OPTIMIZATION OF ETHANOL PRODUCTION FROM ROOTS OF TUBEROUS PLANTS: THE CASE OF CASSAVA

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ABSTRACT

Madagascar has several varieties of tuberous plants such as cassava, sweet potato, and tarot. These tubers can be valorized for energy purposes to be used as a renewable energy source, such as bioethanol. Studies and research carried out in the CNRIT laboratory have contributed to the optimization of the process of making ethanol from cassava. Thus, improvement experiments have been carried out on the manufacturing process, among others: Techniques for pre-treating cassava before fermentation, the choice of the optimal duration of fermentation and The temperature control of the grinding operation. This allowed the identification of the optimal parameters to opt for the production of ethanol from cassava such as:

- *unpeeled, fresh, crushed cassava is the raw material used;*
- *the duration of fermentation is 3 days;*
- *the quantity of yeast is 5%;*
- *the grinding temperature must not exceed 125°C for the set point temperature of the boiler regulator and 78°C for the set point temperature of the head regulator of the grinding column, respectively*

Keyword: *cassava, fermentation, distillation, rectification, ethanol optimization, manufacturing process, optimum parameters.*

1. INTRODUCTION

Access to energy is the spearhead of a country's economic and social development. The world's thirst for energy goes hand in hand with the increase in population, leading to a worrying decrease in fossil resources and, as a result, a rise and instability of the price of oil on the international market. Energy is essential for human activities, without energy, companies cannot produce and therefore cannot create jobs. It also enables communication and travel around the world.

Madagascar has considerable renewable energy potential that has remained under-exploited until now because its current energy source is dominated by wood energy and petroleum products. The promotion of their exploitation could generate interesting prospects in rural areas insofar as it favours local development through the use of endogenous resources. However, one of the most violent causes of environmental deterioration is due to the combined adverse effects of slash-and-burn agriculture, low carbonization yields and excessive use of fuel wood.

This calls for research into technologies aimed at enhancing the value of agricultural products as energy sources, such as innovative technologies for producing ethanol from the roots and tubers of certain plants. This research work attempts to improve the ethanol manufacturing process, enabling us to identify the parameters to be optimized, including the quality (freshness, etc.) of the raw material to be processed, the fermentation time, the quantity of yeast to be used and the rectification temperature relative to the set temperature at the boiler and the column head. It also highlights the reliability of these parameters, thus highlighting the stage at which one can intervene in the process.

2. METHODOLOGIES

2.1. Study area: Rural Commune of Analavory

The cultivation of cassava is spreading all over Madagascar, especially in the Alaotra Mangoro region, in the south-western part of Madagascar, and especially in the region of Itasy. However, we will focus our study on the latter and especially the town of Analavory for various reasons:

- It is known for its profitability in terms of variety of agricultural products. Indeed, the main sector of activity of this commune remains agriculture;
- It has a large area of arable land of volcanic structure.
- There are various varieties of crops such as cereals, tubers, etc....
- The cassava production cycle is very short, the harvest can take place after six months;
- It is located on the RN 1 not far from the city of Antananarivo.

Location

The rural commune of Analavory is one of the communes that make up the Miarinarivo district in the Itasy region. It is located 22 km west of Miarinarivo, which is the capital of the Itasy region. Following the road to the national road number 1 (RN1), which connects the city of Antananarivo and that of Tsiroanomandidy, it is at a distance of 111km. It is limited to the North, East, South, and West by a few rural communes:

- In the North: Anosibe Ifanja, Sarobaratra Ifanja, and Ambatomanjaka.;
- In the East: Miarinarivo II, and Manazary;
- In the South: Ampefy, and Ankaranana;
- In the West: Alatsinainikely, AnkadinondrySakay.

According to the data of Ampandrianomby, the rural commune of Analavory is located on the latitude: 18°58'42.01"S and the longitude: 46°42'45.35"E

Fig-1: Location map of the rural commune of Analavory, Madagascar

Temperature

The following table shows the average monthly temperatures in the Highlands region over the last five years, including the town of Analavory.

