CHEMICAL ENGINEERING TRANSACTIONS

VOL. 70, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš

ISBN 978-88-95608-67-9; **ISSN** 2283-9216

DOI: 10.3303/CET1870339

Technoeconomic Sensibility Analysis of Industrial Agar Production from Red Algae

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Red algae are one of the three main groups of macroalgae, these are found mainly in marine ecosystems and are used for the elaboration of foods, cosmetics, among others. Macroalgae of the genus Gracilaria sp. They are one of the sources of agar production, a polysaccharide formed by different units of galactose, which are associated forming two different polysaccharides, agarose and agaropectin. Because the agar has several purposes, it is appropriate to evaluate the economic response of the production. In this work was developed the economic evaluation and the technoeconomic sensibility analysis of the industrial production of agar from red algae, using the evaporation route, which employs seven units of operation, in order to analyze the behavior of the process when changer occur in the technoeconomic environment of the process as break-even point, on-stream efficiency, raw material cost, among others. Results show that for a processing capacity of 8,640 t/y of macroalgae with a plant life of 15 y, the total capital investment (TCI) was $11,937,000 and fixed capital investment (FCI) was $7,022,000 for a plant located in North Colombia. In addition, annualized total operating costs (AOC) were calculated in $24,514,000. Critical technoeconomic variables were raw material costs, product selling price and normalized variable operating costs (NVOC).

1. Introduction

Colombia is a country that has two coasts, approximately 2,900 km of coastline and with varied marine fauna and flora, thanks to the diversity of aquatic environments and coastal ecosystems. The variety of altitudinal floors allows diversity in the continental aquatic ecosystems. The diversity of aquatic environments in the Colombian geography has allowed the development of a diverse algae flora that belongs to each aquatic ecosystem. Marine macroalgae are a group of multicellular and macroscopic algae that are characterized by an undifferentiated vegetative body, which is why they are included in the group of so-called Talófitos. There are numerous applications of these vegetables, so they have been used by man since immemorial times with very different purposes: human nutrition, agricultural, medical and pharmacological uses cosmetics, phycocolloid industry, etc. (Tasende and Peteiro, 2015). The Caribbean coast of Colombia has approximately 500 species of macroalgae, relatively large populations and the vast majority of species that exceed 20-30 cm in height. By contrast, in the Colombian Pacific Coast have been reported around 134 species with populations of very small plants that do not exceed 15 cm. One of the reasons why the low diversity of species in the Pacific is attributed is the great tidal amplitude. On the other hand, the continental part of the Colombian territory has a variety of aquatic environments consisting of wetlands or swamps, rivers, lakes and large reservoirs of water dedicated to the generation of electricity. In these ecosystems predominates a richness of algae such as phytoplankton, unicellular algae that float on the surface of the water. In recent years, the production of phycocolloids has become the main industrial product derived from algae and has increased the economic value of them. Although the production of these compounds goes back several centuries, their commercialization is a relatively modern phenomenon. (Peña et al., 2005). The production of valuable lipids and chemicals has focused mainly on microalgae, while macroalgae species have been comparatively investigated less. (Francavilla et al.,2013). The macroalgae farming industry is deeply rooted in the Philippines, as a means of extracting carrageenans, traditionally used for the preparation of desserts, dairy products and as a gelling agent in food types, including agar, which is obtained from of different species of red algae (Ibanez and Herrero, 2017).

Please cite this article as: Herrera-Rodriguez T., Parejo-Palacio V., Gonzalez-Delgado A.D., 2018, Technoeconomic sensibility analysis of industrial agar production from red algae , Chemical Engineering Transactions, 70, 2029-2034 DOI:10.3303/CET1870339

