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Babassu coal as a thermal source for absorption refrigeration system in the state of Maranhão

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ABSTRACT
In this work a theoretical analysis of the integral use of babassu as an energy source was developed, seeking to emphasize the potential added to coal. A case study was carried out in the municipalities of Maranhão, aiming to diagnose aspects that relate the man of the field to this important source of biomass. The cooling system consists of a coupling of an oven driven with babassu charcoal in a Platen-Munters absorption refrigerator, through a closed two-phase thermosyphon. The results obtained resulted from a comparative analysis of an experiment already carried out with a similar system, powered by a wood stove, where it was perceived as a significant improvement in the efficiency of the proposed system. The babassu charcoal with the calorific value of the order of 7,300 kcal/kg, allowed us to obtain the amount of coal mass (load) to be used to feed every 10 min the oven to keep running the refrigerator of power of the order of 260w. As an optimization of the process, we propose a load of 400g with a supplied interval of 4hs to keep the refrigerator running.

Keywords: Babassu, biomass, coal, absorption cooling system.

1 INTRODUCTION

With the advent of the energy crisis suffered by our country in recent years, it is necessary to study the feasibility of alternative sources of energy that will not replace electricity, but diversify it in some sectors of industry, commerce, and homes and use materials and or natural resources that can contribute at various levels of scales, provided that its use is economically viable.

Contemporary authors, due to their views in the environmental and strategic fields, have aroused interest in research, such as *D'Avignon* (1993) when he stated that *"the human being, throughout history, has used energy for his development"*. But it plays a key role. If we are not able to develop technologies that allow the large-scale use of renewable and non-polluting energies, we run the risk of irreversibly compromising the environmental quality of life on our planet.

It was within this perspective that we decided to develop this study on the feasibility of using babassu biomass (Orbignya Phalerata Martius) in the generation of energy for use in rural areas. The

State of Maranhão was chosen for having an annual production of babassu coconut in the order of 15 million tons. Of this total, only 2.6 million tons (17% of the total) would be used.

Although babassu has already been exploited for oil for more than half a century, it is emerging today as a replacement for oil sources and coal. We must make it a reality. And this can be achieved in the not-too-long term through an integrated plan, aiming at its full use.

It is estimated that the productive potential of babassu is above a dozen million tons of coconut per year, which could allow an annual production of about 1 billion liters of alcohol, almost 2 million tons of coal, half a million tons of oil, more than 2 billion m3 of fuel gas and about 1.5 million tons of epicarp (primary fuel) (May 1990).

Among the various technological alternatives for the use of the babassu coconut parts is the one that uses **the mesocarp for alcohol production; the endocarp for the production of coal and gases;** the almond for **oil production and the epicarp** for direct use as the primary fuel.

The production of the endocarp in the state is approximately 8.8 million tons and only 1.5 million would be available for the production of coal since this would be the amount that results from the coconuts that are broken down per year. Becoming, therefore, the general objective of this work is to develop a study, as an alternative energy, to drive a cooling system through babassu coal. To this end, a case study was elaborated in 04 (four) municipalities of Maranhão, to evaluate some socioeconomic and potential aspects of coal.

To efficiently achieve the objective, the following phases were developed**:** Theoretically analyze the alternative energy potential of babassu coconut for its full use; establish the indicators for the technology of coal production, use, and market; diagnose through a case study aspect that relate the rural man and the coal produced in Maranhão; Evaluate a cooling system driven by babassu coal.

2 METHODOLOGIES

In the development of the research different methods of investigation were used: <u>theoretical methods</u> (historical-logical, analysis-synthesis, and systemic-structural) and <u>empirical methods</u> (questionnaire, direct observation, and interview with specialists).

A theoretical analysis of the integral use of babassu as an energy alternative was carried out, which shows the composition, productivity and productive and energetic potential of the coconut, in addition to the technology of production, use, and markets for coal, presenting a proposal for the treatment of the feasibility of the activation of an absorption refrigerator (gas or kerosene), through the burning of babassu coal, in a furnace designed to burn coal, connected by a closed two-phase thermosyphon.

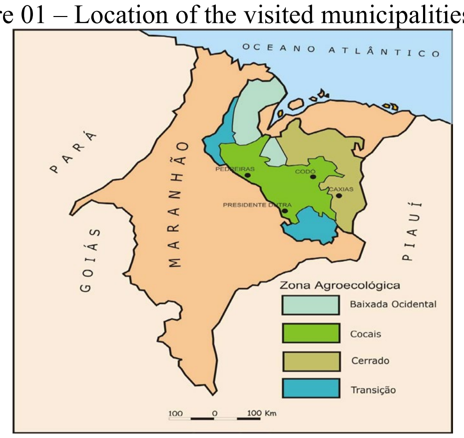
The work was not constituted as experimental, but a comparative analysis of a system already proposed and experienced under similar conditions, evaluating some aspects of the coupled set, which concerns results related to heat flow and mass, the temperature levels considered, and calculation of the efficiency of the system, presenting a structured systemic model of all its stages.

2.1 THE BABAÇU PALM

The babassu, a plant of the palm family, is native to the Central-North region of Brazil, with the areas of occurrence of babassu extending discontinuously through nine states of the Brazilian territory, and approximately 2/3 are in the State of Maranhão, where babassu assumes important economic expression, with existence quantified in "billions" of tons of coconut.

The babassu represents 30% of the surface of the State. The area occupied by palm trees is mainly in the Ecological Regions of Cerrado, Cocais, and Baixada. May (1990).

Figure 01 – Location of the visited municipalities of Maranhão



Source: Google Images 2023

Table 01 - Maranhão – area of occurrences – main regions

Ecological region	área (103 ha)	% about the state
Scrubland	4.488	13,81
Cocais	1.970	6,06
Download	1.770	5,44
TOTAL	8.228	25,31

Source: May (1990).

It is not known precisely the periods of flowering, fruiting, maturation, and fall of the fruits of the occurring species, knowing only that the period of most intense fall of the fruits is located in the second half of the year. Systematic studies still need to be developed to clarify this information.

Although it has been observed its preference for low-lying areas, not flooded, where the highest yields are usually recorded, more detailed investigations on the environment most conducive to palm development and coconut production should also be carried out.

Having the highest incidence of babassu in the regions of the Cerrado, Cocais, and Baixada, it is intuited that it seems to be linked to the characteristics of the transitional nature of these areas, with hot and humid climates. The deficiency of sunlight is a factor that impairs the development of the crop.

There is no study correlating the annual variations of rainfall, temperature, soil fertility, water retention capacity, etc., with production, nor is there scientific information regarding the soils and nutrients needed by the plant: however, the factual knowledge of the areas of occurrence, it can be stated that the soils are predominantly clayey, deep dark and with a medium and high degree of humidity.

There are no known diseases that attack the palm tree. As for pests, it is known that:

- Coleoptera attack the fruit, destroying the almond, Example: Gongo;
- insects destroy the mesocarp, in the open sky and storage;
- pests on the palm stipe, form deep galleries;
- the leaves are attacked by the caterpillar;
- Beetles on the stem and apex cause damage of a small nature.

2.2 BIOMASS, TECHNICAL AND ECONOMIC EVALUATION

Of the possible energy sources, biomass occupies the leading position among all. Nowadays the use of biomass as an energy source varies depending on the state of development of the country in question. In the US, biomass represents 1% of the energy supply, while in Sudan it represents about 65%, with most of this demand in the form of firewood, animal waste, agricultural waste, etc. (Ismail, 2000).

The most important processes by which energy can be obtained from biomass include direct combustion, alcoholic pyrolysis, and biophotolysis. Each of these technologies has its advantages depending on the source of biomass and the type of energy required.

The greatest difficulties in the use of biomass in the conversion of solar energy are:

1. The percentage of solar energy converted into biomass by plants is relatively small (less than 0.1%).
2. The low concentration of biomass per square meter in land and water.
3. Additional land suitable for planting is rare.
4. High moisture content (50 to 95%) in biomass results in collection and transportation, which makes it more expensive, and energy conversion is inefficient.

These factors result in the fact that energy from biomass is expensive, with reduced final energy product.

The advantages of using biomass as an energy source include the following:

1. Biomass produces a low-sulfur fuel.

2. In some cases, fuel is cheap and available, such as firewood, biogas, alcohol, etc.

3. In some cases, biomass processing for fuel production decreases environmental pollution (sewage, processing waste).

4. Production of biological fuels can be coupled to protein synthesis.

Energy consumption in Brazil is provided by coal (3.6%), hydroelectric (20.8%), oil (44.8%), and biomass (30.5%). With an aggravating factor: almost 50% of the oil used in Brazil is imported.