Table 1: Average monthly temperatures in °C for the last five years (2005-2010)

Month / T°	J	F	M	A	M	J	J	O	S	O	N	D
T° max (°C)	26,38	26,4	26,76	25,52	23,65	21,7	20,42	32,45	31,43	25,66	35,7	26,86
T° min (°C)	17,74	17,52	17,18	16,02	14,1	11,67	11,02	11,03	12,47	13,73	16,32	17,06
T° M (°C)	22,6	21,96	21,97	20,77	18,87	16,68	15,72	21,74	21,95	19,7	26,01	21,96

The average annual temperature varies between 18 and 26°C, the hottest month is November with an average temperature of 26°C, the coldest month is July with an average temperature of 15°C. According to this data, we can observe the alternation of two seasons in the course of a year: hot and rainy and dry and cold.

Economic situation

As a rural community, agricultural activities dominate Analavory's economy. The other most frequent activities are the breeding and the exploitation of the eucalyptus forests, as well as trade and crafts.

Agriculture

As far as agriculture is concerned, rice, market gardening and fruit growing dominate in Analavory and this is almost the case of the neighbouring communes: d'Ampefy, Anosibe Ifanja and finally Andolofotsy. Off-season crops are dominated by cassava, maize, and sorghum. The most commonly used fruit crops are papaya and banana. In general, the factors that burden the agricultural sector with low productivity are the following:

- Lack of mastery of agricultural techniques, we are still witnessing the predominance of old techniques using archaic equipment. This phenomenon is caused by the lack of agricultural technicians in the commune and the ineffective follow-up of the training already provided;
- The lack, obsolescence and gradual destruction of infrastructure

Table 2: Agricultural production in the Analavory commune

Type	crop	Unable agricultural area (ha)	Utilized agricultural area (ha)	Productivity	Production
cereal	River rice	3436	2804	3	8258
	Upland rice	2232	1011	2,5	2150
	corn	2805	1904	3	4985,5
Vegetable	beans	1678	739	2	1702,5
	tomato	705,5	292,5	10	4116
	Melon	600	230	6,5	536,1
	Potato	131	8,1	8	290
	Bambara weight	530	29	2	57
	cress	10	10	2	20
	others	186	37,85	2	127,63
Tuberculeuses racines	Cassava	6034	4524	4	24028
	Sweet potato	1570	515,3	3,5	3070,30
	Tarot			3	250
Industrial cultivation	Sugar cane	200	12	10	250
	Pistachio	510	126	1,5	123
	Tobacco	604	10	2	18
Fruits	Papaya	601,;8	50,4	20	312,25
	Melon	10	5	5	50
	Banana	305	10	5	70
	others	300	50	5	80

The average productivity of rice cultivation is still around 3t/ha. Among cereals, this result is the same for maize. However, maize production in t/year is half as high as that of rain fed rice.

Farmers are also working to diversify their agricultural activities in order to increase their income. The cultivation of papaya is a concrete example of this initiative. The Fokontany in Analavory, Ankotrabe, Amparaky, Tsarazaza and Ambatomitsangana are engaged in this practice.

Breeding

Among the activities of the primary sector, animal husbandry holds a significant place in the commune. Cattle breeding is highly regarded in the commune, followed by pig breeding and finally poultry. Meat is first and foremost fed to local butchers. Pigs are sold outside the commune or even outside the region. There are also a few problems in the commune, namely:

- the lack of mastery of new techniques;
- the lack of investment due to the non-access to the micro-finance system.;
- the non-respect of sanitary standards;
- The frequency of diseases;
- Banditry which manifests itself by the theft of zebus ...

These problems are largely due to the lack of management and staff at the commune level despite the presence of private veterinarians who support those employed by the commune.

2.2. Experimental work

In order to achieve the set objective, the following methodological approach was adopted:

- identification of the appropriate pre-treatment and hydrolysis technique;
- Determination of the optimal yeast quantity and fermentation time;
- Identification of the respective limit set point temperature of the boiler and the column head.