2. Materials and methods

2.1 Process description

Figure 1 corresponds to the production of agar (agarose and agaropectin) from algae of the genus Gracilaria sp. Unlike other methods of obtaining agar, the economically evaluated process changes the stages of freezing and thawing by one stage. For the development of the technical-economic study, different equations were used to observe the behavior of the process, that is, the economic analysis helps us identify in which financial conditions the agar production process presents risks, for example if it increases the price of the product, raw material or services, if interest rates change, if product demand decreases, among other factors. The equations applied for the evaluation are as follows: Total Capital Investment, is the money that is needed to buy and install the plant, where FCI is the fixed capital investment, WCI is the working capital investment and SUC (10 % of the FCI) corresponds to start-up costs. Operating costs are expenses necessary to have the plant in operation once production has begun, where DPC corresponds to Direct Production Costs, FCH refers to Fixed Charges, POH is Overhead, and finally GE, which is general expenditures. Annual net benefit (ACF), where FCI_0 refers to the initial value of the fixed capital investment, while FCIS corresponds to the salvage value of the FCI and finally N is the number of years. On the other hand, when annualized operating costs (AOC) are given in monetary units per year. The AOC and ACF allow calculating the total annualized costs of the process (TAC) by means of Eq(4). On the other hand, if the operating costs are given per unit of product, they are named as normalized total operating costs (NOC) as shown in the Eq(5), where m_{RM} is the flow of raw material in tons per year.

$$TCI = FCI + WCI + SUC \tag{1}$$

$$OC = DPC + FCH + POH + GE \tag{2}$$

$$ACF = \frac{FCI_0 - FCI_S}{N} \tag{3}$$

$$TAC = ACF + AOC \tag{4}$$

$$NOC = \frac{AOC}{m_{RM}} \tag{5}$$

Eq(6)is used to calculate the production capacity, where is the quantity of product obtained. Thus, for efficiency, in the line at the break-even point, Eq(7)is used. When you can determine how profitable a process is, you can consider some indicators within them are the Gross Profit (GP), include depreciation can calculate the gross profit (DGP) using Eq(8). Also it is possible to calculate profit after taxes (PAT) using Eq(9), where reference is made to the tax rate stipulated by the government. On the other hand, the relationship between the profits of the process and the investment of capital corresponds to the cumulative cash flow (CCF), this must be less than 1 and the calculation with Eq(10). Another indicator is the Pay Back period (PBP), indicates how quickly you can recover the capital investment, you can calculate the PBP using Eq(11). The indicator of return on investment (%ROI), which can be obtained by Eq(12).

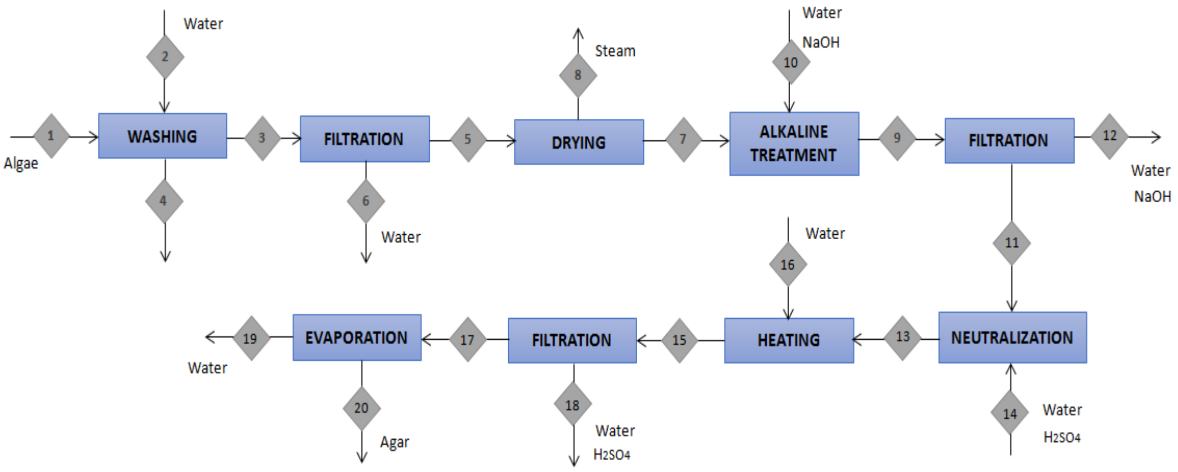

Figure 1: Block diagram of agar production process from red algae (Gracilaria sp.)