2.2.1 Sources of biomass

Animal manure, plant waste, sugar cane, urban waste, municipal sewage, aquatic plants and firewood are potential sources of biomass. Let us detail below the source of the firewood, whose process is similar to that of the babassu bark. Ismail (2000).

2.2.2 Firewood

Firewood represents an important contribution as an energy source in several developing countries. In India this represents 16% of the energy consumed, in Brazil 26% and in the case of Sudan 65%. In reality, most of the energy needs in the rural countryside are suppressed by firewood.

Firewood can be used in heating, steam generation, cogeneration (simultaneous and sequential production of two or more forms of energy from a single fuel) generating electricity widely used in industrial activities (such as in ceramics and brick factories), food processing, rubber production and even in the manufacture of steel.

The increased demand for firewood results in deforestation in certain countries thus causing its reduction, soil erosion and water scarcity.

Brazil has great potential because of the Amazon basin.

2.2.3 Available technologies for biomass energy production

We can obtain biomass through fermentation, pyrolysis and anaerobic digestion. The pyrolysis process is the medium used in babassu coal furnaces.

2.2.4 Pyrolysis

Pyrolysis or destructive distillation is an irreversible chemical change caused by heat in the absence of oxygen. Depending on the raw material, the product of pyrolysis can be solid, liquid, or gaseous fuel. Process variables include temperature, retention time, heating rate, and the air to feed. In the typical process, the material goes through the following operations: a) small primary cutting; b) drying of the cut material; c) air separation to remove inorganics; d) cutting of the material; e) pyrolysis, where the carbon material is heated rapidly (1400ºF to 3000ºF) and f) storage of energy products.

The pyrolysis process operates with a pressure slightly higher than the environmental pressure and with a maximum temperature of 1800ºF. For oil recovery, the temperature in the reactor is 1000ºF and for gas recovery it is 1400ºF. Main products identified in the gaseous fuel coming from the pyrolysis of cow manure, wood sawdust and rice husks include H2, N2, CO, CO4, C2H6 (ethane), C6H6 (benzene) and C7H8 (toluene).

Methanol and charcoal are obtained on an industrial scale from wood pyrolysis. Typical production rates are 1 to 2% dry starting weight for methanol and 37% for charcoal. Laboratory-scale pyrolysis for liquid fuel production from biomass, cow manure, urban waste, rice husks, cotton scraps and vegetable remain is under development. Ismail (2000).

2.2.5 Energy potential of biomass

Manure and municipal sewage can be best processed by anaerobic digestion producing net energy per kg of dried manure based on 784 kcal.

Pyrolysis of urban tailings produces 1417 kcal/kg compared to net energy produced by incineration of these tailings of the order of 2939 kcal/kg. Ethanol production from sugarcane produces 1479 kcal/kg to 1327 kcal/kg.

The use of biomass to reduce energy dependence is an important fact and an alternative of great potential. The conversion of biomass is similar to agricultural production, it requires labor to collect the raw material, prepare and store it. Thus, it is obvious that it is better to operate with community biodigesters to avoid transporting raw materials and energy, as well as using the by-products on-site. The conversion of municipal sewage and tailings is valid and feasible, because, in addition, it solves problems of environmental pollution, in addition to eliminating environmental problems such as throwing this product into rivers, canals, or land.

There is no doubt that the biological conversion of solar energy offers developing countries an opportunity to suppress part of their energy needs that must be utilized and harnessed in the best possible way by avoiding abuse and misuse. Ismail (2000).

2.3 ABSORPTION COOLING SYSTEM

Due to the second law of thermodynamics, cooling can be done at the expense of energy. Steam compression refrigeration cycles use electrical or mechanical energy. An absorption refrigeration plant requires thermal energy for cooling production. The working fluid – the refrigerant (these are those that are used for vapor compression cycles) – in the gas phase, yields heat to the environment, becoming liquid in the condenser. At low pressure and temperature, removing heat from the medium to be cooled, it evaporates.

To maintain the continuous cycle, the low-pressure steam must be compressed to the condensing pressure. In the refrigeration cycle, this process is carried out by the "thermal compressor".

By providing the necessary thermal energy at a higher temperature than that of the environment, the refrigerant vapor will be expelled from the rich mixture.

By removing the heat of absorption, the vapor from the low-temperature refrigerant will be absorbed by the poor mixture.

The binary mixture of the cycle is composed of the refrigerant and an absorbent. The two components should be mixed to a large extent.

The solids, used together with the refrigerants, are the adsorbents, and the liquids of the binary mixture are the absorbents (Stoecker, 1985).

The characteristics and technical specifications of the system chosen for testing are presented by the manufacturer Consul S.A (1984) in its technical publication.

Some experimental studies using this type of refrigerator were also found in Lombardi *et all* (n.d.). They tested their performance to cool the daily milk production of a small farm, using a solution of water and alcohol as a thermal flywheel and LPG and electricity as a thermal source.

The possibility of technical improvement of a traditional Brazilian wood stove, aiming to obtain a burning with less emanation of toxic pollutants for the user and the environment, was proposed by Borges (1994) in his master's thesis.

Another attempt to obtain cooling from the use of the thermal losses of a wood stove, only by removing heat from the exhaust gases of the stove through a bank of heat pipes and using a periodic system of solid absorption with the zeolite-water pair, is reported by Passos & Escobedo (1988).

The stove used is the one developed by EMATER, discussed in the bibliography of wood stoves and the article presents the design and the principle of operation, however, it does not bring any experimental result or conclusion about its performance.

Finally, we used as main reference a theoretical-experimental work, Martins' master's thesis (1989), which studies a traditional masonry wood stove as an energy equipment coupled to a Platen-Munters absorption refrigerator (gas or kerosene refrigerator), through a closed two-phase thermosiphon using water as a working fluid.

This work presents the sizing of the combustion chamber, the necessary heat flow and the temperature levels sufficient for the activation of the refrigeration system and temperature measurements in the cabinet and freezer of the refrigerator.

3 RESULTS AND DISCUSSIONS

3.1 THEORETICAL ANALYSIS OF THE FULL USE OF BABASSU AS AN ENERGY ALTERNATIVE

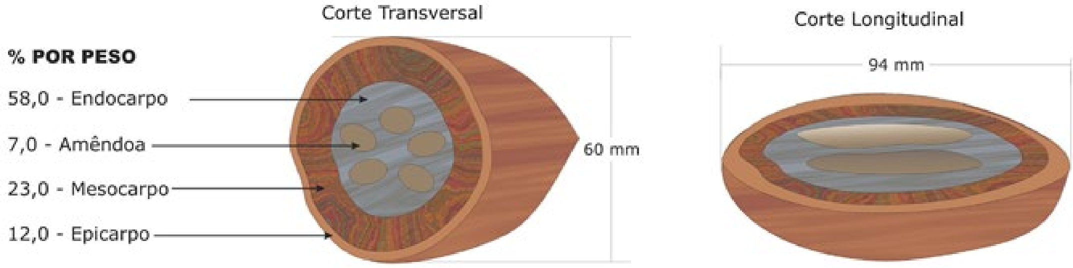
3.1.1 Babaçu Coconut

(a) Composition

The babassu coconut consists of three layers: a fibrous outer layer (epicarp); a fibrous-starchy intermediate (mesocarp) and a woody internal one (endocarp) in which the almonds are inserted. It is usual to call shells the set of three layers, which correspond to about 93% of the weight of the coconut.

Due to the existence of several species and the different regions of occurrence of babassu, it is common to find a certain variation in the composition of the coconut**.** For this study, we will consider an average composition, by weight, with the following percentages: **epicarp=12%,** mesocarp=23**%,** endocarp=58**%**, and **almond=7%**.

Figure 02 Average size and composition of babassu fruits harvested in five states.



Source: May (1990).

The composition of the mesocarp varies with species and provenance. As a result of analyses performed with the mesocarp and separated by manual process, it was observed that the starch content of the mesocarp is approximately 68%, which corresponds to about 16% with the weight of the coconut.

Almonds contain about 65% of the weight of oil. Analysis of the babassu almond carried out by Professor Vivacqua and confirmed by other subsequent analyses presented the following results:

Table 02 - composition of babassu almond

COMPOSIÇÃO	PARTICIPAÇÃO EM PESO (%)
UMIDADE	4,70
ÓLEO	66,20
PROTEÍNAS	7,80
FIBRAS	6,90
CINZAS	2,30
CARBOIDRATOS	12,10
TOTAL	100,00

Source: may (1990).

