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The Nile tilapia viscera oil extraction for biodiesel production in Brazil: An economic analysis

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ABSTRACT

The present study evaluates the viscera of the Nile tilapia (bred in captivity) for bio-oil production and its impact on the biodiesel supply chain. We report in detail all the steps, from viscera extraction to the economic viability of the produced biodiesel, that led to the development of an oil extraction unit and the separation of the resulting sludge. Given that the Nile tilapia's viscera have a mass balance of 10% and that about 40–50% of the oil can be obtained from the viscera, the proposed oil extraction unit is capable of producing of 201.08 kg of oil in an 8-h operational time shift. Physicochemical tests conducted under the American Oil Chemists' Society's methodology indicate that the oil obtained has an acidity level of 0.15 mg KOH/g. The acidity level of the final biodiesel obtained is within the parameters set by the related production directives; that is, 0.22 mg KOH/g. A detailed economic analysis of the developed system showed a net present value (NPV) of US$ 93,561.13 and an internal rate of return of 45%. As for construction investment, the payback period is 1.9 years. In sensitivity aspects, the variance in viscera obtained in 90% over the reference value (US$ 0.05) in the raw material source will lead to a value of US$ 10,443.15 in NPV. The processing capacity will reach its break-even point at 60% of the installed production capacity when there will be neither loss nor profit. Therefore, it is possible to conclude that this new biomass source will be viable along with the development of new technology to process it, generating value for fish viscera and diminishing the environmental impacts of fish farming.

1. Introduction

The world population is increasing at a very fast pace and, hence, new energy sources have become indispensable. Since new energy technologies are expected to continually deal with human needs, the academia and the energy industry are focusing on how to provide new energy sources. Renewable and sustainable energy sources are the preferred options for the energy industry to diversify, aiming at local sustainability and preservation of the environment [1–3]. The use of vegetable oil- or animal fat-based oils in diesel engines do represent an innovation in this scenario since biodiesel has the following advantages over traditional fuels [1–3] obtained from organic sources (e.g., petroleum): it is devoid of sulfur and aromatic compounds; it is rich in hexadecane (cetane); it is oxygenated; it has a high flash point; it has non-toxic characteristics, and it is biodegradable. What makes bio-oil attractive as a fuel, however, is its renewable feature and countless sources.

In 2004, the Brazilian government launched a nationwide program to foster the production of biodiesel (PNPB) with two main objectives: encourage the production of bio-oils, and financially help poor farmers as part of a social program. Credit lines were opened to help fish farmers to use resources from the National Program for the Strengthening of Family Agriculture (PRONAF). Furthermore, bio-oil industries also benefited from this initiative by being allowed to acquire materials directly from family farmers, as well as from the social stamp that comes with tax benefits, representing lower tax payments, and the possibility of participating in public notices for selling the production organized by the Brazilian petroleum and gas authority (ANP – Agência Nacional de Petróleo e Biocombustíveis) [4].

Several studies have analyzed the potential of bio-oil plants such as the Ricinus communis (castor bean), the Helianthus annuus (Sunflower), the Brassica napus, Brassica rapa, and Brassica juncea (all

Abbreviations: NPV, net present value; AOCS, American Oil Chemical Society; ASTM, The American Society for Testing and Materials; EN, Européen de Normalisation; NBR, Brazilian regulatory norms; IRR, internal rate of return; NPW, net present worth; MARR, Minimum Acceptable Rate of Return; ROI, return on investment; BEP, break-even point; TR, total revenue; TE, total expenses; TPC, total production costs; VR, variable costs, FC, fixed costs

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commercially known as canola), as well as the Attalea speciosa (babassu) and the Zea mays (maize) [5–10]. However, some issues (e.g., low productivity, the high price of the produced oils, and low market offer) make their production insignificant in terms of market presence. Hence, further studies and raw materials are still being demanded for the production of biodiesel to become viable nationwide.

Some raw materials, particularly those of animal origins, such as pork and chicken fat have been analyzed for use as a biodiesel source. The negative aspect is that each liter of animal fat disposed of in the sewage system or watercourses has the potential to pollute about one million liters of drinking water. Studies have demonstrated that materials otherwise constituting an environmental hazard can become useful when converted into bio-oil through a realignment of the productive system and economic adjustments leading to the viable production of bio-oils [8–13]. Extraction of oil from fish industry residues is an example [13,19,21,22]. In 2009, the production of fish in Brazil was 290.000 t, whereas, in 2011, the production reached 700.000 t [35]. According to the most recent FAO report, the State of World Fisheries and Aquaculture - SOFIA 2018 (downloadable from http://www.fao.org/3/I9540EN/i9540en.pdf), the fish industry processed approximately 171.000.000 t of fish, with 47% of this number corresponding to fish bred in captivity. The resulting generated economic value is of the order of 362 million dollars.

Despite the economic importance of the fish industry, it is hard to find methods in the specialized literature to tackle the problems related to the production of residues [39,41,42]. The existing methods are mainly intended for big industrial producers. A large amount of potential biomass material is not used, and end up in either dumping grounds or landfill sites. There are currently around 50 operative biodiesel units in Brazil. Raw materials for production, however, have prices that could impair the large-scale production of biodiesel. Considering the prices of diesel, the use of biodiesel obtained from the oil extracted from fish residues is an opportunity to be evaluated in its technical and economic aspects. Also, companies need to maintain a certification of social fuel, which should bring them tax benefits. This study takes one fish species as a model and presents a process that can be adapted for other species. The species studied here is the Nile tilapia (Sarotherodon niloticus). Tilapia is the second-most common fish species produced in captivity, after the carp [44]. This species has been well received in the Brazilian food market, representing 46.6% of the fish produced in freshwater.

Due to its potential impact on biodiesel production, more studies on the use of residues from the fishing activity are needed. Lab-scale studies have evaluated the oil obtained from fish industry residue as a source for biodiesel. These studies have focused on the physicochemical analyses of the oil obtained using different fish species and parts [14–35]. It has been found that the addition of bio-oil to common diesel in a 4.5 kW and 1.500 rpm diesel engine resulted in the reduction of NOx emission [31]. By feeding it in a diesel engine showed that it cannot be considered proper biodiesel, yet it still presents good burning power and emitted different levels of CO2 and NOx [32]. The use of reagents and homogenous catalyzers in adequate stoichiometric ratios have also been studied; however, the contribution of these studies involves only the optimal use of those materials [18].

