Economic Feasibility of Regeneration Plant of Spent Activated Carbon

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ABSTRACT

The purpose of this study was to investigate the maximum annual revenue of regeneration process of spent activated carbon obtained from petrochemical industries, economic feasibility of the project, and the sensitivity analysis of parameters in optimization model. The regeneration process mainly arises from the direct sales of regenerated spent activated carbon and the purchase of fresh activated carbon for nonregenerable activated carbon. The maximum revenue of regeneration process of 24,951,673 baht per annum was used to estimate economic indicators. The values of ROI, NPV, and SPP were 15.20%, 90,233,640.98 baht, and 6.58 years, respectively. It was suggested a profitable regeneration plant. Moreover, amongst these three parameters the selling price of activated carbon was the most sensitive while the variable cost of regeneration process was the least sensitive to the NPV.

Keywords: Regeneration plant, Spent activated carbon, Economic feasibility, Revenue optimization, Sensitivity analysis

I. INTRODUCTION

Activated carbon is applicable in many industries such as foods and beverages, petrochemicals and textile. Activated carbon is widely used as carbonous sorbent for removal of color, odors, dissolved organic chemicals, and metal ions. Mostly, the activated carbon applied in petrochemical industry is prepared from coconut shell containing carbon content more than 20% wt [1]. Coconut shell, an abundant agricultural waste, which is the most preferable raw material for activated carbon. As the consumption of activated carbons was continuously increasing in the world, the available culturing land is limited causing the shortage of raw materials supply. Due to the increase of fresh coconut and versatile applications of coconut shell, the quantity of coconut shell for activated carbon generation is limited quantity. Thus, regeneration process of spent activated carbon is essential to maximize supply of activated carbon for industrial application. The regenerated activated carbon process is the most suitable method for recycle and reutilization of spent activated carbon. Therefore, this study determined the maximum of annual revenue of regeneration plant of spent activated carbon obtained from petrochemical manufacturers. The final decision for the investment of process will depends on the optimal result used in calculation of economic criteria such as ROI, NPV, and SPP [2].

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II. MATERIALS AND METHODS

A. Regeneration Plant of Spent Activated Carbon

Spent activated carbon is commonly regenerated using high temperature steam to remove and destroy the organic compounds adsorbed onto the carbon. The regeneration process is aimed to restore partial original activity level of activated carbon, to maintain their internal porosity and to minimize product losses through gasification. Before introducing feed of spent activated carbons, their properties were measured in order to set up the suitable operating condition. Initially, spent activated carbon is washed with water or chemical agent to remove some of contaminants, i.e. chlorine contamination causing corrosion of rotary kiln. A rotary kiln is used in reactivation due to more flexible operation and typically lower labor and equipment cost. The rotary kiln is heated with a combination of gas burner and air combustion of exhaust gas recirculation (EGR) located outside of its shell at 1,100 °C. During pyrolysis of high boiling point organic compounds adsorbed onto the carbon surface, the temperature of steam is controlled in a range of 900-1,200 °C for a residence time of 3-4 hours. Then regenerated activated carbons was cooled and screened. Emitted hot air containing volatized organic compounds and residues was mineralized any remaining organic compounds in a purification unit. According emission control regulation, some of treated hot air is mixed with air combustion at EGR unit before feeding to the burner [3].

B. Methodology

To satisfy the demand of regenerated activated carbon, the supply in this study consisted of three major sources as follows: (i) the direct sales of regenerated spent activated carbon (Z_1), (ii) the purchase of fresh activated carbon for non-regenerable activated carbon (Z_2), and (iii) the inventory amount of regenerated activated carbon (I) as shown in Fig. 2.

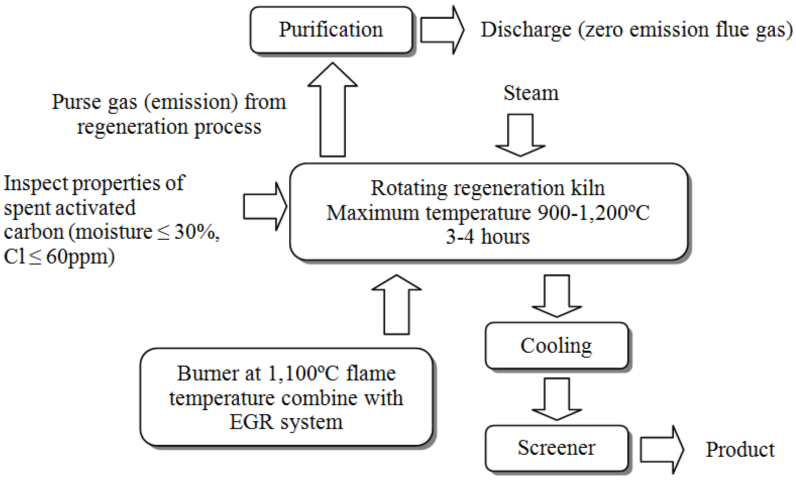

Figure 1 Thermal regeneration process of spent activated carbons [3]