Experimental studies relating to this approach were carried out in the laboratory of the National Centre for Industrial and Technological Research (CNRIT).

2.2.1. Pre-treatment and hydrolysis technique

Pre-treatments

This is a crucial preliminary step in the cassava alcohol production process. Indeed, its success determines the results of the following steps. This stage includes:

- Sorting: to eliminate products in poor condition (for example, with huge traces of mould).
- Washing: to remove various dirt and soiling (mud etc...)
- Peeling: to remove outer bark
- Cutting into pieces and grinding: to obtain a fine homogeneous mixture of starch and cassava, ready for the hydrolysis operation.

Preparation of amylase

The main steps in preparing these paddy seeds to obtain the enzyme are as follows:

- Soaking : Moistening of paddy seeds and conditioning in a warm and humid place for 24 to 48 hours to facilitate and accelerate germination;
- Germination: This is the period during which the barley starts to germinate and therefore produces enzymes such as amylase. This stage lasts four to six days. This gives rise to what is called 'green malt'. The following figure shows the germination of the paddy seed:

Photo 1: Paddy seed germ

2.2.2. Hydrolysis

Hydrolysis is the transformation of starch into fermentable sugar under the action of enzymes at a given temperature and under constant agitation. Hydrolysis consists of two steps: The gelation and the liquefaction.

The gelation:

Gelling is the cooking of cassava at a temperature of 75°C for about 45 minutes, coupled with agitation. Gelling consists in modifying the structure of the starch by the action of heat and water. Because of its semi-crystalline structure, starch is practically insoluble in cold water and brought to a temperature of 75°C, it becomes amorphous and miscible with water. The prior gelling of cassava starch facilitates the action of enzymes present in the malt.

The proportion adopted for this operation is 1.5 L of water for 1 kg of cassava.

The liquefaction:

The liquefaction consists in the activation of the enzyme in the gelled cassava juice. Thus we mixed 1 Kg of gelled cassava with 0.25Kg of malt milk. The latter being obtained by diluting the powder coming from the germination of the paddy with water. This step is carried out at a temperature of 55°C during 40 minutes under permanent stirring.

The gelling and hydrolysis operation is illustrated by the following series of figures:

2.2.3. Quantity of yeast and duration of fermentation

Fermentation

Fermentation is a biochemical reaction that converts the chemical energy contained in a carbon source (often glucose) into another form of energy directly usable by the cell in the absence of oxygen (anaerobic environment). Fermentation consists of transforming glucose into ethanol. To do this, the addition of yeast to the mixture is necessary. Fermentation lasts about a week. The alcoholic fermentation must take place anaerobically, at a temperature between 15°C and 35°C. The anaerobic environment allows the yeast to change glucose into ethanol.
The fermentation procedure is illustrated by the following figures