Productivity tests of biodiesel using the oil of Cyprinus carpio (common carp) showed parameters that can be characterized as a first-order reaction, with an activation energy of 32.46 kJ/mol [18]. Optimization of the reactions of using the oil of Silurus triotegus (Mesopotamian catfish) as alkaline catalyst demonstrated the versatility and potential of many fish species as raw material for biodiesel [19]. The pollutant emissions of diesel engines can be reduced by 44% by using the biodiesel generated from fish residues, as studies have shown [27]. The optimal time to produce biodiesel from fish residues is 120 min and the oil thus obtained would have a combustion heat of 42.1 MJ/kg [24].

The use of canned industrial oil for the production of biodiesel was also tested. Here, unlike similar works, sulfuric acid was esterified in a concentration of 1–3% of mass. The oil potentially obtained through chemical silage of fish residues was found to show an oil efficiency of 42.8% (m/m). The authors considered the high acidity of oil as arising from the enzymatic processes occurring in the raw material. This makes the oil unusable for biodiesel production, but can be tackled with the use of an antioxidant, such as alpha-Tocopherol [34]. It is used to determine the oil conversion in methyl esters and was evaluated as a mechanism to optimize the reaction and synthetic parameters [34]. As already mentioned, a big problem in oil extraction and quality of fish oil is the increase in acidity. Since fish oil has elevated water content, enzymatic activities could occur, leading to hydrolysis of the triglycerides and the release of fatty acids [36–38,53]. This can be avoided by introducing a preliminary phase in the oil extraction process involving a sterilization process; the final oil obtained would then have low acidity levels.

It is worth pointing out that even if the quality of the bio-oil originating from fish residues is verified, the economic viability of the oil depends on a great extent on the volume of the oil produced, in order to motivate a large scale industrial production. However, in order to produce large volumes of oil, it is necessary a well tuned (i.e. structured) supply chain for storage and transportation of fish viscera. Since the production of Tilapia in Brazil and other developing countries involves to a great extent local communities, and since these communities are spread around the huge territory of the country, adequate storage and transportation of fish residues to larger urban areas in order to be processed are unfeasible due to the high costs involved.

Bearing these logistic constraints, we argue that the governmental efforts should be directed not only to large scale producers but also (and especially) to small local fishing communities. To test our hypothesis, we report the results of a thorough analysis of all stages of the process of generating bio-oil from Nile tilapia's viscera. Firstly, a careful physicochemical analysis is carried out to assess the quality of the extracted oil from fish viscera. Secondly, the design and construction of a portable and affordable oil extraction unit targeted at small fishing communities. Thirdly, a comprehensive economic analysis is developed in order to evaluate the affordability of the proposed oil extraction unit for poor fishermen communities and fish farmers.

The remainder of the paper is organized as follows. In Section 2, the materials and methods used in this research are described. The results, including those from the economic viability analysis of the biodiesel extracted from Nile tilapia's viscera, are reported and discussed in Section 3. The practical implications of this work are discussed in Section 2. The paper is concluded in Section 5.

2. Material and methods

In this section we explain the extraction procedures for and characterizes the oil obtained from the Nile tilapia viscera as well as the transesterification process to produce biodiesel. A previous characterization of Nile Tilapia's viscera appears in [54]. In the current paper, however, the viscera sample was carefully selected for a better quality and efficiency of the oil, as illustrated in Fig. 1.

2.1. Physical-chemical analyses of oil extracted from fish viscera

The oil was characterized according to the American Oil Chemical Society (AOCS) guidelines (see Refs. [26,38,40,51,53]), and the acidity level, saponification value, refractive index, iodine level, peroxide value, specific mass, humidity, and viscosity were analyzed. The following parameters of biodiesel were also analyzed: acidity level, specific mass, free and total glycerol, oxidative stability with and without antioxidants, and humidity. The American Society for Testing and Materials (ASTM), Européen de Normalisation (EN) and Brazilian regulatory norms (NBR) guidelines were used for the analysis.

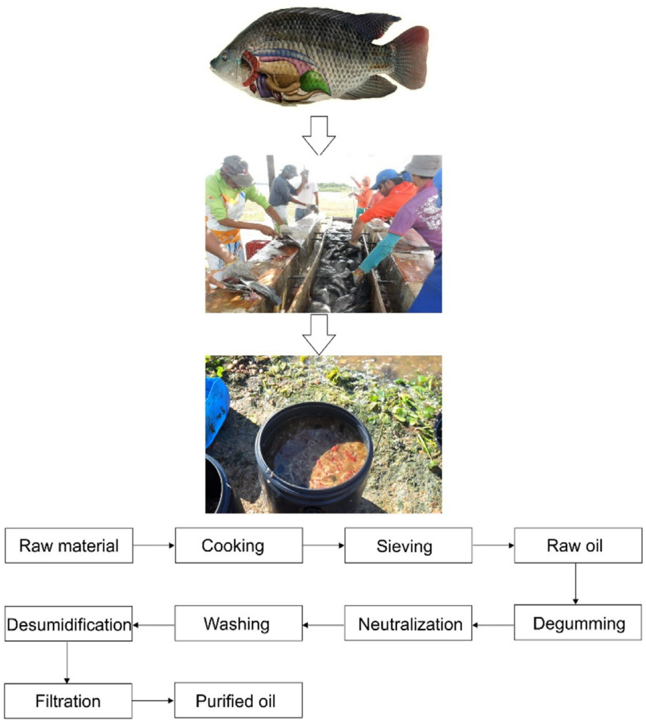

Fig. 1. Sequence of steps involved the process of oil production from fish viscera.