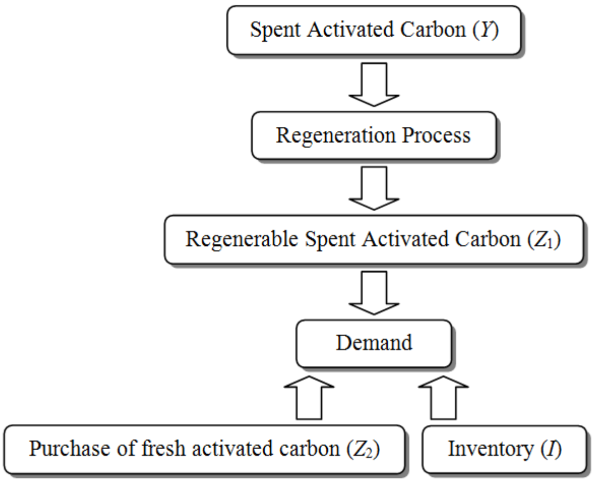

Figure 2 Flow chart of the regenerated activated carbon demand

TABLE I. PRODUCTION COST BREAKDOWN AND ITS APPLICATION IN REGENERATION ACTIVATED CARBON PLANT

No.	Item	Calculation factor	Cost (Baht)
1	Land	10 rai X 500,000 Baht and other land adjustment.	9,000,000
2	Machines and equipments cost	Base on production requirement.	45,550,000
3	Office building construction	12,000 Baht / square metre X 400 square metre and other interior.	7,000,000
4	Plant construction	8,000 Baht / square metre X 2,000 square metre.	16,000,000
5	Computers and office materials	IT equipments, computer, printer, copier, scanner and other stationary.	1,500,000
6	Vehicles and assets	Trucks, pick up car and containers.	13,000,000
7	Utility construction	Underground water supply, water supply, electricity and gas supply.	23,343,800
8	Cash flow	Purchasing cost for operation plant and marketing cost.	10,000,000
9	Transportation and	Labor cost, machines and equipment for installation works, import cost.	10,000,000

	installation		
10	Commissioning and consulting	Trial run process cost and consultant fees.	15,000,000
11	Expenses before operation	Government fees and EIA.	5,000,000
12	Insurance	Vehicle, Building, Plant, Machine and equipments insurances.	4,000,000
13	Salary	Manpower for operation, engineer, R&D, QA, finance, account and HR.	4,741,000
			164,134,800

1) Demand of Regenerated Spent Activated Carbon

(See Fig. 2 as an explanation)

2) Cost Information

The costs involved with the regeneration project were summarized in Table I. The costs listed in Table I was combined as fixed cost (f_R) and variable cost (v_R).

3) Problem Statement

The objective function of the optimization problem was the discounted annual revenue of regeneration process. The decision variable were Regenerated activated carbon (Z_1), Purchase of fresh activated carbon amount (Z_2), Inventory of product (I). Symbols used in the problem formulation are illustrated in Table II. The optimization model was expressed as follows:

Decision variables:

$$Z_{1,t} \quad Z_{2,t} \quad I_t$$

Objective function: Annual revenue

$$\text{Max} \quad \sum_{t=1}^{t} \frac{\pi_t}{1+\delta}^{t-1}$$

where
t = Feb-May, June –Sep, Oct-Jan

Set of constraints:
Mass balance of regeneration process:

$$Z_{1,t} = \beta \cdot Y_t$$

Mass balance of production:

$$D_t = Z_{1,t} \quad Z_{2,t} \quad I_t$$

Mass balance of inventory:

$$I_t = Y_t + Z_{1,t} + Z_{2,t} + I_{t-1} - D_t$$

Total cost of regeneration:

$$C_{R,t} = f_R + v_R \cdot Z_{1,t}$$

Cost of inventory:

$$C_{1,t} = qI_t$$

Purchase cost of fresh activated carbon:

$$C_{p,t} = rZ_{2t}$$

Discounted revenue:

$$\pi_t = p \cdot D_t - C_{R,t} - C_{I,t} - C_{p,t} \qquad \forall t$$

Budget limit:

$$C_{R,t} + C_{I,t} + C_{p,t} \leq C^{\max} \qquad \forall t$$

Capacity limit:

$$0 \leq Y_t \leq Y_t^{\max} \qquad \forall t$$

Capacity limit:

$$0 \leq Z_{1,t} \leq Z_{1,t}^{\max} \qquad \forall t$$

Capacity limit:

$$0 \leq Z_{2,t} \leq Z_{2,t}^{\max} \qquad \forall t$$

Inventory unit:

$$0 \leq I_t \leq I_t^{\max} \qquad \forall t$$

Initial inventory unit

$$I_{t=1} = 1{,}000$$

TABLE II. NOMENCLATURE

Symbol	Representation	Unit
Y	Spent activated carbon	Ton/Time period
Z_1	Regenerated activated carbon	Ton/Time period
Z_2	Purchase of fresh activated carbon amount	Ton/Time period
β	Yield of regeneration process	Ton of product/Ton of input
C_R	Regeneration cost	Baht/Period
f_R	Fixed cost of regeneration process	Baht/Period
v_R	Variable cost of regeneration process	Baht/Ton
C_I	Inventory cost	Baht/Period
I_t	Inventory of product	Ton/Period