The epicarp and endocarp are made up of cellulose and, due to their physical characteristics, should have their most immediate uses as fuel and in the production of coal, respectively.

The epicarp can provide a fuel with a calorific value of origin of 3,800 Kcal/kg (MIC/INT (National Institute of Technology), 1977).

From the endocarp can be obtained charcoal of excellent quality, with a yield of up to 25% of its weight, in addition to gases resulting from the carbonization process itself.

Part of these gases is condensable, from which a series of by-products such as tar, acetic acid, formic acid, methanol, etc.

The rest of the gases can be used as fuel. It is necessary to highlight that the yield of each product resulting from the carbonization process of the endocarp is a direct function of the speed of the process and its temperature.

b) Productivity

Data on babassu productivity are controversial. Some researchers consider this productivity to vary between 10 and 15 tons of coconut per ha/year: Others, around 2 to 3 t/ha-year. The lack of knowledge about babassu is still great and the few careful studies are limited and specific to a particular region. The productivity rate of around 2.5 t/ha-year can be considered a reasonable average value.

c) Productive and Energy Potential

The area of vegetation cover in babassu trees is estimated at 15 million hectares. In this area only part of the palm trees is productive. It becomes necessary, therefore, to establish a correction factor that allows us to obtain an idea of productive coverage. Let's adopt 33% as this index, taken from experience, with cultures similar to babassu. Thus, it is possible to estimate the productive potential (**Pp**) in coconut, as follows:

$$\mathbf{Pp = A \times F \times P} \quad (1)$$

Where:
Pp = Productive potential of coconut (t/year) A = Babassu coverage area (ha)
F = Productive coverage factor P = Productivity (t/ha)
Pp = 15.0 x 106 x 0.33 x 2.5 Pp = ➔ **12.4 X 106 t/year of coconut**

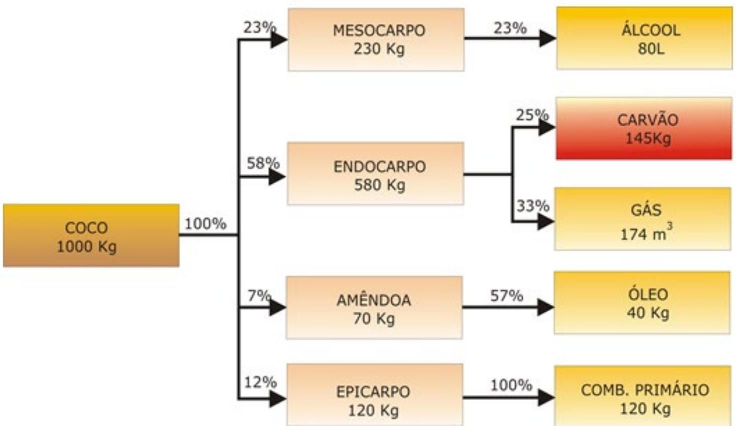
Since this result will be the basis of all subsequent calculations, it should be clarified that, although this potential is based on still precarious data, care was taken to make it as significant as possible, even resulting in a conservative picture of the current situation.

The full use of babassu coconut aims, in the first place, to improve the national energy balance, through the replacement of conventional fuels from non-renewable sources, oil and coal.

In this sense, babassu can provide alcohol, oil and coal, in addition to the possibility of using the epicarp directly as a primary fuel in the process of alcohol production that, together with the fuel gas originating from the carbonization of the endocarp, are more than enough to meet the energy needs of an alcohol plant, in an industrial complex for the full use of coconut.

For the global energy vision, the following average yields for the production of alcohol, coal, fuel gas, oil and primary fuel, about the components and those concerning the coconut itself, are shown below.

Figure 3 – Division of the babassu coconut



Source: STI/MIC, INT (1977)

When babassu is mentioned as a raw material for alcohol production, the comparison with sugarcane and cassava immediately arises.

This comparison has to be faced with due care because, while these last two are extracted, respectively, only fermentable sugars and starch for the production of alcohol, with the use of sugarcane bagasse and cassava branches, to improve the energy balance of the plant, babassu coconut, in addition to providing starch for alcohol production, It provides other raw materials for the production of coal and oil, resulting in fuel gas and epicarp, which can be used as a primary energy source, not to mention a series of non-energy by-products that will result from the integral industrialization of coconut.

In addition, still compared to sugarcane and cassava, babassu is a native, perennial product, with annual harvests, not requiring investments in planting or expensive crop treatments.

However, it is essential to make it clear that the use of each of these raw materials for energy purposes should not be considered exclusive. Each of them has its characteristics, and one can be adopted one or the other, according to ecological, social or economic, local or regional conditions.

3.2 TECHNOLOGY OF PRODUCTION AND USE OF BABASSU COAL

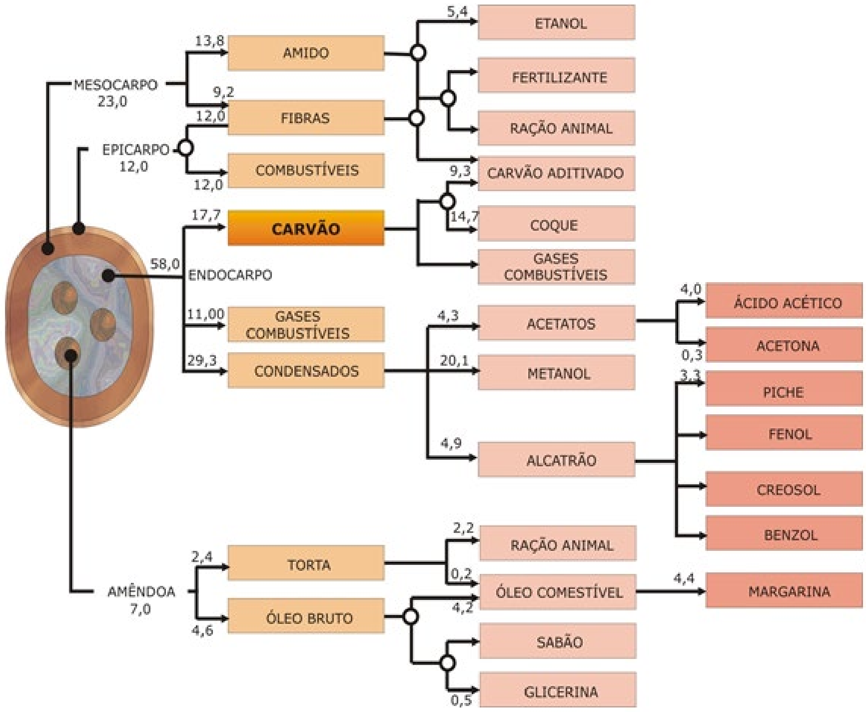
The babassu industry is beginning a phase of major structural changes between the oil production system and the full use of coconut. The oil industry made up of small companies that have in plant extractivist their source of raw material - coconut, is suffering strong competition from other types of edible oils: palm, soy, etc. Their future tendency is not to endure competition.

On the other hand, several factors have contributed to open markets for other babassu products. Within this perspective, the following parts of the coconut, in addition to other parts of the palm tree, are capable of exploitation:

- **epicarp** - as primary fuel; for methyl and ethyl alcohol, furfural and agglomerates;
- **mesocarp** - for ethyl alcohol; starch for food, animal feed and industrial uses;
- **endocarp** - for coal; furfural; pyrogenation gases; methyl and ethyl alcohol;
- **sheets** - for cellulose and agglomerates;
- **stem** - for heart of palm (exclusively of palm trees resulting from thinning);
- **Almond** - oil for traditional uses and as a fuel to replace diesel; biodegradable detergents; feed pie.

Because of their importance, alcohol and coal are products that deserve special attention, which is why the propositions of the industrial-technological program are concentrated in them. In the flowchart below are presented the main unit operations to obtain alcohol, **coal** and other derived products.

Figure 04 - Alternative babassu products



Source: Teixeira M. A (2003)

The major problem for the integral industrialization of the coconut was the lack of efficient industrial equipment for the peeling, breaking, and separation of the various parts of the coconut. However, today there is already on the market a marketable national equipment, manufactured by Máquinas Piratininga S/A, with the capacity to process 6 t/h of coconut. The 120 KW machine requires, for installation, an area of 200 m^2.

a) Babaçu Coal Production Technology.