2.2. Determination of fatty acids

For the determination of methyl esters from fish viscera oil it was used the European Standard EN 14103. The analyses were carried out in Shimadzu equipment 17A model, Supelco capillary column with 5% of phenyl and 95% of dimetilpolisiloxane (100 m × 0.25 mm and 0.25 µm). The carrier gas used was nitrogen. The operating conditions were: initial column temperature 150 °C, detector temperature of 280 °C, column temperature programming: 15 °C/min until 240 °C and maintained for 2 min and then 20 °C/min to 260 °C maintained for 21 min [52].

2.3. Determination of calorific value

To evaluate the calorific value of biodiesel from fish oil it was used a Automatic Calorimeter Bomb, manufacturer: IKA, model: C-200.

2.4. Methodology for the extraction of oil from fish viscera

Fish viscera weighing 700 g was placed in a heated system (60 °C) under constant stirring for 20 min, and the solid residues were collected using a filtration system made with sieves. The system was left to rest for decantation of the sludge (mostly dark and watery non-fatty material from the viscera matter).

Next, a degumming process was carried out after adding 2 g of heated water (60 °C) (representing 5% of the obtained oil mass, 350 g) under constant stirring for 20 min, and the oil was left to rest. Then, the polar compounds in suspension (bile acids, phosphorus compounds, and solid particles) were decanted. The supernatant was neutralized to eliminate any excess free fatty acid and other specks, such as proteins, oxidized acids, and pigments. This was carried out under continued stirring for 15 min. The next step involved washing the material with distilled water heated up to 80 °C (5% of the oil mass) under continued stirring for 10 min. This process eliminated any traces of soap, hydroxides, and other contaminants in suspension. The final step was to dehumidify the oil (100 °C) under continued stirring for 30 min, followed by vacuum drying. This sequence of steps is illustrated in Fig. 1.

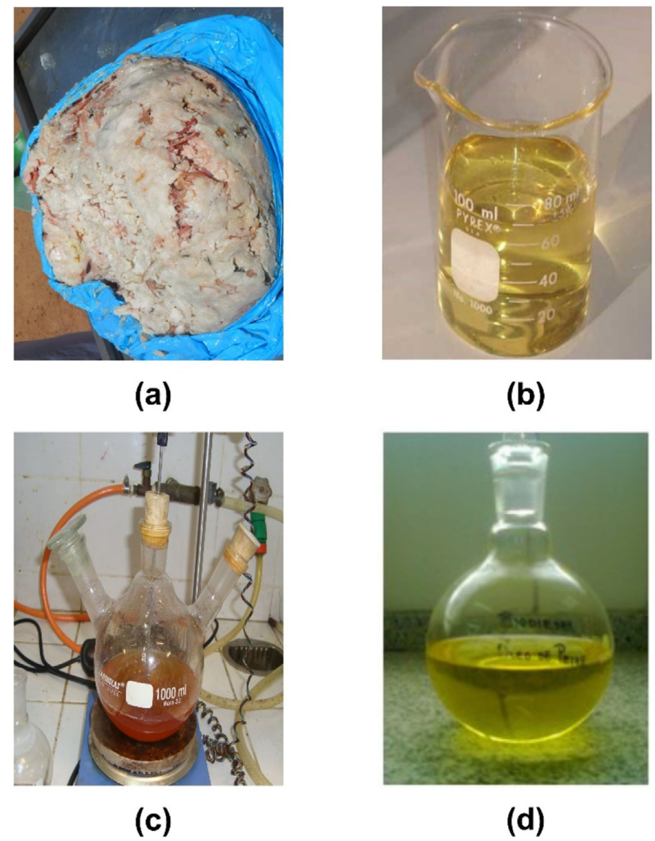

Fig. 2. Phases of methyl transesterification of the biodiesel from tilapia viscera. (a)Viscera (raw material); (b) extracted oil; (c) transesterification reaction; and (d) fish biodiesel.

2.5. Methodology to produce biodiesel from the oil extracted from fish viscera

The oil extracted from the tilapia viscera was subjected to a transesterification process using a conventional alkaline catalyst [500 g of oil and methyl alcohol in the molar ratio of 1:6 (oil: alcohol)] [51]; the NaOH catalyst was in relation to the mass of oil. The process was carried out under constant temperature (60 °C) with continuous stirring for 1 h, and then the compound was left to rest in a decantation flask to separate the glycerol. The superior ester phase – biodiesel – was purified through a humid route. Heated distilled water (80 °C) was added to the mixture in the proportion of 10% (m/v) of the ester phase mass. This step was repeated three times, with a 1-h interval between each washing for decantation and water collection, as illustrated in Fig. 2.

2.6. Physical-chemical analyses of biodiesel

The physical-chemical properties assessed were the following ones: (i) iodine value by volumetry using Wijs reagent according to the norm EN 14111; (ii) kinematic viscosity stated by the norm ASTM D 445-97; (iii) specific weight 20 °C according to the norm ABNT NBR 14065; and (iv) water content by the norm EN ISO 12937.

2.7. System engineering

For the development of an oil extraction unit from fish viscera, it was necessary first to gather laboratory data in order to assess the physicochemical properties of the raw material, such as density and viscosity. Once these properties have been analyzed and the adequate

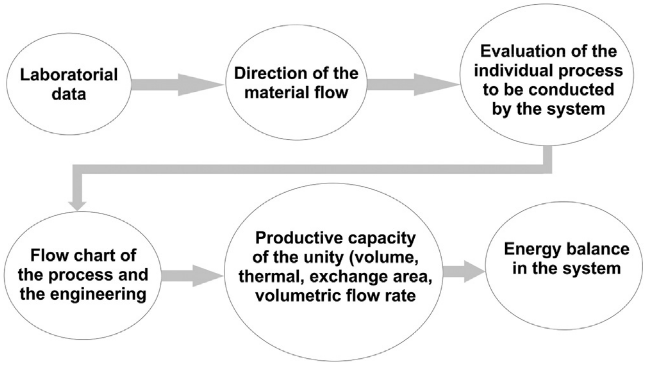

Fig. 3. Flowchart of the decision stages in the basic engineering leading to the design of the oil extraction unit from Tilapia's viscera.

direction of the flow of products and residues have been defined, we carried out the choice and specification of the constituent parts of the physical unit itself; from general equipments, such as pumps, instrumentation, valves and pipes, to specific ones, such as tanks, reactors and heat exchangers. It should be noted, that the choices of building materials followed chemical compatibility norms and standards in order to avoid potential problems with corrosion. Last but not least, we determined the productive capacity of the unit that eventually led to energy/mass balance. The flowchart of the whole process is presented in Fig. 3.