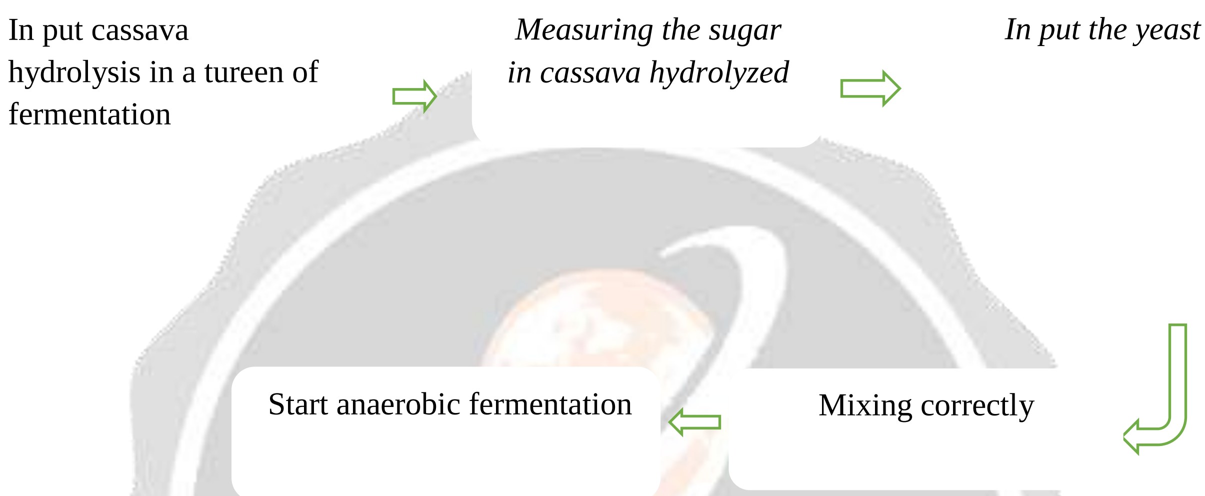

Photo 2: fermentation preparation

2.2.4. Set point temperature limits the boiler and the column head.

Distillation

Just after fermentation, we obtain what is called a wort, the distiller is then prepared and the wort is loaded into the boiler. Check the distiller's pipes for leaks and start the distillation process.
The distillation steps are as follows: *Procedure for distillation:*

- Collect the alcohols from the distillation and measure the alcoholic strength of the resulting mixture.
- Prepare the alcohol then pour it into the boiler through the loading funnel. The minimum quantity of alcohol to be rectified is 1L and maximum 4.5L;
- After loading, close the tap tightly to avoid leakage;
- Open the cooling water circuit, then check that all the taps on the appliance are closed;

Rectification

Rectification, also known as fractional distillation, is a process of separation by fractionation. Its purpose is to separate the different constituents of a mixture of miscible liquids with different boiling temperatures. To do this, it uses the same principle as conventional distillation but differs by the use of a separation column, which allows better discrimination of the constituents of the mixture.
The operation must be carried out at a well-controlled temperature, since the boiling temperature of water is 100°C and that of ethanol 78°C.

Conduct of the rectification

The alcohol obtained by distillation will be introduced into the rectifier's boiler and heated by the electrical resistance. The vapor thus formed passes through the column lined with structured material (tray). The temperature drops as it rises in the column. The vapor consisting of the least volatile component (water) cools and condenses on the trays of the column and falls back into the boiler. The vapor rich in the most volatile component (alcohol) continues to rise in the distillation column, then passes through the piping (vapor circuit) and passes through the condenser to give distilled liquid alcohol.

Start grinding;

During the rectification operation, collect the distillate formed with a graduated container, then measure and record each corresponding alcoholic degree;
At the end of the rectification, wait for the apparatus to cool down, then open the discharge valve and collect the residue.

3. RESULTS

3.1. Fermentation result

Fermentation takes place in a non-renewed medium, varying the percentage of yeast and the duration of fermentation for the same mass of hydrolyzed cassava. The results of the fermentation will be summarized in the following tables:

Table 3 : Fermentation Result

N° Essay	Cassava hydrolyzed(g)	Yeast (%)	Yeast (g)	Fermentation duration (days)	Sugar before fermentation (°Brix)	Sugar after fermentation (°Brix)	Attenuation (%)
1	8000	5	400	3	16	6	62,50
2	8000	7	560	4	14,5	8	44,83
3	8000	8	640	5	14	8	42,86
4	8000	9	720	6	13	8	38,46
5	8000	10	800	7	11	**7**	36,36

This table easily shows that trial number 1, carried out with a 5% yeast content, during a 3-day fermentation period, resulted in a highest fermentation yield of 62.50%. This is a better fermentation yield. We can therefore assume that the optimal fermentation parameters will be:

- Yeast content of 5%,
- Fermentation time of 3 days

Recall that the attenuation of the sugar level after fermentation is given by the following formula:

$$\mathbf{Attenuation} = \frac{\mathbf{E} - \mathbf{Ea}}{\mathbf{E}}$$

E: sugar rate into first solution
Ea : sugar rate at the final solution
Fermentation yield can be determined by knowing the initial sugar level (before fermentation) and the final sugar level (after fermentation).

