these residues were used as raw material, since they have a large amount of hemicelluloses [43] [44]. From the bibliographical research carried out it was only possible to find works of obtaining furfural from sawdust.

It should be noted that the conditions used for the following tests correspond to the use of an aqueous solution of 5.4 M HCl, being added to the reaction medium at the beginning of the test.

In the table the value of total yield obtained for the different tests are shown, since these were carried out with collection of distillate in samples of 25mL. For all substrates, except pine sawdust, the yield behavior obtained or each sample of distillate collected was similar to the behavior of the rice husk shown in Figure 2. The results obtained for pine sawdust are shown in Figure 5, the results obtained for grass was similar.

Table 8- Variation of furfural yield with the different catalyst and substrates used.

Residue	Yield (%)			
	without catalyst	with NaCl	with AlCl ₃	with MgCl ₂
Vine leaf	3.2	1.4	1.6	2.1
Green grass	5.9	-	-	3.1
Dry grass	16	-	-	4.5
Pine sawdust	4.2	2.4	11	2.9

In all experiments, except those with pine sawdust, the best yield corresponds to no solid catalyst used, which is in accordance with the results shown previously for rice husk.

In this series of tests, the one which presented a higher yield value corresponds to using AlCl₃.6H₂O. The remaining tests have very similar yield values in furfural.

Considering all the results presented throughout the present work it is possible to verify that for the same conditions without catalyst the substrate where the best results were obtained was the dry grass. However, if the use of AlCl₃.6H₂O as catalyst is considered, the substrate with the best result corresponds to the pine sawdust.

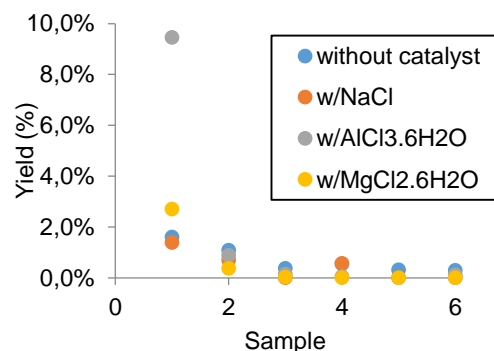


Figure 5- Variation of furfural yield with the catalyst used, when the distillate was collected in samples and the acid used was HCl (5.4 M) and the substrate used was pine sawdust.

3.2 Silica extraction

As previously described in this paper, extraction of the silica from the rice husk in basic medium was carried out at the boiling temperature of the mixture, at atmospheric pressure, under stirring and 60 mL of 1 M aqueous NaOH solution was used.

Table 9 shows the results obtained only for the tests whose experimental procedure originated silica gel, since in other tests the filtrate remained in the form of solution, i.e. not forming any gel.

Table 9- Results for the mass and for the silica yield of NaOH treatment.

Test	raw material	m _{silica} (g)	η (%)
7	rice husk ash	5.68	71
8	ash residue	2.11	62
9	residue	0.02	0,3
10	rice husk	2.14	13
12		6.15	85
13	Ash residue	7.15	96
14		6.40	96

It can be seen that the yield is quite high when using ash, i.e. husk or residue after being subject to high temperatures in the furnace. Differences in the yield values may be related to the loss of solid in the filtration, i.e. solid remaining in the filter paper during the washing step of either the gel or the silica after drying.

Considering the cases where the raw material was not introduced in the furnace, it is found that the value of the yield is lower and the aspect of the obtained solid is different from the solids obtained from ash. Thus, it was considered in both cases that what would influence the mentioned factors would be the fact that silica forms very stable organic complexes whose bonds are not destroyed by the NaOH solution [45]. In addition, since the residue has a very low

pH value the base (NaOH solution) added may not have been sufficient to neutralize the pH of the dispersion and to carry out the basic attack for silica extraction.

From the results presented above, it is concluded that it is possible to extract silica starting from any of the four substrates as raw material. However, the yield value to obtain this solid is higher when the ash is used as raw material.

These tests make it possible to conclude, that it is possible, in high yields, to obtain silica from the residue resulting from the previous production of furfural. In addition, based on these results, it is possible to optimize the silica extraction process by two different ways, avoiding energy costs by not taking the samples to the furnace or being able to elaborate an integrated process, i.e. first to produce furfural and then proceed to the extraction of silica, without passing through the furnace.

3.2.1 X-ray diffraction

X-ray diffraction analyses were carried out on different final samples and solids obtained after treatment of the furnace, rice husk or solid residue resulting from the furfural production process, where it was found that in all, except two samples, the solid was composed exclusively of silica. Figure 6 is an example of an X-ray diffractogram made to one of the solid samples.

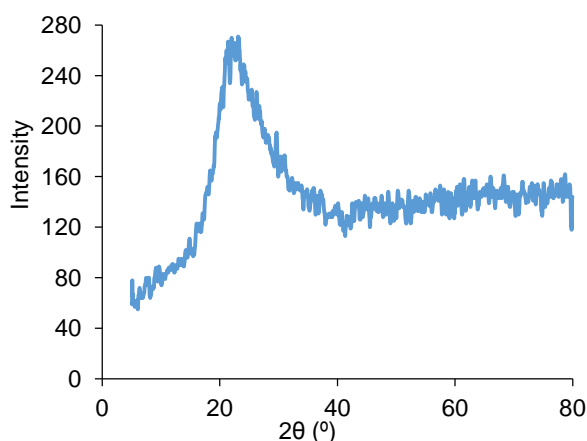
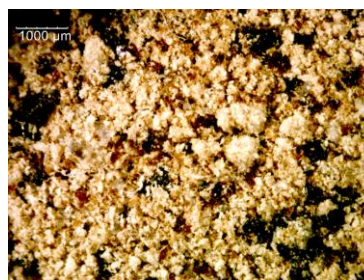


Figure 6- Example of obtained X-ray diffractogram.