2.8. Cost analysis

A unit involving small equipment was developed. The total capital invested was based on the data given in Table of Peters and Timmerhaus (1991) [50], where typical fixed capital component costs are shown in percentage. Peters and Timmerhaus (1991) obtained the percentages from a Bauman study, as well as from more recent sources and modern industrial experience. The cost parameters were obtained from the literature [44–50]. Depreciation is the book value that is added to the production cost to compensate for the depreciation of the installations and equipment. In developing countries, this period is usually 10 years for machinery.

The working capital was 15% of the fixed capital, and the maintenance and repair costs were estimated as 6% of the fixed capital [45]. Other parameters used in this study are based on the literature [43,45] and tests (15% of the operational workforce), supervision and office tasks (1.5% of the fixed capital), operational supplies (15% of the workforce and repairs), patent and royalties (3% of the manufacturing cost), local taxes (1.5% of the fixed capital), distribution and sales (10% of the manufacturing cost), research and development (5% of the manufacturing cost), other expenses, packing and storage (60% of the result of adding the operational workforce, maintenance, and repairs), and administrative costs (25% of the cost).

The total production cost of oil extraction from viscera was based on the fixed and variable costs of the process. These results were obtained using a percentage method, as described in the methodological analysis. The variable costs are the costs that can be increased or decreased according to the supplier market. Some of the variable costs are the costs for the viscera, thermal oil, electricity, and cooling water. The fixed costs are determined as those for activities needing supervision in the unit. Examples are those for the workforce, product quality tests, maintenance and repairs, depreciation of equipment, local taxes, insurance, indirect costs (packing and storage), and general expenses (distribution and sales).

The analysis decision is based on the methods and criteria well accepted in academia to measure profitability and the economic viability of investment alternatives. The following are some of the methods used: the net present value (NPV) method, internal rate of return (IRR) method, and the return of the investment period (4851–4952). A sensitivity analysis gives the net value that would be obtained from the isolation of the variable that, all other factors remaining constant, and produce significant changes in the project and in the investment decision. The project, the system, and the operative unit helped to verify the ability to generate income and profits from the extraction of oil from captivity Nile tilapia viscera.

Table 1
Physicochemical parameters for the oil from tilapia's viscera.

Parameters	Values and deviation	Units
Acidity level	0.150 ± 0.06	mgKOH/g
Iodine level	82.61 ± 0.64	gI_2/g
Saponification value	165.36 ± 6.00	mgKOH/g
Peroxide value	13.94 ± 0.00	mg KOH/g
Refractive index	1.468 ± 0.00	Dimensionless
Specific mass at 20 °C	914.20 ± 0.00	kg/m^3
Oxidative stability	5.417 ± 0.02	Hours
Viscosity at 40 °C	37.07 ± 0.02	mm^2/s
Karl Fischer humidity	583.02 ± 0.52	mg/kg

3. Results and discussion

3.1. Physical and chemical characterization: extracted oil and resulting biodiesel

The physical and chemical characteristics of the compounds are analyzed instead of the percentage of components, and these are used with the qualitative reactions to evaluate and identify the compounds of a substance. See Table 1 for the results. The AOCS methodology was used as the guideline for test characterization using the tilapia's viscera.

The physicochemical analysis was conducted using the methodology proposed by the Brazilian oil and gas authority ANP and is summarized in Table 2. By analyzing this table, we can infer that the biodiesel made from the Nile tilapia's viscera was found to agree with the parameters specified for the biodiesel supply chain.

The chromatographic profile of fatty acids found in the tilapia's biodiesel revealed a major presence of oleic esters (C18:1), palmitic (C16:0), linoleic (C18:2), palmitoleic (C16:1), stearic (C13:0), myristic (C14:0), linolenic (C18:3), arachidic (C20:0), erucic (C22:1), lauric (C12:O), behenic (C22:0), erucic (C22:1), and other minor components. All these data are gathered in Fig. 4 for better visualization.

3.2. Design and construction of an oil extraction unit

A diagram of the unit is shown in Fig. 5. It has a modular platform to incorporate all the equipment described in the flow chart. The production follows a sequential batch feeding system, enabling the equipment to be installed and fish residues to be processed even in remote areas. The equipment has the capability to process up to 25 l of

Table 2
Physicochemical characterization of the Methyl Biodiesel from Tilapia's viscera.

Parameters	Values and deviation	ANP	Unit
Acidity level	0.22 ± 0.06	0.5 (max.)	mgKOH/g
Iodine level	83.29 ± 1.35	–	gI_2/g
Free glycerol	0.0163 ± 0.00	0.02 (max.)	%
Total glycerol	0.32 ± 0.01	0.25 (max.)	%
Specific mass at 20 °C	875.64 ± 0.01	850–900	kg/m^3
Oxidative stability (without antioxidant)	5.80 ± 0.25	6.0 (min.)	Hours
Viscosity at 40 °C	4.53 ± 0.00	3.0 – 6,0	mm^2/s
Karl Fischer humidity	235.5 g ± 2.75	500 (max.)	mg/kg
Calorific value	39.76		Mj/kg