3.2. Distillation result

It should be noted that the volume of the distiller in the CNRIT laboratory was too small, so that the distillation of the wort from a fermentation operation took place in two waves.
Moreover, the distillation series took place under the same conditions. The temperature at the distiller's head was monitored by means of a mercury thermometer.
The distillation resulting from the 5 fermentations was therefore carried out in 5 series:

(a) First distillation series

Table 4: First distillation series

Jet Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Volume alcohol (ml)	89	90	90	90	92	90	91
Degree (°GL)	64	72	72	70	61	61	54
jet Number	**8**	**9**	**10**	**10**	**11**	**13**	**14**
Volume alcohol (ml)	90	89	90	92	90	95	90
Degree (°GL)	45	41	35	28	19	18	13

The total volume of ethanol obtained is 1268 ml with an alcohol content ranging from 13° to 72°.

(b) Second distillation series

Table 5: Second distillation series

jet Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume alcohol (ml)	90	92	94	90	92	92	92	
Degree (°GL)	71	71	71	67	65	60	55	
jet Number	**8**	**9**	**10**	**10**	**11**	**13**	**14**	**15**
Volume alcohol (ml)	91	99	99	92	92	105	88	95
Degree (°GL)	54	47	40	40	28	24	14	10

The total volume of ethanol obtained is 1403 ml with an alcohol content ranging from 10 to 71°.

(c) Third distillation series

Table 6: Third distillation series

jet Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Volume alcohol (ml)	90	93	92	89	85	92	92	
Degree (°GL)	70	70	65	61	56	54	54	
jet Number	**8**	**9**	**10**	**10**	**11**	**13**	**14**	**15**
Volume alcohol (ml)	91	96	93	96	97	105	84	84
Degree (°GL)	46	41	35	31	25	20	15	15

The total volume of ethanol obtained is 1385 ml with an alcohol content ranging from 15 to 70°.

(c) Fourth distillation series

Table 7: Fourth distillation series

jet Number	**1**	**2**	**3**	**4**	**5**	**6**
Volume alcohol (ml)	90	92	91	90	93	92
Degree (°GL)	59	59	55	54	50	48
jet Number	**7**	**8**	**9**	**10**	**11**	**12**
Volume alcohol (ml)	90	89	94	100	91	133
Degree (°GL)	41	31	25	25	12	11

The total volume of ethanol obtained is 1145 ml with an alcohol content ranging from 11 to 59°.

(d) Fifth distillation series

Table 8: Fifth distillation series

jet Number	**1**	**2**	**3**	**4**	**5**	
Volume alcohol (ml)	95	96	95	96	95	
Degree (°GL)	56	55	50	41	40	
jet Number	**6**	**7**	**8**	**9**	**10**	**11**

Volume alcohol (ml)	97	97	103	100	60	93
Degree (°GL)	35	29	21	20	15	10

The total volume of ethanol obtained is 1027 ml with an alcohol content ranging from 10 to 56°.

The following figure shows the evolution of the alcoholic strength of the distillate as a function of the rank of appearance of the jet, for the five series of tests.

