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Enteromorpha compressa macroalgae as biosorbent for heavy metal removal: a preliminary economical evaluation

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ABSTRACT

In this study, the feasibility of using *Enteromorpha compressa* macroalgae for developing a biosorbent for the use in metal removal from industrial wastewater was discussed in the light of economic models. The net present value and the internal rate of return were used to evaluate the economics of the process. It was concluded that supply to the market as a biosorbent of *E. compressa* creates an economic benefit to the producing institution.

Keywords: *Enteromorpha compressa*; Biosorption; Financial feasibility; Cash flows; Net present value; Internal rate of return

1. Introduction

Industries such as mining, metal plating, or pigment and battery manufacturing release a high volume of heavy metal containing wastewater to the environment and aquatic ecosystems. Heavy metals are toxic pollutants and non-biodegradable [1]. They accumulate and their amounts increase along the food chain owing to non-biodegradability. Thus, their toxic effects are more pronounced in the animals at higher trophic levels [2]. Heavy metals accumulated in living tissues cause various diseases and disorders. Therefore, the elimination of toxic metals from wastewaters is of great important in the field of environmental context and health care [1].

Due to the toxic effects, the industries are advised that the wastewaters have to be treated systematically to remove/minimize the metal contents in their effluents. There are a number of methods for heavy metal removal from wastewater [2]. However, removal of such contaminants from wastewater at very low concentrations is much more difficult and expensive. Processes suitable at high concentrations are often either ineffective or expensive when applied to wastewaters containing low heavy metal concentrations [3].

Recently, biosorption using micro-organism biomass as the biosorbent has appeared as a potential low-cost and environmentally friendly alternative technique to the existing methods for heavy metal removal [1]. Due to their good performance, low cost and large available quantities, a wide array of

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biological materials, especially bacteria, algae, yeasts and fungi have received increasing attention for heavy metal removal and recovery [4].

Up to now, algae were used as a biosorbent for heavy metal removal by various researchers [5–12]. For example, the biosorption of Cd^{2+} from aqueous solutions was studied in a batch system using dried *Enteromorpha compressa* macroalgae (ECM). The maximum biosorption capacity of dried ECM was found as 9.50 mg/g [11]. Recently, Zn^{2+} removal using dried ECM from aqueous solution was investigated. The maximum biosorption capacity of dried ECM for Zn^{2+} ions was found as 625 mg/g [12]. However, the economical evaluation of supply to the market as a biosorbent (passive biosorbent) of dried ECM for use in heavy metal removal from aqueous solutions has not been discussed in any literature.

The present study attempts to discuss the economic benefit of supply to the market as a biosorbent by preparing dried ECM for use in metal removal from wastewater. The cash flows of the process were estimated and the economic outputs were examined using net present value (NPV) and internal rate of return (IRR) models.

In the methodology of evaluating investment projects, the NPV method and the IRR method are recognized as the most reliable and widely used ones. In practice, an investment project analysis assumes that the reliability of these methods is equal and the result of any of them can serve as a criterion for the acceptance or rejection of a project [13]. Consequently, NPV and IRR are two very widely used models in project analysis.

E. compressa belongs to *phylum chlorophyta* and *ulvaceae* family. It is elongated, tubular (although the tubes are often partially compressed), hollow fronds and composed of single layer thick cells [14]. *E. compressa*, which is a chlorophyte macroalgae, is found in freshwater as well as marine environments. The freshwater form is present only for a short time, from late May to July. The marine form is present along the coast throughout the year [15]. It is known that *E. compressa* cause eutrophication and harmful effects to the environment [14].

2. Methodology

2.1. Generating economic benefit from alga as a biosorbent: the financial feasibility

The cash outflows, including initial investments of equipment's such as oven and sifters whereas wages, packaging and other utility expenses should also be computed for each step and included in the analysis. Cash inflows are the sales revenues of algae powder after sieving the dried organism. This process usually requires manpower. Thus the main expense exposed within the process is the wages. Number of employees work in each step and days of operation differs due to season. There are various factors affecting the formation of algae such as light, oxygen, heat, pH and salt. Therefore, seasonal changes influence the quantity collected. It is well known that green algae are formed less in autumn and winter time. The peak season is the end of summer months.