Other indicators take into account the value of money with time within them are the net present value (NPV) and the annual cost / benefit (ACR), can be calculated using Eq(13)and Eq(14), respectively.

$$m_{RM-BEP} = \frac{ACF+FCH}{\left(\sum \frac{C_i^v}{\theta_i}\right) - NVOC}\ ; \quad \theta_i = \frac{m_{RM}}{m_i} \tag{6}$$

$$\eta_{On-stream}^{BEP} = \frac{m_{BEP}}{m_{max}} \tag{7}$$

$$DGP = \sum_i m_i C_i^v - TAC \tag{8}$$

$$PAT = DGP(1 - itr) \tag{9}$$

$$CCF = \frac{\sum_i m_i C_i^v - AOC}{TCI} \tag{10}$$

$$PBP = \frac{FCI}{PAT} \tag{11}$$

$$\%ROI = \frac{PAT}{TCI} x100\% \tag{12}$$

$$NPV = \sum_n AFC_n (1+i)^{-n} \tag{13}$$

$$ACR = NPV \left(\frac{i(1+i)^n}{(1+i)^n - 1}\right) \tag{14}$$

3. Results and discussion

3.1 Economic evaluation

Some of the results obtained in the economic study of the macroalgae agar production plant can be seen in Table 1, it is this observation of the characteristics and parameters that were taken into account to perform the economic evaluation of the silver.

Table 1. Techno-economic assumptions for agar production plant.

Processing capacity (t/y)	8,640
Main product flow (t/y)	3,417.64
Raw material cost ($/t)	2,000
Cost of product ($/t)	15
Useful life of the plant (years)	15
Salvage value	10 % of depreciable FCI
Construction time of the plant (years)	3 years
Income taxes rate (itr)	34 %
Interest	8 %
Subsidies	0
Type of process	New and unproven
Process control	Digital
Project type	Plant on non-built land
Soil type	Soft clay
Percentage of contingency (%)	30
Tank design code	ASME
Specification diameter vessels	Internal diameter
Number of workers per shift	15
Salary per operator ($/h)	30

Table 2 shows the total capital investment, that is, all the money needed to start up the plant and also the obtaining of agar. This process employs an evaporation step, which replaces the freezing and thawing stages, and other ways of obtaining agar from macroalgae.

Table 2. Total capital investment for agar production plant

Costs of capital investment	Total (US$)
Delivered purchased equipment cost	1,716,237.34
Purchased equipment (installation)	343,247.47
Instrumentation (installed)	137,298.99
Piping (installed)	343,247.47
Electrical (installed)	223,110.85
Buildings (including services)	686,494.94
Services facilities (installed)	514,871.20
Total DFCI	3,964,508.26
Land	171,623.73
Yard improvements	686,494.94
Engineering and supervision	549,195.95
Construction expenses	583,520.70
Legal expenses	17,162.37
Contractors' fee	277,515.58
Contingency	514,871.20
Total IFCI	3,057,820.07
Fixed capital investment (FCI)	7,022,328.34
Working capital (WC)	4,213,397.00
Start up (SU)	702,232.83
Total Capital Investment (TCI)	11,937,958.17

3.3 Techno-economic sensitivity analysis

Techno-economic sensitivity analysis was based on the variability of the plant regarding to different variable as selling price, on-stream efficiency, raw material costs, among others.