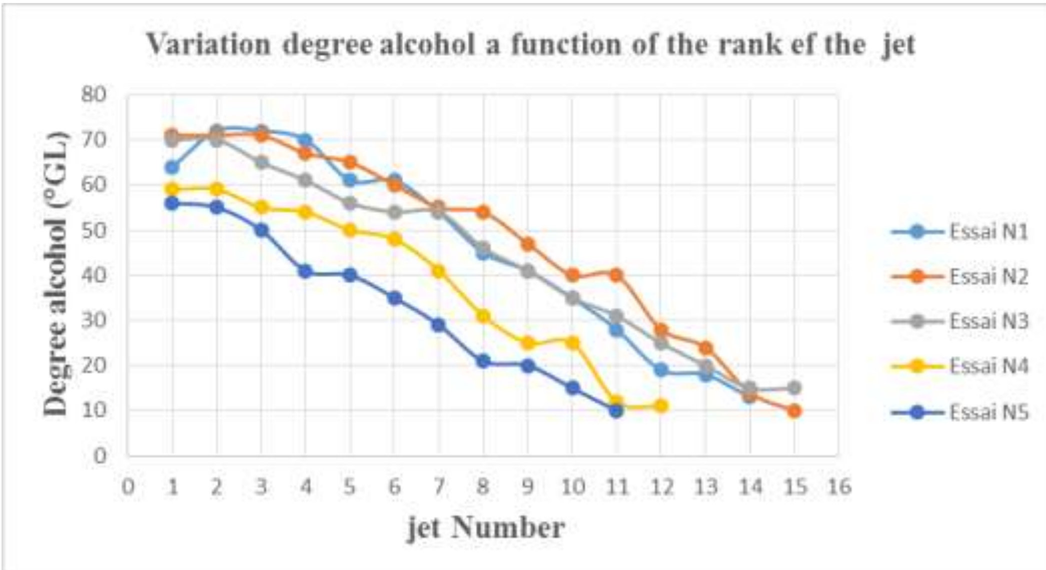

Figure 2: Variation in the alcoholic strength of the distillate as a function of the rank of the jet

In general, with the exception of the first and second sprays, there is a decrease in the alcoholic strength of the distillate obtained, depending on the row of sprays.

3.3. Results of rectification

Before the rectification, we gathered the alcohol obtained by the first distillation in 4 groups of alcoholic degree: 66°; 51°; 33°, 19°.

a) First rectification group

The operating conditions:

- Alcoholic degree 66 °GL
- Initial volume of alcohol 1.5L
- Boiler regulator set point temperature (Ɵb): 125°C then 150°C
- Set point temperature of the head controller (Ɵtc): 78°C

We have obtained the following results:

Table 9: First rectification

Rubriques						
Jet Number	**1**	**2**	**3**	**4**	**5**	**6**
Volume (ml)	150	150	148	150	150	135
Degree (°GL)	92	91	90	88	86	85
Duration (mn)	**50**	34	43	**40**	21	25
Θ_b (°C)	127	129	127	157	151	158
Θ_{tc} (°C)	71	70	70	71	71	79

The total volume of ethanol obtained is 883 ml, of which the first three distillates collected with a boiler temperature of 125°C have alcoholic degrees ranging from 90 to 92°, while those of the other three, operated at 150°C, have alcoholic degrees ranging from 85 to 88°.
Moreover, it is noted that the time of appearance of the first draft of the rectification made at the set temperature of 125°C is greater than that under 157°C.

(b) Second rectification group

The operating conditions:

- Alcoholic degree : 51 °GL
- Initial volume of alcohol 1.5L
- Boiler regulator set point temperature (Θb): 125°C then 150°C
- Set point temperature of the head controller (Θtc): 78°C

At the end of this second group of rectification, we obtained the following results:

Table 10: Second rectification

Rubriques						
jet Number	**1**	**2**	**3**	**4**	**5**	**6**
Volume (ml)	150	150	140	150	130	146
Degree (°GL)	90	90	90	88	84	75
Duration (mn)	67	53	58	60	86	131
Θ_b (°C)	129	124	132	156	158	156
Θ_{tc} (°C)	78	70	79	72	79	72

The total volume of ethanol obtained is 866 ml of which the alcoholic degrees of the first three distillates collected with a boiler temperature of 125°C remain constant 90° while those of the other three, operated under 150°C vary from 75 to 88°.
Compared to the first rectification, the lower the alcoholic degree of the initial mixture, the longer it takes for the first draft to appear.