2.1.1. Steps of the process

A flow sheet of biosorbent preparation is shown in Fig. 1. The steps of the process are explained in details and summarized below:

(1) *Collection step*: the ECM is collected from the banks of Kucukcekmece Lake, Istanbul, Turkey by hands or algae net.
(2) *Washing step*: the collected ECM is first washed with freshwater then with distilled water.

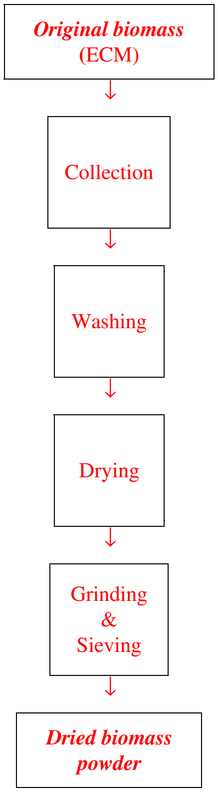

Fig. 1. Flow sheet of preparation of ECM as a biosorbent.

(3) *Drying step*: the washed ECM is dried in the sun and wind in open air (solar drying). If needed, ECM is dried in an oven for 24 h at 60 ℃. At this step, an initial investment for oven is made for $4,250. The economic life of the equipment is estimated as five years. The oven is depreciated within its economic life at a depreciation expense of $66.67 per month and $200.01 quarterly.
(4) Grinding & *Sieving step*: this is the final step of the process. The dried ECM is grinded with mortar and pestle and then sieved to have the diameter of 0.5–2 mm. After sieving, the biomass is packed and is sold for $11.5 per pack. The sales price is expected to increase by the expected inflation of 8% per year in Turkey. The number of packs ready for sale differs due to collection season. Furthermore, each year a $250 of additional investment for maintenance of the equipment is projected and included in cash flow estimations.

2.1.2. Assumptions used in the economic analysis

The assumptions used in the analysis are as follows:

(1) ECM is collected at each quarter of the year. February, May, August and November are accepted as convenient time period for this process.
(2) August is assumed to be the peak month of ECM.
(3) Number of employees and days of operation differs in each collection, washing, drying, and grinding & sieving steps (Table 1).
(4) No chemical activation costs are involved in the preparation of ECM.
(5) Amount of ECM collected is assumed to be equal amount at the same time of every year so will be the labour expense.
(6) For the first year, daily gross wage is $15 per employee and it increases by 8% yearly according to expected inflation in Turkey.
(7) The economic life of the project covers a period of five years.

2.1.3. Cash flows

As the next step, the cash flows of the process are projected NPV and IRR models are employed to figure out the economic benefits.

Cash flows are estimated as follows:

Sales revenues
-Costs of algae sold
=*Sales profit*
-Depreciation expense
=*Gross profit*
-Tax
=*Net profit*
+Depreciation
=*Net cash flows*

3. Results and discussions

It can be said that after various processes, the prepared algal-based biosorbent becomes ready to use in wastewater treatments (Fig. 1). The process is completed over four steps. Firstly, ECM is collected. Then, collected ECM is washed, dried, and grinded & sieved. The prepared biosorbent is packed. Then it becomes ready to use in wastewater treatment plants.

The economic evaluation of supply to the market by processing (preparing) as a biosorbent of ECM was performed by considering data relating to the previous studies of Sahmurova et al. [11,12]. As stated above, the preparation of the original biomass as a biosorbent includes collecting, washing, drying, and grinding & sieving. Since ECM is abundantly available in some freshwater and marine environments in Turkey, its own cost was neglected. As the ECM biosorbent were used without chemical activation in metal removal from wastewater, the chemical activation costs were neglected. The other assumptions used in the economic analysis were described as detailed in "Methodology".

Total operational costs for each step were presented in Table 1. The gross profit is obtained by the deduction of depreciation expense from sales profit. Then a tax expense of 8% is decreased to get net profit. Depreciation is a periodic charge against income which reflects the estimated currency cost of capital equipment used up in the production process. It is a non-cash expense. It is added back to net income to obtain net cash flows. Table 2 illustrates the net cash flows for each process for a five-year period. The initial investment of $4,250 for the oven, results in a negative net cash flow for the first February of the project. Although there are maintenance expenses of $250 annually, the following periods report positive cash flows which is mainly because sales revenue of ECM to wastewater treatments exceed the total costs.