Charcoal is the carbonaceous residue obtained by heating without burning (i.e., without oxygen) plant matter. The closed chamber for its obtainment can be either a hole in the ground filled with babassu coconut shells, a common technique in Maranhão, or industrial ovens of various formats, with heating and with the use of gases.

Although it is possible to carbonize the whole coconut, in general, it is considered more interesting to do it only with the endocarp, releasing the other parts for other uses.

CIT - Cia. Industrial Técnica developed and built a horizontal carbonization furnace consisting of a rotating cylinder.

The raw material (endocarp) received at one end, runs the entire length of the cylinder, slightly inclined, exiting at the other end. In this path, the endocarp is heated and expels the volatile material that will heat the incoming raw material. It is a furnace with a small production capacity (currently 7 t/day of coal) and low investment cost.

SIDERBRÁS is studying the adaptation of the Spulgas furnace, currently used for devolatilization of highly volatile mineral coals, to make the carbonization of babassu. This process has a higher production capacity and is suitable for large industrial projects.

The IPT - Institute of Technological Research is studying a column-type oven, built-in refractory, to continuously carbonize the babassu.

Other important experiments have already been carried out in Brazil, highlighting the pioneering experiences of Silvio Froes Abreu at INT, the plant of Professor Antônio Vivacqua Filho, those of AGRIMA, TOBASA, Plant Products of Piauí.

The quality of the coal depends exclusively on the carbonization parameters, that is temperature and speed of carbonization. Preliminary tests of endocarp carbonization, carried out by STI/SIDERBRAS, indicate that the coal/endocarp yield by weight decreases with increasing carbonization temperature (May 1990).

Table 03 Endocarp yield as a function of temperature

TEMPERATURA (ºC)	RENDIMENTO (%)
340	36,9
400	33,7
500	30,6
520	29,3
750	24,7

Source: lima (1954)

Immediate analysis of this same coal produced at 7500C showed the following composition by weight:

Moisture.................................. 0,9 %

Ashes................................... 4,7 %

Volatile matter................. 3,2 %

Fixed carbon............... 91,2 %

This shows us that without a shadow of a doubt, it represents coal of excellent quality. 6It is also verified that during the carbonization of the endocarp, a series of by-products are released in much larger quantities than those obtained in the distillations of coals usually used in the steel industry.

Thus, for carbonization carried out at 5200C, we have, in addition to the 29.3% of coal, the participation, by weight, of the following by-products:

Gas (including losses) 15,9%	Tar 28,8%	Ammoniacal Water 26,0%

According to Professor Vivacqua, the gases released in the carbonization of the endocarp at a temperature between 450 and 5500C, have an average yield of 300 m3/t (washed gas). These gases, before purification, contain a high percentage of CO_2 and N_2, and their calorific value is relatively low. After washing and filtering these gases come out significantly enriched.

This crude tar must, by distillation, produce from 30 to 60% of components, such as phenolic oils, phenolates, anthracene oils, etc. Depending on its nature, raw tar can also be used to improve the strength and composition of babassu coal briquettes with mineral coal.

Ammoniacal water, in turn, results in the following end products: acetic acid, formic acid, methanol, etc.

b) Technology for the Use of Babassu Coal

The excellent qualities of babassu coal make it possible to advantageously replace imported metallurgical coal, requiring in certain cases the use of new steel techniques. The biggest possibilities are:

1. addition of babassu charcoal in the mixtures to be coking - about 2%;
2. partial or total replacement of coke breeze in the process of synthesizing iron ore;
3. manufacture of molded coke, using a mixture of mineral coal and babassu coal in up to 70%;
4. use in cubilô furnaces of iron casting, replacing the special coke now imported;
5. Use around electric reduction, in the production of pig iron or ferroalloys.

STI and SIDERBRAS are working on items 1,2,3 above, conducting tests on a pilot or semi-industrial scale. In initial tests, carried out in France, the molded coke, produced with 70% babassu coal and 30% mineral coal from Santa Catarina, presented characteristics of mechanical strength and composition better than the coke currently used in our steel mills (70 to 80% imported)

About item number 4, USIMINAS, at the request of Companhia Industrial Técnica, carried out tests with babassu charcoal briquettes in one of its cubilô furnaces, obtaining surprising results concerning the quality of the iron produced. The use of babassu coal in the ferroalloy industry is already a reality.

3.3 MARKET AND ANALYSIS OF BABAÇU COAL IN BRAZIL

a) Potential Market for Babassu Coal

In the current stage of technological development, babassu coal, due to its excellent qualities, has assured participation in several segments of the metallurgical market. With the development of new carbonization technologies and uses these segments will expand and all supply should be absorbed since it presents itself as an ideal substitute for imported coke. Babassu coal already finds its main applications in mixtures to be coking, in the sintering process, in coal for the production of ferroalloys and smelting.

(b) Coal analysis

In the project, the coal market is sized to meet part of the demand of the national steel sector, aiming to contribute to solving one of the fundamental problems of the current National Steel Plan, which is the quantitative and qualitative lack of charcoal or mineral in the country.

The high quality of babassu coal was already known in 1927, when the coke produced from the babassu endocarp was presented for examination to the American steel expert, William Smith of Ford Mills in Detroit, who qualified it "as one of the best species of coke, suitable for the smelting of iron of the highest quality." The ash content contained in babassu coal is small, phosphorus and sulfur do not exist, and its high melting point indicates it is for the production of non-porous irons. Babassu charcoal also has a high degree of filtration and absorption and thus can be used as filtration charcoal.

In the table below, the comparison between babassu charcoal and wood, is worthy of greater attention, the calorific value and absence of sulfur.

Table 04 Comparison of the characteristics of babassu charcoal and wood, may (1990)

ELEMENTOS	BABAÇU	MADEIRA
Umidade	4.100	5.860
Materiais Voláteis	16.400	23.520
Carbono Fixo	75.250	63.690
Cinzas	4.250	6.930
TOTAIS	100.000	100.000
Calorias	8.010	6.230
Enxofre	0,000	0,000

Source: may (1990)

3.4 ANALYSIS OF A CASE STUDY IN MARANHÃO

After analyzing the potential of babassu coconut, its technology, use, and market, for a better understanding of this universe, we conducted a case study in 04 main municipalities of Maranhão, located in the regions of cocais and cerrado, where the occurrences of babassu are higher (Figure 01).

The research took place in the rural area of the municipalities of: Presidente Dutra (cocais); Codó (cocais); Quarries (cocais) and Caxias (cerrado). A total of 60 interviews were conducted in households and rural cooperatives, with an average of 15 families per municipality.

We seek to cover in the focus of the research a qualitative and quantitative analysis of the full use of babassu, especially coal.

The results are presented in a unified way since there was no great variation in the responses tabulated in the different municipalities. The main aspects evidenced by the study were grouped into the following items: socioeconomic profile of rural people, current exploitation system, coal manufacturing process, coal consumption, and environmental impacts, which are presented below:

a) Socioeconomic Profile of Rural Men

The research showed that in the area of the cocais and cerrado of Maranhão, the breakdown of babassu is a typical burden of low-income families, where 54 of the 60 families (90%) have an income of less than one minimum wage.

The average of inhabitants per family is 6 people and on average each breaker breaks from 8 to 12kg/day and sells at a price ranging from R $ 0.80 to R $ 1.20 the almond. Already the coal is sold at R $ 15,00 a bag.

In the owner/breaker relationship, it is common to oblige the sale of the almond to the owner of the land, which offers a price of 10 to 20% lower than that sold in the market, working the difference as a kind of lease paid to the owner. The marketing of almonds is mounted on a system of intermediation between producers and the processing plant.

b) Current Operating System

In response to the 10th question of the questionnaire, which focuses on how the almond is extracted from the shell, we obtained 100% of the answers that use the axe as the main instrument. The operation of manual braking is time-consuming and exhaustive and the labor used in the sector is, almost entirely, composed of women and children over 10 years of age, with minimal participation of men, more dedicated to the work of subsistence farming or collection of the coconut to be broken by the family. The collection system is rudimentary with mule transports, with the use of jackfruit to the destination of breakage and/or sales.

c) Coal Manufacturing Process

The research revealed that the process of manufacturing babassu charcoal is done by the traditional way, practiced by most extractives, consisting of a hole in the ground, with varying dimensions, called "caeira", where the bark is burned until they become embers, when they are then muffled with babassu leaves and covered with earth.