C_P	Cost of purchase of fresh activated carbon	Baht/Period
p	Selling price of activated carbon per unit	Baht/Ton
q	Inventory cost per unit	Baht/Ton
r	Purchasing rate	Baht/Ton
π	Revenue	Baht/Period
t	Time index (Feb-May, June –Sep, Oct-Jan)	Period
δ	Discount rate	%

The optimization problem was solved using GAMS/CPLEX [4]. The optimization result is shown in Table III.

III. Results and Discussion

A. *Results of Revenue Optimization*

The annual revenues of regeneration process mainly derived from the direct sales of regenerated spent activated carbon, the purchase of fresh activated carbon for nonregenerated activated carbon, and the inventory of regenerated product. Each year was divided into three time periods such as February-May, June-September and October-January. The calculation was based on the regeneration plant capacity of 10 tons per day, the available cash flow of 100 million baht per year, discount rate of 7.5% per year, and the initial inventory of product of 1,000 tons.

TABLE III. Summary of Annual of Annual Revenue Optimization

Time period	Million baht / year		
	C_r	C_p	C_i
Feb-May	6.5598	12.392	0.2000
Jun-Sept	8.3361	68.816	0.1000
Oct-Jan	12.982	74.385	0.0500

4) *Calculation of Economic Indices*

a) *Return on investment (ROI)*

It measure annual rate of return on capital investment

$$\text{ROI} = \frac{\pi_t}{K} \times 100\%$$

where

K = Total investment cost

π_t = Annual revenue, Table I.

thus

$$\text{ROI} = \frac{24,951,673}{164,134,800} \cdot 100\% = 15.20\%$$

b) *Net present value (NPV)*

It is the total income from the investment during its life span of investment

$$\text{NPV} = \sum_{n=1}^{T} \frac{\pi_t}{(1+\delta)^n} - K$$

where

T = Investment life of 20 years

Thus,

NPV = 254,368,440.98 – 164,134,800
= 90,233,640.98 Baht.

c) *Simple payback period (SPP):*

It calculates the time required for the pay-back of investment

$$\text{SPP} = \frac{K}{\pi_t}$$

Thus

$$\text{SPP} = \frac{164,134,800}{24,951,673} = 6.58 \text{ years}$$

A positive ROI and a positive NPV represent that the regeneration plant is profitable which was verified by the payback period of investment of 6.58 years. Simple payback period (SPP)

It calculates the time required for the pay-back of investment

5) *Economical Feasibility*

In this study the project period of the regeneration plant of spent activated carbon was set to be 20 years and the initial capital investment of 164,134,800 million baht in year 0 (see Table I). The result of ROI, NPV and SPP (in the subsection 1) showed the economic feasibility of this regeneration project.

6) *Sensitivity Analysis*

To investigate the effect on the project economic viability of possible perturbation in the calculated result, a sensitivity analysis of main factors on NPV values was studied. The three selected factors were variable cost of regeneration, selling price and purchasing rate [5, 6]. The result of sensitivity is shown in Fig. 3.

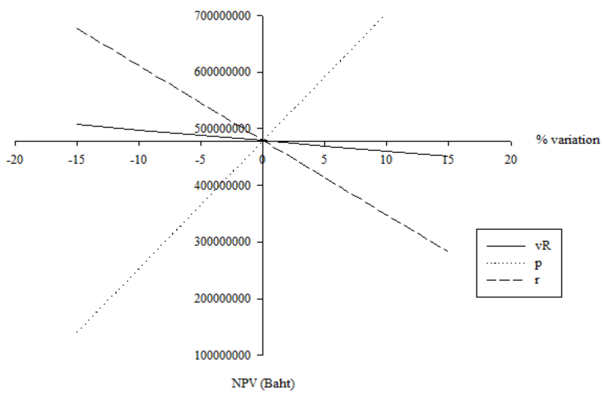

Figure 3 Sensitivity analysis of NPV on variation of v_R, p, and r

Fig. 3 shows the effect of variations of these three factors on NPV over the range -15 to +15%, with the 5% increment each time. Amongst these three parameters p was the most sensitive while v_R was the least sensitive to the NPV. The change in p had a direct effect on NPV. In addition, at the increase of v_R and r values, NPV was decreased.

IV. Conclusions

The maximum value of discounted annual revenue of regeneration process was applied to determine the economic indicators such as ROI, NPV, and SPP. The economic feasibility of the project was profitable. The selling price of activated carbon was the most sensitive whereas the variable cost of regeneration process was the least sensitive to the NPV.

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