The cash flows should be analysed to figure out the financial feasibility of the project. Once the net cash flows are computed, NPV and IRR models can be implemented to test if the project has economic

Table 1
Total operational costs for each step

		Wages/day ($)	Number of employee *C*	*W*	*D*	*G & S*	Days of operation *C*	*W*	*D*	*G & S*	Total cost ($)
Year 1	February	15	4	2	1	1	3	2	1	2	285
	May	15	4	3	1	1	3	3	1	2	360
	August	15	8	5	2	3	6	3	2	3	1,095
	November	15	4	2	1	1	7	3	2	3	570
Year 2	February	16.2	4	2	1	1	3	2	1	2	308
	May	16.2	4	3	1	1	3	3	1	2	389
	August	16.2	8	5	2	3	6	3	2	3	1,183
	November	16.2	4	2	1	1	7	3	2	3	616
Year 3	February	17.5	4	2	1	1	3	2	1	2	332
	May	17.5	4	3	1	1	3	3	1	2	420
	August	17.5	8	5	2	3	6	3	2	3	1.277
	November	17.5	4	2	1	1	7	3	2	3	665
Year 4	February	18.9	4	2	1	1	3	2	1	2	359
	May	18.9	4	3	1	1	3	3	1	2	453
	August	18.9	8	5	2	3	6	3	2	3	1,379
	November	18.9	4	2	1	1	7	3	2	3	718
Year 5	February	20.41	4	2	1	1	3	2	1	2	388
	May	20.41	4	3	1	1	3	3	1	2	490
	August	20.41	8	5	2	3	6	3	2	3	1,490
	November	20.41	4	2	1	1	7	3	2	3	775

Notes: *C*: collection step; *W*: washing step; *D*: drying step; *G & S*: grinding & sieving step.

benefits. The feasibility analysis should provide a positive NPV and an IRR greater than the respective cost of capital. NPV is the present value of future net cash flows discounted at the cost of capital of the project.

As known, NPV is the most important criteria in benefit and cost analysis. NPV is an absolute index for the net contribution of a program to its economy. It is a sum of the net benefit in every year by the end of the program in terms of the present value [16]. If NPV > 0, the investment project is considered effective from the economic point of view. If NPV < 0, the project is considered ineffective from the economic point of view and is rejected [13]. In other words, when NPV < 0, the costs exceed the benefits and the project is not economically feasible. The best economic options offer the greatest NPV [17]. The NPV equation can be written as follows [18]:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{CF}_t}{(1+r)^t} \tag{1}$$

where CF_t is the expected net cash flow at period t, r is the project's cost of capital and n is its life.

In the study, the feasibility includes dollar amounts of all cash flows. Thus, "r" is accepted as the interest rate for US dollars with an acceptable risk premium added. The highest US dollar interest rate employed in Turkey is 4.75%. A risk premium of 3.25% is added and r is computed as 8% per annum. The cash flows are calculated quarterly, therefore "r" is divided by 4 and the discount rate is used as 2%.

$$r = i_{\mathrm{US}} + p \tag{2}$$

$$r = (4.75\% + 3.25\%)/4 \tag{3}$$

$$r = 2\% \tag{4}$$

Implementing the NPV model, the net cash flows of the project should be estimated. All forecasted expenses are subtracted from all forecasted revenues to obtain the annual net income. The quarterly analysis includes a period of five years. Therefore, a series of 20 period cash flows are computed. Each cash flow is discounted by 2%. NPV is computed as $4,510. The rationale for the NPV method is very straightforward. A NPV of zero signifies that the project's cash flows are exactly sufficient to cover the opportunity cost of the capital (r) invested. If a project has a positive NPV, then it generates more cash than the opportunity cost of capital, leaving excess cash for the investor.