(c) Third test group

The operating conditions:

- Alcoholic degree 33 °GL
- Initial volume of alcohol 1.5L
- Boiler controller set point temperature (Θb): 125°C
- Set point temperature of the head controller (Θtc): 78°C

We have obtained the following results:

Table 11: Third rectification

Rubriques			
jet Number	**1**	**2**	**3**
Volume (ml)	150	150	100
Degree (°GL)	90	89	82
Duration (mn)	93	81	123
Θ_b (°C)	122	127	129
Θ_{tc} (°C)	76	79	79

The volume of alcohol obtained is 400 ml with an alcoholic degree of 90 for the first jet while the last two jets vary from 82 to 89°.

(d) Fourth test group

The operating conditions:

- Alcoholic degree 19 °GL
- Initial volume of alcohol 2.345L
- Boiler controller set point temperature (Θb): 125°C
- Set-point temperature of the head controller (Θtc): 78°C

At the end of this fourth test group, we obtained the following results:

Table 12: Fourth rectification

Rubriques			
jet Number	**1**	**2**	**3**
Volume (ml)	150	150	62
Degree (°GL)	88	80	69
Duration (mn)	147	112	220
Θ_b (°C)	122	126	128
Θ_{tc} (°C)	78	76	79

The volume of alcohol obtained is 362 ml with an alcohol content ranging from 69 to 88.
It should be noted that for these last two rectifications (3rd and 4th) we have set the set temperatures respectively at Ɵtc =78°C and Ɵb =125°C. Indeed, the application of these parameters during the first two rectifications led to promising results, namely: alcoholic degree of distillate between 90 and 92°.

4. DISCUSSION

The research work carried out at the CNRIT laboratory with a view to optimizing cassava manufacturing processes has yielded satisfactory results. We are therefore able to suggest the following protocol sheet for the production of ethanol from cassava:

Protocol for the production of ethanol from cassava

Pretreatments:

- Sorting: eliminating products in poor condition
- Washing: remove various dirt and soiling (mud etc...)
- Peeling: removing outer bark
- Cutting into pieces and grinding: to obtain a homogeneous fine mixture

Hydrolysis

- Enzymatic hydrolysis based on paddy grain comprising the following steps:

Preparation of amylase

- Soaking: Moistening of paddy grains and conditioning in a warm and humid place to facilitate and accelerate germination.
- Germination: a period of four to six days during which the barley starts to germinate and gives birth to what is called 'green malt'.

Hydrolysis:

- . The hydrolysis itself consists of two steps:
  - Gelation: Aimed at modifying the structure of starch by the action of heat and water. The gelling of cassava starch facilitates the action of the enzymes present in the malt.
  - Liquefaction:

-Liquefaction improves and accelerates the activation of the enzyme in the gelled cassava juice.
-Optimal fermentation and rectification parameters
-The optimum parameters to be used for fermentation and rectification operations are summarized in the following table:

Table 13: Optimum parameters for fermentation and rectification operations

Rubriques	Parameters
Quantity of yeast	5%
Duration of fermentation	3 days
Boiler Target temperature	125°C
Set point temperature of the head of the column	78°C

This table summarizes the Optimum Parameters to be considered for all fermentation and rectification operations.

4. CONCLUSIONS

At the end of this study, it is clear that the objective initially set has been achieved. The "optimization of the process of ethanol production from cassava" was studied in all its aspects.

The experimental part consisting of the transformation of fermentable sugars present in cassava into alcohol goes through the enzymatic hydrolysis of starch, followed by fermentation and ends with distillation and rectification.
This has made it possible to obtain the optimum parameters for the production of ethanol from the following cassava :

- the raw materials used are fresh unpeeled ground cassava;
- the duration of fermentation is 3 days;
- the quantity of yeast is 5%;
- the grinding temperature must not exceed 125°C for the setpoint temperature of the boiler regulator and 78°C for the set point temperature of the grinding column head regulator, respectively.

The use of these optimal parameters led us to the acquisition of satisfactory rectification results, namely ethanol with an alcoholic degree of more than 90° for the first three distillate streams.

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