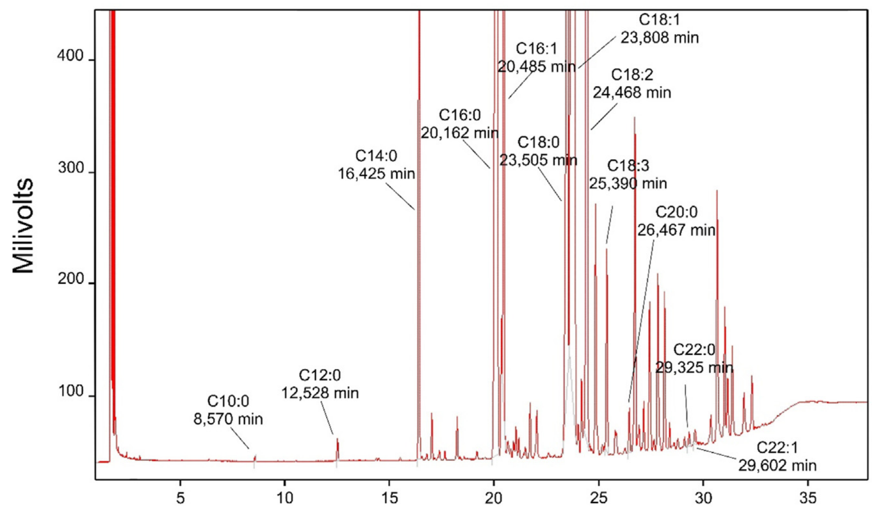

Fig. 4. Percentages of fish biodiesel esters.

oil per hour. A first prototype of the unit was implemented in [55], but the unit proposed here has an improved design and, hence, much better performance.

The laboratory data for extraction of the viscera are shown in Table 3. These data form the basis for developing the equipment needed for the unit's correct operation. Production and handling tests using the tilapia's viscera were conducted. A total of 420 kg of viscera was processed. The ratio of viscera to corporal mass was 10%, corresponding to the evisceration of 4.2 t of raw fish, to produce 201.08 kg of viscera oil. The productivity of the system is 50% in terms of mass of the processed viscera. The system and its template are shown in Fig. 6.

3.3. Total invested capital

The main equipment's price was verified from the final user market because the considered cost analysis correlations did not include small systems like the one developed in this work. The equipment's specifications were sent to metallurgical enterprises to find the value of the equipment and the cost to build it. The direct costs, indirect costs, fixed costs (FC) (direct + indirect), working capital (WC), and total amount required to build one oil extraction unit are shown in Table 4. The direct costs are the most important, comprising 58.3% of the total capital invested to install the unit. The indirect costs represent only 28.6% of the total fixed costs.

3.4. Annual production total cost

In order to properly evaluate the total annual production cost, a production line working for three shifts during a given day was considered. In the best scenario, a production system would work close to its maximum capacity. Therefore, by evaluating the costs incurred in one productive day, the best production system can be found.

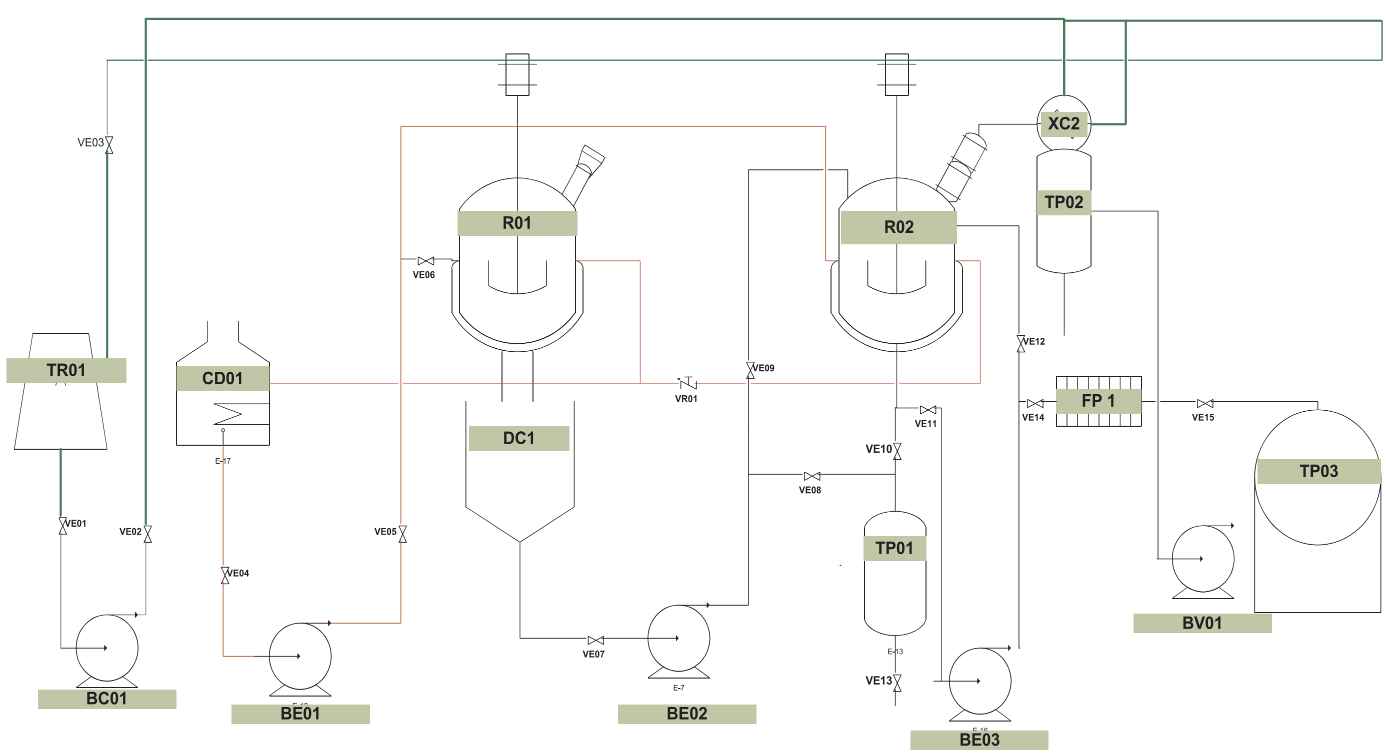

Fig. 5. Schematic diagram of the fish oil extraction/production unit.

Table 3
Operating conditions of the oil extraction system.