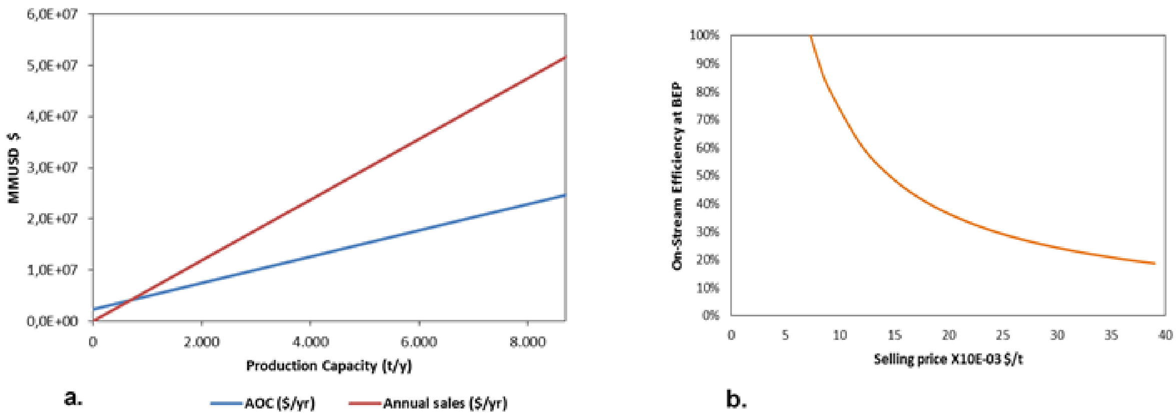

Figure 2: Break-even analysis of agar production from macroalgae. a) Production capacity for the process of obtaining agar from red algae. b) Effect of the sale price of agar on the On-Stream efficiency of the process at the break-even point.

It is known that the installed capacity of the plant is 8,640 annual tons of red algae. Figure 2a shows that the annual sales line is above the line of operating costs for the values below the installed capacity of the plant, which indicates that the process is feasible from the technical-economic point of view operating under 100 % of the capacity of the plant. The intersection of the lines shows the break-even production capacity, which for this process is around 4,200 tons of red algae per year. The process presents a high sensitivity to the decrease in production capacity, because the plant capacity of the intersection, more resistant to the process, which is beneficial due to the availability of macroalgae for processing depends on many factors among which the climatic conditions of the area play an important role. This process can diminish its production capacity up to an eighth part that cannot be compensated with operating costs, besides it is evident that the increase in its production capacity above the installed capacity will not impact the operating costs in the same proportion, probably due to economies of scale. Figure 2b presents three regions one where On-Stream efficiency presents a high sensitivity to the selling price, the other one means the transition period because the change in on-stream efficiency is not pronounced allowing to greater operability to changes in the selling price, and third one it is observed that although the price increases to a great extent there will be no significant change in the decrease in On-Stream efficiency. The selling price established for the agar (15 $/kg) is located in second region, which allows increasing price of the product if it is necessary by differents reasons.

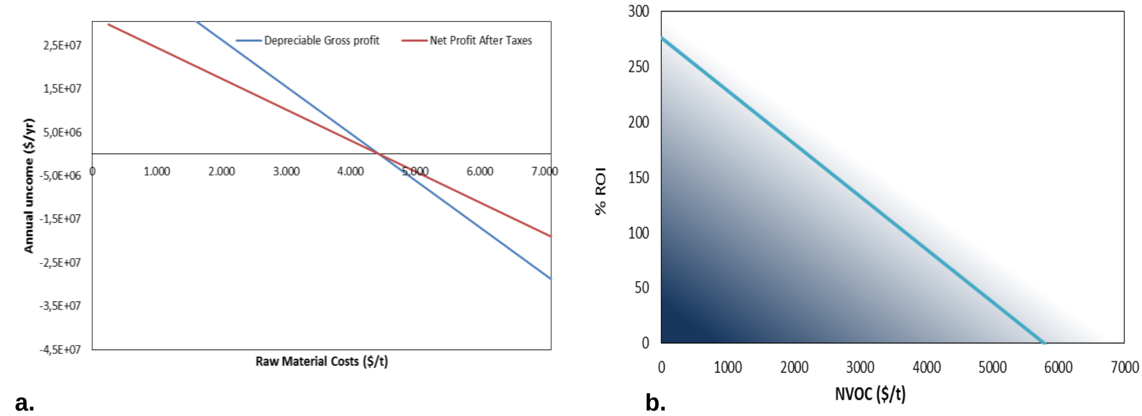

Figure 3: Sensitivity analysis of the cost of raw material and variation of ROI. a) Sensitivity analysis of raw material cost on process profitability. b) Effect of operating costs on the process ROI.

Figure 3a shows a critical point around $ 4,500 per ton, which indicates that the process begins to dawn above that value. Taking into account that the price of the raw material is 2,000 dollars per ton, the raw material can double its price without generating the process. Obviously, a decrease in the cost of the macroalgae ton represents the economic benefits to the process. The influence of the variable operating costs can be seen in the Figure 3b, which shows the strong dependence of the return on investment with respect to them. Variable costs have a critical value around $ 5,800 per ton, from which the return on investment is zero. The plant for the production of agar from macroalgae for NVOC (normalized operative variable costs) has a value of $ 2,738 per ton, which makes the process more reliable in the face of changes in variable costs (include industrial services, maintenance, employee salaries) by providing a high elongation of this indicator. When analyzing the other vertex of the triangle, we find that the maximum return value of the investment in this process is around 276 % in a hypothetical scenario where the variable costs tend to zero.