The coal produced is of low quality, without uniformity in terms of humidity and volatile and fixed carbon contents, due to the lack of temperature control and carbonization speed.

d) Coal Consumption

Results obtained in a survey conducted in the main municipalities of Maranhão showed different results, because in the cities of Pedreiras and Codó, about 50% of families produce coal only for their consumption, while in the cities of Presidente Dutra and Caxias this percentage decreases to 30% of their consumption, all the rest is destined to commercialization (sale). The percentages of coal produced intended for sale are delivered to local merchants. Where they are later sold to industries (cement factories, bakeries, pottery, ceramics).

Some uses attributed to the clay stove powered by babassu charcoal in these localities visited, it is about in addition to using it to cook food, it is used for heating water for washing clothes. Another use detected is the heating of the iron with the flame of the stove.

e) Environmental Impacts

The felling and burning of palm trees are a constant throughout the region to plant pastures for cattle. This practice is being monitored by IBAMA technicians, who regulate percentages of palm trees per ha to be felled for the purposes previously mentioned. However, with the practice of using babassu charcoal to replace charcoal firewood, environmental impacts such as induced deforestation of the native forest, loss of biodiversity, acceleration of erosion and loss of soil fertility occur, contributing to the advancement of the desertification process.

4 THE COOLING SYSTEM: ACTIVATION OF A REFRIGERATOR BY ABSORPTION

We tried to establish in this chapter an individualized study on the construction project of an oven for the production of babassu charcoal with better qualities, then to study the closed two-phase thermosiphon as an element of heat exchange between the oven and the refrigerator and a Platen – Munters system of the refrigerator, only then to establish the final coupling of the three systems, making a quantitative and qualitative evaluation, comparing to the results already established in experimental character by Martins (1989).

4.1 THE PROPOSED FURNACE AS THERMAL EQUIPMENT

Our goal now is to have a quantitative idea of the heat fluxes that occur in the oven, analyzing the losses with the experiments carried out with the wood stove by Martins (1989) and Borges (1994) and maintain the same location to affect the removal of heat for the activation of the refrigerator.

a) characteristics of babassu coal as fuel.

In addition to the analysis of the constitution of the endocarp as a natural po1imer, consisting on average of 23% cellulose. 22% of hemicellulose and 39% of lignin and 16% of other materials, another way of analyzing it, of greater interest to determine the heat of combustion and the amount of oxygen required for combustion, is the so-called elemental analysis (ultimate analysis). Elemental analysis gives the percentage by weight of the main chemical elements: C, H, N, O, S and ashes. Despite a small variation in the relative amounts of each constituent in different types and parts of coal several studies adopt different values, so we will take in this work an average constitution, proposed by the MIC (1990).

C .... 78%   Or............ 8%   H .... 6%   Ashes..... 8%

In addition to the constitution of wood other physical properties of wood are of vital interest to the phenomena of combustion: moisture and calorific value. Being a hygroscopic material, the endocarp used for the manufacture of charcoal for burning in domestic stoves always has a certain amount of humidity, which can be determined relatively simply according to the ASTM D 2016-65 standard. Martins (1989).

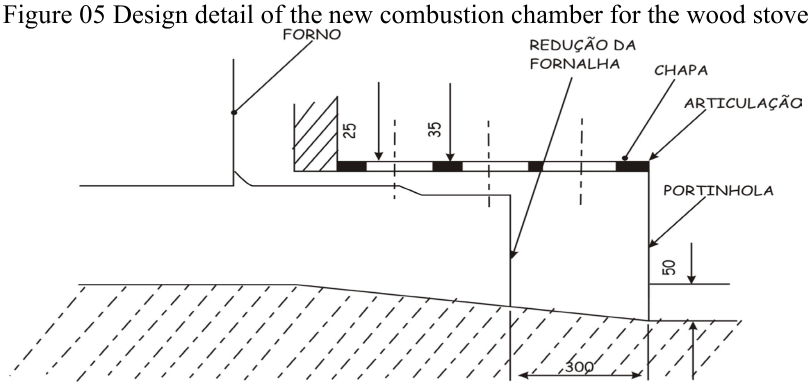
b) Geometry proposed for the furnace

The chamber was sized for an average power supplied between 8 and 9 kW (obtained with a feed of about 400g of firewood every 10 minutes), with an excess of air of 100%.

The principle of sizing is to equalize the buoyancy forces in the design conditions to the total pressure loss inside the stove, seeking to locate the largest pressure losses at the base of the pans, and not at the chimney entrance as usual.

Figure 05 shows the design of the chamber and Table 05 the efficiency of the stove obtained by Martins (1989).

Figure 05 Design detail of the new combustion chamber for the wood stove



Source: Martins (1989)

Table 05 – Efficiency of the stove

CARGA	FOGÃO	COMUM		COM CHAPA		COM PORTA		PORTA + CHAPA	
400 g cada 10 min	Panela	η [%]	λ [%]	η [%]	λ [%]	η [%]	λ [%]	Η [%]	Λ [%]
	1	3,56	156	4,69	170	5,01	147	5,70	103
	2	2,97		4,44		4,10		4,70	
	3	1,10		1,79		1,59		2,15	
	total	7,63		10,92		10,70		12,55	

Source: martins (1989)

Our work proposes the same geometry of the stove tested by Martins (1989) with the modifications made, for a single oven, without the three openings for pots. We believe that the percentages of heat losses used in them is converted into useful heat for the furnace.

4.2 THE CLOSED BIPHASIC THERMOSIPHON

The purpose of this unit is to study a simple, inexpensive and efficient way to promote heat transfer from the wood stove to drive the conventional absorption cooling system (gas refrigerator).

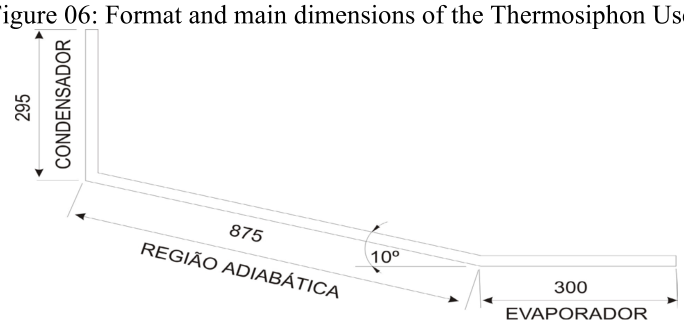
Within the approach chosen in the work: low-cost solution, high reliability and durability, and, trying to minimize the effect of the transients to the use of the furnace, the solution initially considered for the thermal coupling between the combustion chamber and the ammonia generator was that of a closed two-phase thermophon.

The operation of the closed two-phase thermosiphon involves boiling (vaporizing) the working liquid in the evaporator. Flow of steam along an adiabatic zone, condensation of the same in the condenser and return of the condensate by gravity to the evaporator in countercurrent with the steam.

In the first phase of the work, a two-phase thermosiphon was dimensioned for a heat flow of 300 W, working temperature of 280 ºC, working pressure corresponding to 6.4 MPa, evaporator temperature of 350 ºC and condenser temperature of 220 ºC. The shape and diameter of the thermosiphon were determined from the existing geometric constraints for the coupling of the two existing systems: the stove and the refrigerator.

The thermosiphon consists of a copper tube of 1.46 m in length, an external diameter of 3/8" (9.525 mm), and internal diameter of 1/4" (6.35 mm), with the horizontal evaporator of 300 mm, the adiabatic region inclined in 10º with 875 mm and the vertical condenser, as shown in Figure 06.

Figure 06: Format and main dimensions of the Thermosiphon Used



Source: Martins (1989)

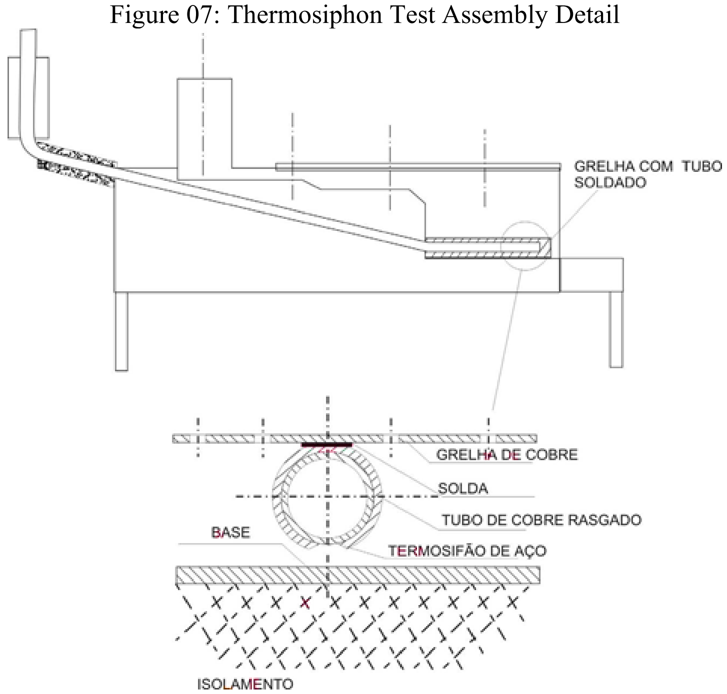
The next step towards improving the heat exchange from the burning region to the thermosiphon evaporator was to provide the evaporator with a fin.