Stages	Function	Acronym for identification	Residence time (minutes)	PVT conditions	Variable
Cooking	Physical extraction of the oil	R01	10	60 °C	Supply volume, reactionary time
Decantation	Separation of the oily and watery phases	DC1	15	Terminal velocity	Decantation time; terminal velocity
Degumming	Extraction of the sludge and the phospholipids	R02	20	80 °C	Degumming time
Drying	Removal of the water	XC01	15	110 °C	Condensing temperature
Filtration	Final oil cleaning	FP1	2	20 micro meters	Particle diameter
Sludge collection tank	Store protein material	TP01	Hours	60 °C	Material volume
Condensed collection tank	Store condensed water	TP02	Hours	40 °C	Material volume
Product tank	Store fish oil	TP03	Hours	35 °C	Daily production

Among the variable costs, the costs to acquire viscera represented the largest cost per year. The estimated cost of a 1 kg viscera is US$ 0.05. This cost can be reduced to zero by giving the fish farmers full access to the unit because the tilapia's viscera would then be readily available. In a 24-h period, one batch of viscera can be expected every hour. If this value is multiplied by 60 kg per batch, 432 t of viscera would be used in a production year of 300 days. The estimated cost of the raw material would then be as high as US$ 20,061.42 per year. This cost can be reduced by installing the unit as a co-operative responsible for the local evisceration of fish.

The distribution (in percentage) of the variable and fixed costs is shown in Fig. 7. From the data, the cost of viscera for processing takes up about 80% and electricity costs represent 19% of the total variable costs. The lowest percentage of variable costs is for thermal oil and cooling water, which do not have a visible impact, representing only 1% of the total variable costs. Fixed costs represent almost 73% of the total annual cost of the whole system. In amount, the annual fixed costs sum up to US$ 68.775,96, while the annual variable costs (27%) total US$ 25,031.42.

3.5. Financial indices evaluation

The NPV or net present worth (NPW) is the amount after subtracting the invested value (initial project investment) and the expected cash flow, discounted by conventional financial mathematics methods. The Minimum Acceptable Rate of Return (MARR) is the rate of return the investor expects by the end of the productive period. In this study, the MARR is stipulated as 20%, which would justify the investment. In Table 5 we show the financial indices obtained following the fish oil extraction process.

The economic indices indicate high economic viability for the system. The Return on Investment (ROI) of 26% for the process is an attractive estimate, indicating that the unit can generate income and form a labor market in its location. The IRR is higher than the MARR.

In Fig. 8 it is shown the variance in viscera price over the NPV in a 15-year period. The base value for this model is US$ 0.05. This is the price the vendors in fish markets charge for the Nile tilapia. The base value NPV is US$ 93,561.13. The variance in fish price will have a negative effect on the NPV when the price per kg of that raw material reaches 90% of the base value, leading to a value of US$ 10,443.15. For a value of US$ 0.09, considering all the taxes, the proposal will not be economically viable. If the viscera can be acquired without having to be purchased, the NPV would be US$ 209,121.45. Note that the present analysis considered a fixed price for oil, US$ 0.62. This price is reasonable because the unit would be under fish farming co-operatives and fish farmers would not have to spend a huge amount to acquire fish viscera. In a study of the impact of the viscera's price, the IRR ranged from 13% in the case of a 100% addition in the value of raw material to 74% in the case of no costs incurred to acquire fish viscera. The value of 74% is approximately equal to a 15% increase in the sale price of the oil.

A sensitivity analysis showing a variance on the oil price is presented in Fig. 9. The values were around zero in the figure's scale (in the present case, zero is equal to US$ 0.62). This corresponds to US$ 133,746.13 in a production line having three daily shifts, as explained earlier (financial indices), with an NPV of US$ 93,561.13. The limit to avoid a negative NPV is US$ 0.03. For a reduction of up to 10% of base value, the IRR is 27%, with the current net value of US$ 23,524.58. From the analysis, a 20% reduction will lead to an IRR value of 5%. However, for that reduction, the NPV was US$ 46,511.97. Therefore, for values below 10% of US$ 0.62, considering the legal impositions and tax, a compromise is possible in the system.

The break-even point (BEP) gives the production level when the total revenue (TR) and total expenses (TE) are equal (TR = TE), and there is no profit or loss. This analysis is important in order to verify the daily operative time for the unit to become profitable. This has a huge