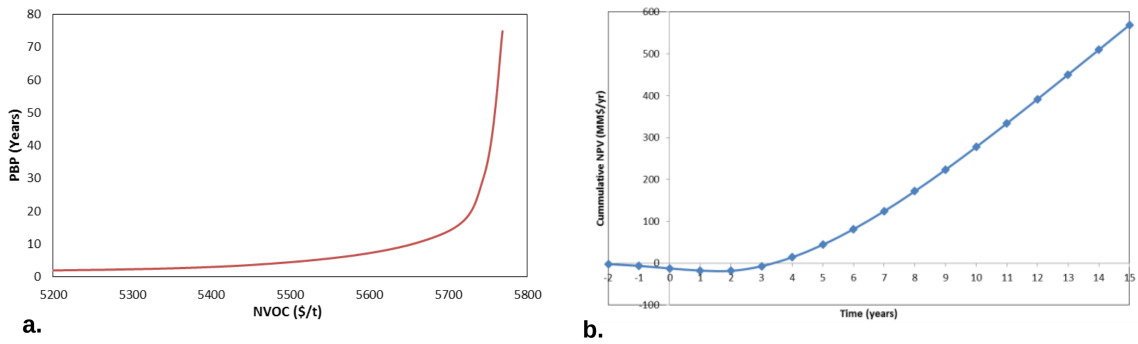

Figure 4: Sensitivity analysis for the payback period and Net present value. a) Effect of process operating costs on the Payback Period b) Net Present Value of the project.

It can be seen in Figure 4a the high sensitivity of the plant before the changes in operating costs, where it should be avoided that these equal the selling price of the agar; because this causes the gross profit before taxes to be zero and the FCIs are not recovered, causing the pay back period (PBP) to go to infinity; In the agar production plant, this happens when the operating costs are close to $ 5,800 per ton. This implies that modest changes in operating costs make the difference between an attractive project or bankruptcy, however the high sensitivity to this factor is unavoidable when working with a volatile raw material in its price, such as macroalgae. In this graph, a zone of stability of the NVOC can also be detected up to 550 dollars per ton; then from that point the zone of decontrol is established for the 5,700 dollars per ton in forward where the affectation of the variation of the operative costs no longer appears in years but in decades, causing that the project stop being attractive and profitable.

The Figure 4b indicates that the proposed agar production project yields approximately $ 568 MM of NPV (net present value). The project presents a positive NPV from the third year. If the NPV of the process begins to be positive close to the last period of the project, the risk of recovering the investment increases considerably in the event of unforeseen events during the operation time of the process. On the other hand, when the NPV of the process begins to be positive in the first years of the project, as is the case with the agar production plant, the chances of a suspension of the project at some point of its useful life preventing the recovery of the investment in the plant, if for some eventuality the process is suspended or economically affected after the third year, the investment made taking into account the change in the value of the money over time has already been recovered.

4. Conclusions

Evaluation of agar production plant under Colombian conditions was performed using techno-economic sensitivity. The agar production plant from macroalgae was an attractive project under the established conditions. It was determined that the period of recovery of the investment is three years, being beneficial because the risk of recovering the investment is reduced in the event of unforeseen events during the time of operation of the process; this guarantees the reduction of the possibilities that a suspension of the project at some point of its useful life prevents the investment in the plant from being recovered. On the other hand, the sensitivity analysis shows us the sensitivity of the process to the value of the raw material, due to the fact that this significantly influences the recovery period of the investment. The influence of the location of the plant depends basically on the total tax rate that the Government applies to the industrial sector in each country. In the case of Colombia, it was found that the income tax rate (ITR) is 34 % and the 8 % interest rate; For this reason, it is advisable to search for tax deductions in order to reduce the effect of the total tax rate on the profitability of the project.

Acknowledgments

Authors thank to University of Cartagena for the supply of equipment and software necessary to conclude successfully this work.

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