This fin: a copper plate in the shape of the base of the combustion chamber, with a thickness of 1.5 mm, was welded to a copper tube.

In addition, holes of 5 mm in diameter were made throughout the plate so that it acted as a grate, allowing a better distribution of the airflow through the burning region and thus an improvement of combustion.

Figure 07 shows this assembly in detail. The grate is located about 25 mm above the base of the combustion chamber, which thus acts as an ash deposit.

Figure 07: Thermosiphon Test Assembly Detail



Source: Martins (1989)

These results showed us that the thermosiphon under study can already transmit heat flows above 300 W, and can therefore be used in the coupling between the stove and the refrigerator.

We know from the researched literature that the vaporization temperature of NH3 in the ammonia generator of the refrigerator should be between 150 and 180ºC.

Thus, we can assume that with a burning rate of 400 g every 10 minutes, the operating conditions of the system will be similar to those experienced by (Martins, 1989). If the "overall heat transfer coefficient in the condenser" remains constant on the order of 550 W/m2K, we can predict an increase in the temperature and working pressure of the thermosiphon, but with a sufficient heat flow for the refrigerator feed.

We will thus move on to the next phase: the study of the behavior of the refrigerator and the final coupling of the three systems.

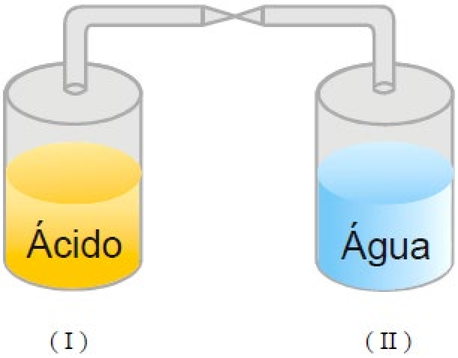
4.3 PRINCIPLES OF REFRIGERATION SYSTEMS (PLATEN-MUNTERS REFRIGERATOR)

4.3.1 - Systems with two fluids (absorption systems)

a.1) Periodic (or intermittent) operation

In 1810, Sir John Leslie built equipment composed of two containers connected by a tube, as shown in Figure 08 one of them contained pure water (soda) and the other contained sulfuric acid (absorbent). The system was then evacuated and the sulfuric acid began to absorb the water vapor, forcing more water to vaporize from the other container to equalize the pressures until the water froze.

Figure - 08: Schematic of a periodic absorption cooling system



Source: Martins (1989)

The operation of this system can be better understood with the help of the diagram in Figure 09. Starting from a temperature equilibrium situation at T_o, the vapor pressure of the pure refrigerant is greater than that of the refrigerant-absorbent mixture.

By opening the valve of the connecting tube between the containers, the refrigerant vapor will go from container II to container I.

The equilibrium pressure of I is exceeded, forcing the condensation of the refrigerant, which yields its latent heat of condensation to the mixture, thus increasing its temperature and consequently the equilibrium pressure.

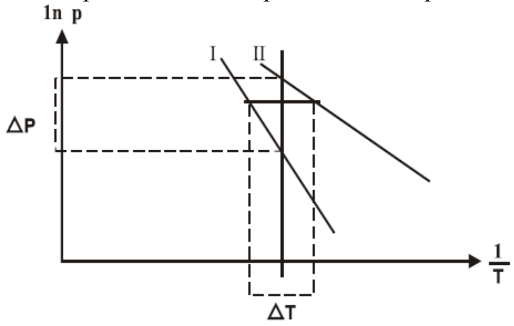
The reverse process occurs in II: the temperature drops due to the evaporation of the refrigerant, thus causing the vapor pressure to fall in II.

Because the amount of mass in the system is limited, the system works by receiving heat at a low temperature in II and yielding heat at a higher temperature in I until all the refrigerant from II is consumed.

One then has to regenerate the resulting solution in I, that is, separate the refrigerant from the absorbent to restart the process, which is done by heating container I, forcing the water vapor to evaporate, simultaneously with the cooling of container II, where it should condense.

Thus, this cycle works periodically.

Figure 09: Equilibrium of pressure and temperature in the periodic absorption process



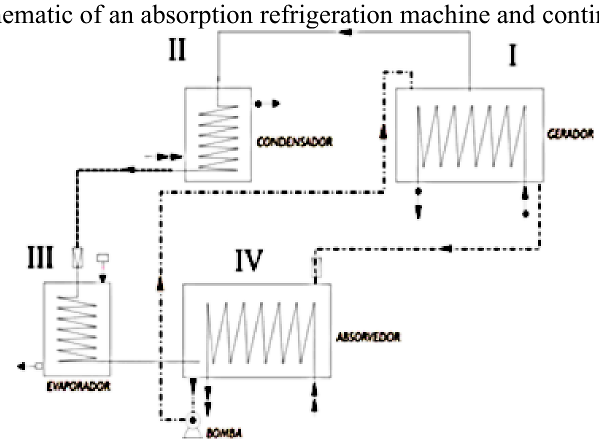
Source: Martins (1989)

Periodic refrigeration equipment using this principle had a large penetration at the residential level in the U.S. and Europe between 1920 and 1930.

a.2) Continuous operation:

The principle of continuous absorption refrigeration machines was presented by Ferdinand Carré in a series of patents between 1859 and 1862. In these machines, the classic ammonia-water (coolant-absorbent) pair was used. The simplified schematic of this machine is shown in Figure 10.

Figure 10: Schematic of an absorption refrigeration machine and continuous operation



Source: Martins (1989)

The water and ammonia solution are heated in the generator (I). Because the volatility of ammonia is greater than that of water, it evaporates at high pressure and temperature. The ammonia vapor then goes to the condenser (II), where through cooling it liquefies still at the pressure of the generator. At the end of the condenser, an expansion valve promotes the pressure reduction necessary for the ammonia to vaporize in the evaporator (III) at low temperatures, removing heat from the medium to be cooled.

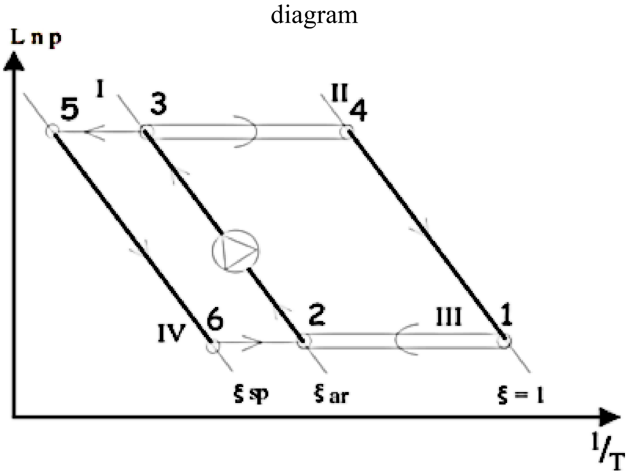
The poor solution that comes out of the bottom of the generator passes through a valve that causes the same pressure drop as the condenser outlet valve.

This poor solution comes into contact with the ammonia vapor that comes out of the evaporator, and with the removal of the absorption heat, the ammonia vapor condenses enriching the concentration of the solution in the absorber (IV). From the absorber, the rich solution is then pumped into the generator again.

The ideal process described above can be represented in the diagram in Figure 11. The solution describes the 3-5-6-2 circuit, where steam generation occurs between states 3 and 5 (lowering the concentration of the solution from **ξar** to **ξap**) and absorption between states 6 and 2. The 5-6 process is the pressure and temperature reduction that occurs in the poor solution valve.

The part of the ammonia that is vaporized performs the 3-4-1-2 circuit. The process of condensation of pure ammonia (**ξ=1**) is represented by point 4, just as vaporization is represented by point 1 between these two processes, we have the process that occurs in the expansion valve between 4 and 1. The 2-3 process is common to both circuits, representing the pumping of the rich solution from the absorber to the generator.