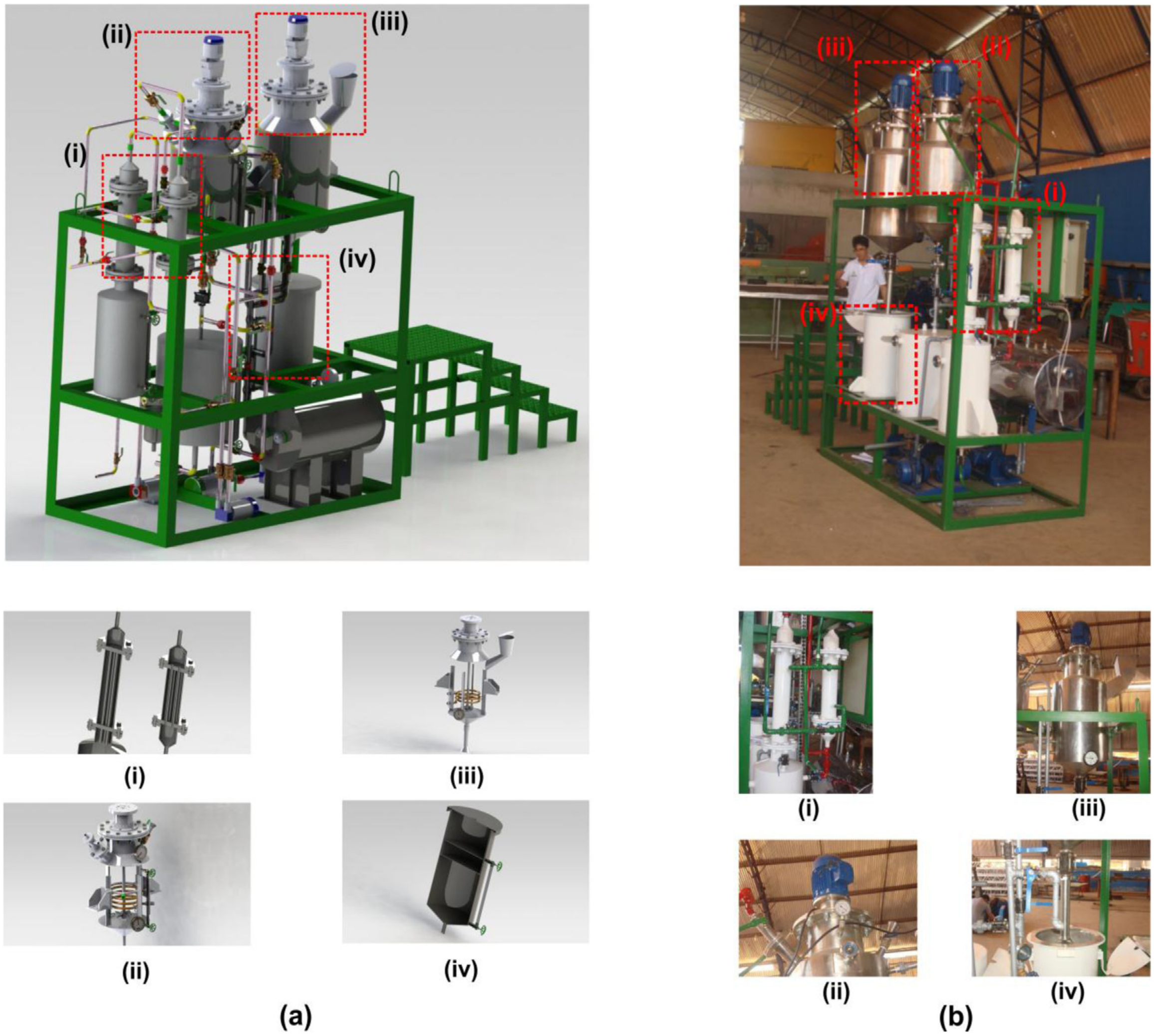

Fig. 6. (a) 3D drawing generated in CAD software for the oil extraction unit. (b) The constructed physical prototype of the oil extraction unit. Components: (i) - Heat exchanger (condenser), (ii) serpentine reactor, (iii) serpentine reactor, (iv) decanter.

Table 4
Total capital invested in the unit using the percentage method.

Direct costs (US$)	
Reactors	5960.37
Tanks	7021.67
Decantation tanks	4643.96
Boiler	4024.77
Heat exchangers	1300.31
Cooling tower	1238.39
Electric material	1616.10
Building	10,258.33
Area improvements	2849.54
Utilities	2849.54
Lot	1139.63
Indirect costs (US$)	
Engineering and supervision	11,968.67
Contracts	9127.80
Total (US$)	
Fixed costs (direct + indirect)	63,999.07
Working capital (15% of the fixed costs)	9599.86
Total capital invested (FC + WC)	73,598.93

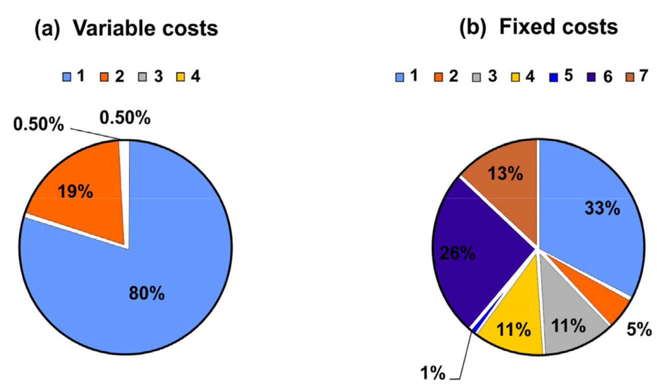

Fig. 7. (a) Variable costs: (1) Acquisition of fish viscera; (2) Electricity; (3) Thermal oil; (4) Cooling water; (b) Fixed costs: (1) Labor force; (2) Laboratory tests; (3) Maintenance and repairs; (4) Depreciation; (5) Local tax; (6) Indirect costs; (7) Distribution and sales.

economic impact. The total revenue (TR), total production costs (TPC), variable costs (VR), and fixed costs (FC) are used graphically, to find that there is no profitability at each point.

From Fig. 10, only after 60% of the installed capacity is used, will the system reach its BEP, when the unit will have neither profit nor loss. When over 60% of the capacity (259.2 t) is used, the unit will have a monthly profit. The amount of viscera used at this stage corresponds to two operative shifts of the unit (288 t). Therefore, the importance of productivity can be better understood in the regions where the unit is installed.

Table 5
Financial indices for the unit productive process.

Index	Evaluation
Return on Investment (ROI) (%)	26.0
Payback period	1.90
NPV (US$)	93,561.13
Internal Rate of Return (IRR) (%)	45.0
Production cost (US$/kg)	0.22

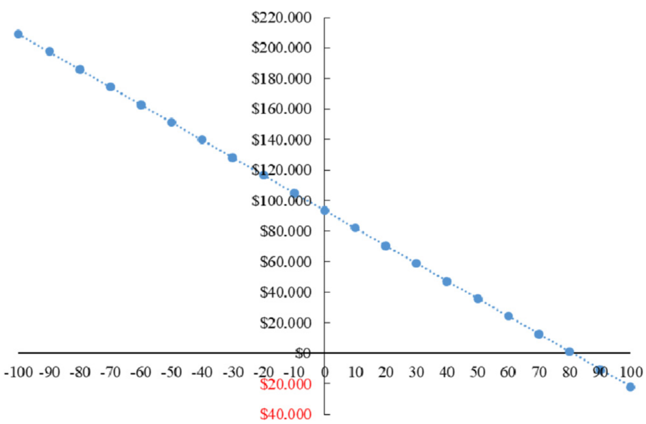

Fig. 8. Sensitivity analysis of the viscera price over the NPV.