Table 2
Cash flow projections

	Period	Price	Sales quantity (packs)	Total revenue	Total cost	Depr.	Gross. profit	Tax	Net profit	+Depr.	CF	Inv.	NCF
Year 1	February	11.50	60	690	285	200.01	204.99	16.40	188.59	200.01	388.60	4,250	−3,861.40
	May	11.50	85	977.5	360	200.01	417.49	33.40	384.09	200.01	584.10		584.10
	August	11.50	150	1,725	1.095	200.01	429.99	34.40	395.59	200.01	595.60		595.60
	November	11.50	90	1,035	570	200.01	264.99	21.20	243.79	200.01	443.80		443.80
Year 2	February	12.42	60	745.2	307.8	200.01	237.39	18.99	218.40	200.01	418.41	250	168.41
	May	12.42	85	1,055.7	388.8	200.01	466.89	37.35	429.54	200.01	629.55		629.55
	August	12.42	150	1,863	1.182.6	200.01	480.39	38.43	441.96	200.01	641.97		641.97
	November	12.42	90	1,117.8	615.6	200.01	302.19	24.18	278.01	200.01	478.02		478.02
Year 3	February	13.41	60	804.8	332.42	200.01	272.38	21.79	250.59	200.01	450.60	250	200.60
	May	13.41	85	1,140.2	419.90	200.01	520.24	41.62	478.62	200.01	678.63		678.63
	August	13.41	150	2,012.1	1,277.21	200.01	534.82	42.79	492.04	200.01	692.05		692.05
	November	13.41	90	1,207.2	664.85	200.01	342.37	27.39	314.98	200.01	514.99		514.99
Year 4	February	14.49	60	869.2	359.02	200.01	310.17	24.81	285.36	200.01	485.37	250	235.37
	May	14.49	85	1,231.4	453.50	200.01	577.86	46.23	531.63	200.01	731.64		731.64
	August	14.49	150	2,173	1,379.38	200.01	593.61	47.49	546.12	200.01	746.13		746.13
	November	14.49	90	1,303.8	718.04	200.01	385.76	30.86	354.90	200.01	554.91		554.91
Year 5	February	15.65	60	938.74	387.74	200.01	350.99	28.08	322.91	200.01	522.92	250	272.92
	May	15.65	85	1,329.9	489.78	200.01	640.09	51.21	588.88	200.01	788.89		788.89
	August	15.65	150	2,34.8	1,489.74	200.01	657.10	52.57	604.53	200.01	804.54		804.54
	November	15.65	90	1,408.1	775.48	200.01	432.62	34.61	398.01	200.01	598.02		598.02

Table 3
Economic outputs of the project

Cost of capital (r)	2%
NPV	$4,510
IRR	12%
NPV > 0	Acceptance zone
IRR > r	Acceptance zone

Investment appraisal is a central issue in the literature and real-life applications. While the NPV is widespread as a measure of value created, it is most common in real-life applications to require a rate of return, for a relative measure is more intuitive than an absolute measure. The IRR is the standard rate of return used by decision-maker [19]. The IRR is defined as the discount rate that forces the NPV to equal zero [18]:

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{CF}_t}{(1+\mathrm{IRR})^t} = 0 \tag{5}$$

The goal of the IRR is to determine what discount rate will result in net benefits equalling the net costs. The IRR approach uses the NPV formulation to sum costs and benefits. However, the NPV is set equal to zero and the discount rate that equates benefits and costs is determined. The resulting discount rate can then be compared to the discount rates that could be applied. If the computed discount rate is greater than the selected discount rate the project is considered justified [20]. Normally, priority is given to the IRR method which is more understandable and obvious to investors as an indicator demonstrating the limit profitability of the project [13]. If the IRR is lower than the required return (discount rate) then the project should be rejected [21].

The IRR on a project is its expected rate of return. If the IRR exceeds the cost of funds used to finance the project, a surplus remains and accumulates for the firm's stockholders. Therefore, projects with an IRR higher than r should be accepted. The IRR of this project is computed as 12% which is higher than cost of capital of 2%. Table 3 summarizes the feasibility outputs of the project.

Consequently, it can be said that the ECM creates an economic benefit to the producing institution.

3. Conclusions

This manuscript aims to present an economic model that evaluates the feasibility of preparing algal-based biosorbent to be used in the treatment of industrial wastewater. When the cash flows were computed for collecting, washing, drying, and grinding & sieving steps which were repeated four times a year for five years, it was seen that each of these steps require various amount of investments. The major expenditures include the purchase of oven and mainly the labour expense. Furthermore, it is estimated that additional investment of $250 is required for each year for maintenance and utilities expenses.

After exposure of various cash outflows at each steps of the process, sieved biomass is packed and sold at a price of $11.50 per pack. The price is projected to increase by 8% according to the expected inflation in Turkey. The cash flows computed and analysed under NPV and IRR models indicated that it is possible to generate economic value from supply to the market as a biosorbent of ECM.

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