Figure 11: Representation of the theoretical cycle of a continuously operating absorption machine in the Lnp x 1/T diagram



Source: Martins (1989)

We must point out that, as in compression systems, absorption systems work with two levels of pressure: high pressure in the generator and condenser and low pressure in the evaporator and absorber.

However, unlike the compression cycle which has two levels of temperature, the absorption cycle has three levels: high temperature in steam generation, low temperature in evaporation, and intermediate temperature in condensation and absorption.

This type of equipment, introduced in the USA by Carré himself during the Civil War, when the supply of ice by the Northern States was cut off, had great diffusion at the industrial level, declining already at the end of the nineteenth century due to the development of the mechanical design of compressors and the diffusion of electrification. Martins (1989).

b) Systems with 3 fluids (Platen-Munters System)

The continuous absorption cooling system, despite being fundamentally powered by thermal energy, has a rich solution pump and therefore requires mechanical work for its operation.

To avoid mechanical pumping of the solution rich in the absorption cycle, Geppert (1899) suggested the introduction of an inert incondensable gas into the low-pressure parts of the system (evaporator and absorber) to complete the total pressure, which is more or less equal to the condensation pressure.

He used air as an inert gas but to no avail. The process of diffusion of ammonia in the air is very slow, and in addition, the mixture of air and ammonia vapor has a lower density than that of air thus not promoting the circulation of gases in the desired direction.

Two Swedes, Baltzar Carl von Platen and Carl George Munters (1922), suggested the use of hydrogen as an inert gas, Pure H2 is lighter than mixing with ammonia vapor, thus achieving circulation in the desired direction. In addition, the diffusion of NH3 into H2 is more intense than in the case of air.

The idea of Von Platen and Munters worked and was marketed with great success by Electrolux in Europe and Servel in the USA for the domestic refrigerator market from 1930, thus inhibiting the development of periodic systems that in the previous decade had flourished greatly in this market range.

Taylor (1945) presents a series of devices that can be used to promote the pumping of the rich solution from the absorber to the generator without the use of external work, using differences in temperature, concentration, pressure, liquid level (gravity), etc. However, for domestic refrigerators, the Platen-Munters system using an ammonia-water pair and hydrogen as an inert gas is the most widespread.

4.3.2 Platen-Munters refrigerator

The operation of the system chosen for testing, a refrigerator produced by Consul S/A. is described by Martins (1989) according to the manufacturer's specifications and temperature values obtained from tests with the system operating with electrical resistance of nominal power 260 W constant, without load (empty refrigerator).

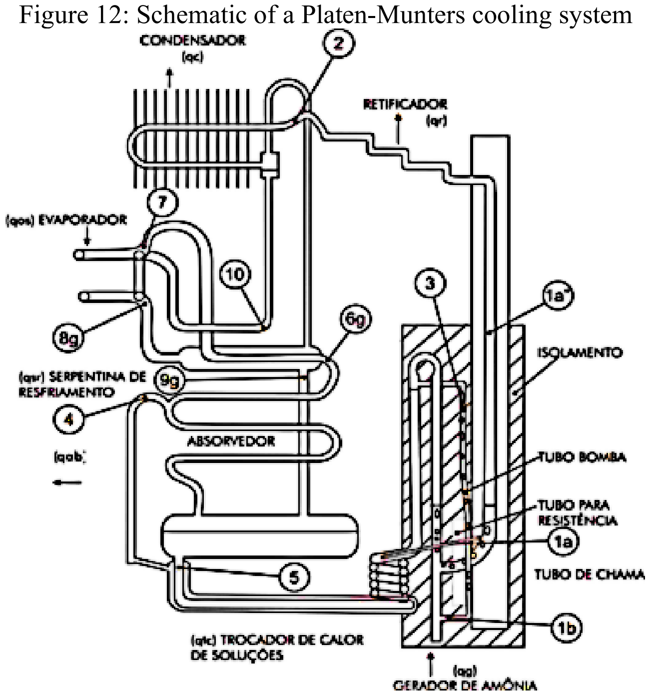
Figure 12 presents a schematic drawing of the equipment with its main components; the temperature measurement points and the heat fluxes involved per kg of ammonia entering the condenser.

When heat is supplied to the pump tube through the contact weld (with the flame tube or with the electrical resistance insertion tube), it heats up to the vaporization temperature of the solution that is there at a pressure of 25 atm. With this there is the formation of vapor bubbles that, due to the small diameter of the tube and the difference in density between the vapor and the liquid, form a biphasic flow of the pistonated type, transporting the solution to the outlet of the pump tube (point 3).

At this point, the poor solution, with a temperature of about 180ºC and a concentration of 0.15, separates from the steam that is in equilibrium with it at the same temperature and concentration of about 0.58. With each increment of poor solution that is transported by the pump tube and reaches point 3, an identical amount overflows into the absorber (point 4), passing through the annular space between the tubes of the solution heat exchanger. The steam that comes out of the pump tube, goes down the other tube and is forced to bubble into the rich solution that comes from the inner tube of the solution heat exchanger.

This is the so-called "analyzer", whose function is to increase the concentration of ammonia that comes out of the generator. The steam that comes out of the "analyzer" is in equilibrium with the rich solution that enters it, at a temperature of about 145ºC.

Figure 12: Schematic of a Platen-Munters cooling system



Source: Martins (1989)

The solution that comes out of the "analyzer" at (point 1b) is warmer and less concentrated than the rich solution that reaches it by (1 a) (about 180ºC and 0.23), and then goes to the pump tube.

The steam that leaves the "analyzer" by (1 a), in equilibrium with the rich solution has a concentration of about 0.84, then passes through the rectifier where through the cooling by the ambient air occurs the condensation of the water vapor (less volatile) that runs back to the generator, obtaining at the end of the rectifier practically pure ammonia at a temperature of about 58ºC, which is the condensation temperature of ammonia at the pressure of 25 atm.

In the condenser, through cooling by ambient air, the ammonia will be cooled to a temperature close to the final evaporation temperature. The construction of the coil allows a siphon to form, which serves as a liquid ammonia seal that prevents hydrogen from passing from the evaporator to the condenser.

When overflowing into the evaporator at (point 7), the liquid ammonia comes into contact with the gaseous mixture of H_2 and NH_3 that left the absorber through (point 6g) and passed through the inner tube of the coil and sub-cooling. This mixture is poor in ammonia and therefore its partial pressure in the gaseous mixture is small (between 1.0 and 1.5 atm). The evaporation process is conjugated with the diffusion of ammonia vapor into hydrogen, so the vapor pressure of liquid ammonia must be higher than the partial vapor pressure in the gas mixture for diffusion to occur.

As ammonia evaporates and diffuses into H_2, its partial pressure in the gas mixture increases. The vapour-rich gaseous mixture of NH_3 is heavier than the poor one, thus causing a counterclockwise circulation of the gases in Figure 12. At the beginning of the evaporator, where the partial pressure of NH_3 in the poor gas is lower (1 to 1.5 atm), the vaporization temperature is also lower (around –25ºC) this upper part of the evaporator is used as a freezer.

At the bottom, the partial pressure of NH_3 vapor in the gas increases to 2 to 3 atm, depending on the thermal load, consequently increasing the vaporization temperature to values between –15 and 0ºC. This part of the evaporator with higher temperatures is used to cool the refrigerator cabinet through fins.

From the end of the evaporator, the NH_3-rich gas at a low temperature (point 8g) passes through the annular space between the tubes of the sub-cooling coil, where it will cool both the poor gas and the liquid ammonia that will enter the evaporator. It then goes to the absorber (point 9g), where it will come into contact with the poor solution that descends in countercurrent with a great tendency to absorb ammonia. Here too, to have the absorption of NH_3 vapor from the rich gas into the solution the partial pressure of NH_3 in the gas must be always greater than the vapor pressure of the solution.

Because the process is countercurrent, the vapor pressure of the rich solution must be less than the partial pressure of NH_3 in the rich gas and that of the poor solution less than that of the poor gas. In addition, for absorption to occur, it is necessary to reject the condensation heat of ammonia vapor and the heat of NH_3 solution in H_2O.

At the bottom of the absorber, there is a reservoir that collects the enriched ammonia solution. This reservoir is connected to the input of the "analyzer" through the heat exchanger of solutions. In this heat exchanger, the poor solution that leaves the generator at high temperature (180ºC), yields heat to the rich solution that goes to the "analyzer", where it will enter with a temperature of about 145ºC.