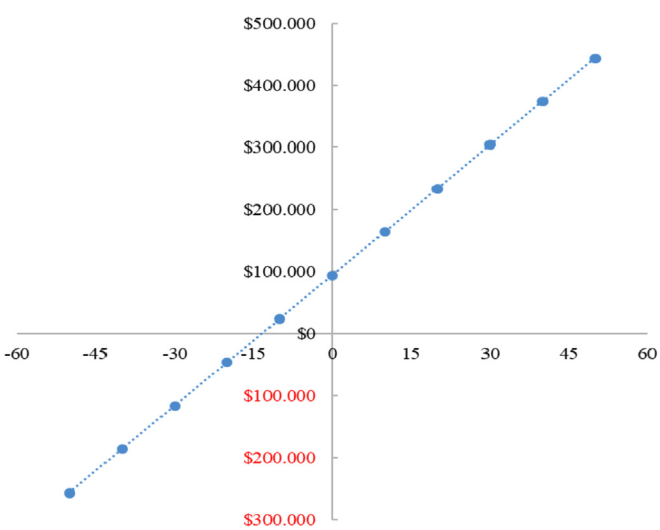

Fig. 9. Sensitivity analysis of the oil price over the NPV.

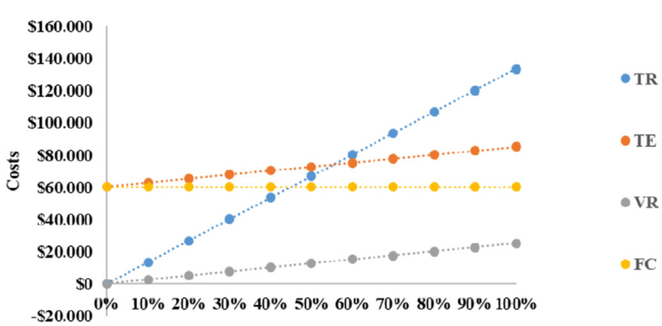

Fig. 10. Graphical representation of break-even point of the fish oil extraction unit.

As a final remark related to the economic analysis just carried out, especially due to the novelty of the proposed prototype of an oil extraction unit, we are not aware of similar projects. Furthermore, the particularities of each country may hinder a fair comparison between similar systems developed for these countries. I mean, Brazilian fishermen communities may be very different from those in African countries, or in North American countries. Certainly, a portable oil extraction may be useful for several fishermen communities elsewhere in the world, but with respect to the economic analysis, we have used as references prices and costs gathered from the Brazilian market (which is regulated by the National Petroleum Agency – ANP for the acronym in Portuguese). Thus, the reported results in specific to the Brazilian fishermen communities' reality.

4. Practical implications of this study

To conclude, the studies we conducted for developing the system allow us to infer that the unit has social, environmental, technological, and economic potential in regions where fish waste/residues can be found. Environmental implications: the system has the potential to reduce the environmental impacts related to the pollution of watercourses used for human consumption. That corresponds to the amount of water that one individual drinks during a 14-year period [52].

4.1. Social implications

It should be noted that the target users of our study are small isolated fishermen communities and poor fish farming cooperatives. Brazil, as one of the biggest international producers of fish for food purposes, is also one of the largest producers of fish waste/residues, such as fish viscera. Due to the continental dimensions of the country, fishermen communities and fish farming cooperatives are spread around the countryside and along the Atlantic coast as well, the vast majority of which comprised of people with very limited economic resources. Thus, the transportation of large quantities of fish viscera in adequate environmentally-safe and refrigerated conditions to large cities to produce biodiesel is greatly unfeasible, economically speaking. Thus, the construction of a portable financially accessible oil extraction unit becomes of interest to those communities.

4.2. Technological implications

To the best of our knowledge, the proposed unit for oil extraction from fish viscera is the first of its kind. There are previous studies on the use of other modalities of fish waste for bio-oil production, such as the head, but a complete unit fed exclusively by fish viscera has not been proposed before. As a consequence, the oil extraction unit described in this work has a patent request already deposited in the Brazilian office of industrial property (INPI), registered under the number PI013120000074.

4.3. Economic implications

The northeast region of Brazil is one of the poorest of the country. However, it has the largest seashore (approx. 3317 km) along the Atlantic coast and all the 9 states in this region have poor fishermen communities. Additionally, the countryside of the northeast region suffers from severe droughts and 7 out of 9 northeastern states are within the region known as Brazilian semi-arid [56]. It is very common to have water reservoirs of different sizes that local communities use for non-recreational fishing purposes. One of such water reservoirs is the Castanhão, located in the northeast state of Ceará, the largest in this state. In fact, it is the largest in the country (see https://en.wikipedia.org/wiki/Castanh%C3%A3o_Dam). After constructing the prototype oil extraction unit, it was moved to a fishing community in the vicinity of the Castanhão dam. After adequate training of the locals for operating the unit, it was left there for a while in order to gather opinions of the users about its operation and productivity. The feedback from the fish farmers was positive and reached the Petrobrás office responsible for the national policies involving biofuels. The advisory board of this office then decided to work in the production of this type of bio-oil production unit and in the distribution and adequacy of the unit to several fishing communities along the country.

Finally, but not less relevant, it should be pointed out that the demands from poor fishermen communities and workers' cooperatives are essential to orient social policies by public decision-makers and the correct implementation of these policies has a direct impact the amelioration of the life quality of those communities.

5. Conclusions and further work

In this paper, we reported the results from a comprehensive study aiming at the economic viability of the production of oil from the Nile tilapia's viscera. The study involved the physicochemical analysis of the oil extracted from the viscera according to international standards, design and construction of a prototype unit for the oil production, and the economic analysis of the whole supply chain involved in the process of production of biodiesel.

Since the target users of the present study and the developed technology are isolated rural communities of fish farmers, we believe that this study has great potential for promoting social development. Once the system becomes fully operational, it can promote better living conditions for the members of fishermen cooperatives who can use the proposed production unit. This can be a possible new income source for fish farmers. The system can also contribute by reducing the environmental impacts of the fishing industry. Fish viscera would be used as new raw material, thus avoiding its discharge into watercourses.

Future studies need to combine the unit's extraction and processing processes of the protein content. The integration of new technologies to process the protein content and oil can help generate income and reduce the environmental damages of the fishing industry supply chain. Furthermore, the current prototype of the proposed bio-oil production unit is operated in batch mode, but we are building another prototype for continuous operation.

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