From the previous figure the diffractogram shows to a non-crystalline or amorphous substance, since it does not have defined peaks, which can be corroborated by the fact that the diffractogram has a broad peak between the diffraction angle (2θ) 20° and 30° [46].

3.2.2 Treatment with NaOH

Figure 7 shows the pictures obtained under the microscope of the product resulting from the treatment with NaOH for extraction of silica from the rice husk or the solid residue as raw material.



(a)

Figure 7- Solid obtained after treatment with NaOH (1 M) using the rice husk as raw material.

Based on the figure above, it is possible to verify that the obtained silica has yellow coloration and the solid particles are agglomerated, this aspect is related to the fact that the silica is bound to organic compounds, as previously explained.

On the other hand, after x-ray diffraction analysis was carried out, it was verified that the sample had NaCl together with SiO_2 in its compositions was due to a wash of solid which was not done correctly, and the formation of this salt occurs due to the addition of a certain amount of acid to the aqueous solution of sodium silicate (Na_2SiO_3), which will give rise to the silica gel. Thus, since 2 M HCl was used in the present test, NaCl precipitation occurred upon gel formation.

3.2.3 Treatment with furnace

Figure 8 shows the pictures obtained under the microscope of the product resulting from the furnace treatment, using the temperature program mentioned earlier, for extraction of silica from the rice husk or the solid residue as raw material.



(a)



(b)

Figure 8- Solid obtained after furnace: (a) rice husk and (b) solid residue after furfural production.

Considering the pictures presented above, the appearance of the solid obtained is quite similar in both cases, that is, they are both elongated and

narrow. However, the solid obtained from the rice husk has some darker parts while the solid obtained from the residue is predominantly white.

This fact may be related to the treatment performed before the residue, that is, while the rice husk was taken directly to the furnace, the solid residue suffered an acid attack to produce furfural, which could have eliminated some compounds present in the rice husk.

3.2.4 Treatment with furnace and treatment with NaOH

Figure 9 shows the pictures obtained under the microscope of the product resulting from the treatment with furnace and NaOH for extraction of silica from the rice husk or the solid residue as raw material.

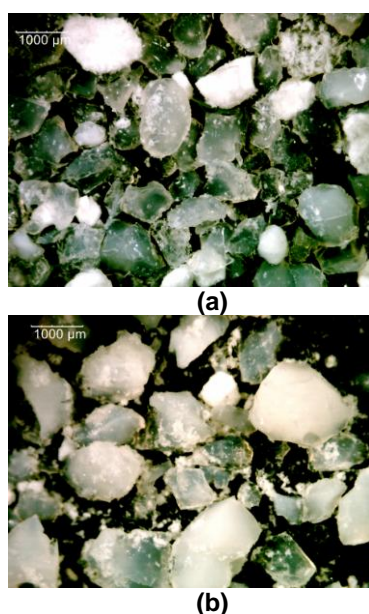


Figure 9- Solid obtained after furnace and treatment with NaOH (1 M): **(a)** rice husk and **(b)** solid residue after furfural production.

Comparing the above cases in Figure 8 it is found that after furnace and treatment with NaOH the solid obtained shows not only a larger grain size but also some vitreous aspect, which may be due to water content in the interior, because the milling after the first drying was not efficient.

4 Conclusions

In the production of furfural from rice husk the optimal conditions that maximized the production of this compound (yield of 9,1 %), corresponds to a total 5.4 M concentration of HCl, which was added drop by drop and where 25 g of NaCl (dissolved) were used as a catalyst. However, it was further concluded that this mode of acid addition was not the most reliable, since the aqueous HCl solution dripping was not uniform throughout the reaction.

It was also studied the furfural formation, from rice husk, along the reaction. It was concluded that the first two samples collected had higher furfural concentration compared with the remaining fractions obtained.

Based on these results, it was concluded that the colour of the collected samples is due to the presence of furfural. However, the experiments with metal chlorides the colour due to the presence of furfural was disguised by the colour of another compound that formed and gave the samples a darker shade. When using $AlCl_3 \cdot 6H_2O$, the colour of the first sample has equal to any other sample using catalysts, however, the furfural yield is much lower.

Taking into account all the substrates used in the furfural production, it was concluded that using grass enhances the furfural produced.

Considering the results obtained for the silica production, it was found that the extraction of this compound is maximized when the organics are removed from the substrate, through a furnace pre-treatment. It was also concluded that, after removal of the organics, with treatment with NaOH or not, the silica purity is practically identical, differing in the microscopic aspect that it presents.

From the tests carried out it was found that the integrated process for the production of furfural and silica was a viable process, and in a typical test from 25 g of rice husk was produced 2.3 g of furfural and 6.4 g of silica.

5 References

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