This allows a more efficient absorption by the poor solution and decreases the amount of heat to be supplied in the generator.

In the experiment carried out by Martins (1989) with the refrigerator, it was observed that the decrease in the final temperature of evaporation with a very sharp drop in both the refrigerator effect and the cooling capacity. Another fact that should be noted is that despite the changes in the operating conditions of the evaporator, the behavior of the other components of the cycle is little changed. This behavior was also observed by Pagliuso *et all* (n.d.) who experimentally determined the refrigeration capacity of an ammonia absorption refrigeration system similar to that used by Martins (from the same manufacturer included) simultaneously measuring, through thermocouples, the temperatures at the main points of the system for two powers supplied to the generator through electrical resistance (260 and 380 W).

4.4 COUPLING OF THE THREE SYSTEMS (RESULTS OF THE COMPARISON)

4.4.1 Coupling Test

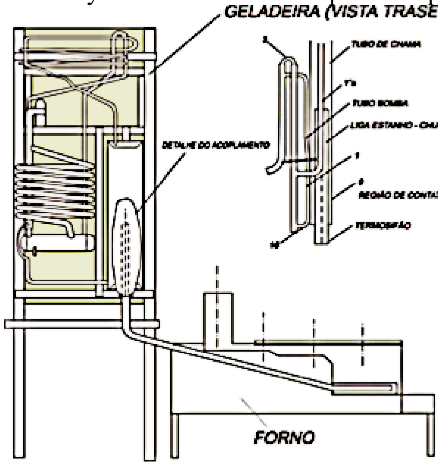
Knowing the behavior of the systems (stove - thermosiphon and refrigerator) when subjected to relatively constant operating regimes, we can then finally perform the coupling (oven - thermosiphon - refrigerator).

This coupling is done in a similar way to what Martins (1989) suggests, that is, by inserting the thermosiphon condenser inside the flame tube of the ammonia generator and using the same alloy (60% lead and 40% tin) to improve the thermal contact between them.

Temperatures can be taken at various points in the ammonia refrigerator refrigerator, indicated in the detail of Figure 13, as well as the air temperatures in the center of the freezer and at three points in the refrigerator cabinet and in three points in the adiabatic region of the thermosyphon.

In the test with the steel thermosiphon fitted to the grid, whose test methodology followed that which had been used in the previous phase, two measurements were made and the average air excess was 147% with a heat flow in the flue gases of the order of 2.7 KW, and the Power supplied was 9 KW. Martins (1989).

Figure 13: Final assembly of the oven-thermosiphon coupling and refrigerator



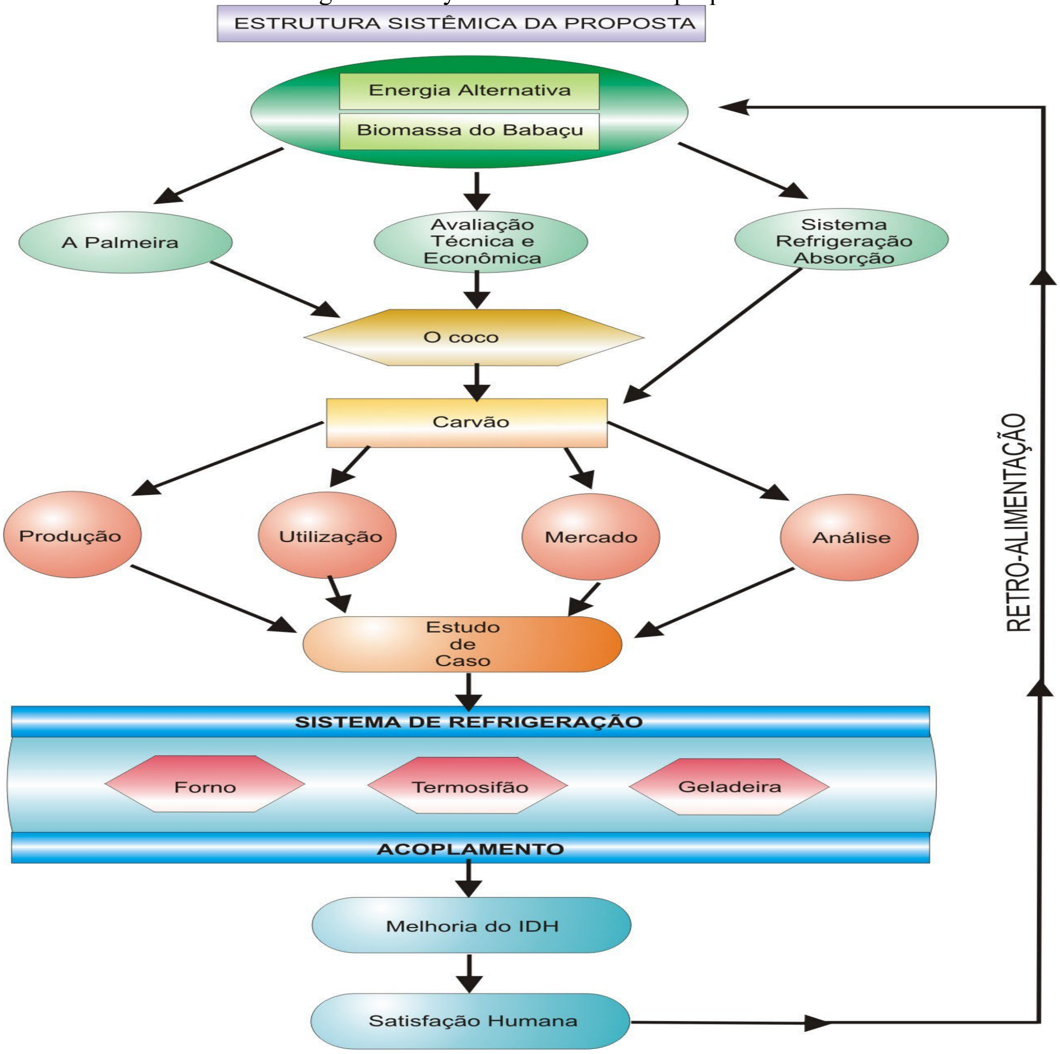
Source: Martins (1989)

4.5 SYSTEMIC STRUCTURE OF THE PROPOSAL

The system approach of our proposal is summarized in Flowchart 03 below. It integrally guides the work and reveals various relations, properties, components and qualities that are manifested in the process of development, of the states or levels through which this process passes and that materialize in the improvement of the HDI (Human Development Index) and satisfaction of the man of the Maranhão countryside.

"The systemic approach is based on the principle of systematization, but differs from it, meaning that the object of study is structured with a set of invariants, but constitutes the expression of the essential content and guides the process of search for the remaining knowledge that gives it precision, depth and solidity" (Nascimento, 2000).

Figure 14: a systemic model of the proposal



Source: Author (2004)

5 CONCLUSIONS

After the knowledge of the entire system of operation of the coupled set (stove, thermosiphon and refrigerator) and the experimental results obtained by Martins (1989), it is up to us a compared analysis of the proposed system consisting of (oven-thermosiphon and refrigerator) using babassu charcoal.

As the oven is an equipment intended purely for the burning of coal (without upper openings for pots - stove) this amount of heat is absorbed by the body of the same, increasing its efficiency transferred to the thermosiphon.

The babassu coal with the calorific value of the order of 7,300 kcal/kg allows us in a simple way to obtain the amount of coal mass (load) to be used to feed every 10 min the oven to keep the power refrigerator running the order of 260w.

Q (j) = P (w) x t (Δs) (3.1) (2)

For P = 260w and t = 10 min = 600s, we have:
Q = 260 x 600 => Q = 156,000 J or Q = 37.3 Kcal.

In real conditions, due to the large number of variables that make up the phenomenon of coal combustion in the furnace, losses reach 70%, so we calculate the mass of coal for 30% of its calorific value.

30% x 7300 kcal/kg => 2,190 kcal/kg, corresponding to the mass of 0.017 kg, which in grams, is: 17g for every 10 min or 102 g/hour.

Keeping the same load suggested by Martins (1989) of 400g of coal to meet the volume capacity of the furnace, we have 235.29 min, which in hours corresponds to: 3.92 h.

We conclude that initial objective of the work: To develop a study for the activation of a cooling system through babassu coal, was largely fulfilled. The use of babassu charcoal to replace wood in addition to providing a use of the by-product (endocarp) contributes to the preservation of the environment.

The result allowed us to conclude that the supply interval of the load (coal) to the oven is 4hs to keep the refrigerator running.

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