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Abstract. One of the stages in edible oil refining is bleaching, which aims to reduce pigments, gums and metals. Bleaching produces large amounts of spent bleaching earth (SBE) solid waste. SBE is usually treated in traditional processing such as landfill, incineration, compost or using the services of third-party. This paper investigated the best scheme for reactivation of SBE based on economic and environmental aspects. The basis of economic and environmental analysis used reactivated SBE with the best treatment, i.e. extraction of residual oil using n-hexane, thermal activation at 600°C for 60 minutes, acid activation using HCl 10% with impregnation $BaCl_2$ 5% (RBE-Ba) and without impregnation (RBE). BET analysis results of RBE-Ba and RBE were obtained with a pore surface area of 160 and 150 m^2/gr, a total pore of 0.209 and 0.11 cc/gr, and a total pore size of 2.62 and 6.14 nm. The reactivation schemes being compared were build a new plant (NP) in an existing factory and build a new factory (NF). The most profitable scheme is RBE NP, with ROI is 20.97 % and PBP is 3.23 years. RBE NP is more economical because there is no need to buy new land, buildings, transportation, and low cost for chemicals and labour. NPV of RBE NP is USD 446,633.71, IRR is 15%, and B/C ratio is 53.31%. Based on environmental aspect, it can reduces air pollution resulting from SBE transportation, the risk of water and air contamination, and RBE will reduce the mining of bentonites to prevent environmental damage.

1. Introduction

In the edible oil refining process, crude palm oil will be bleached to get lighter and stable oil by removing contaminants such as pigments, gums and metals. The bleaching process use adsorbent of bleaching earth (BE). The range of BE from 1% to 3% of the weight of the oil [1]. BE is a type of clay or bentonite which has the main structure of montmorillonite with the main composition consisting of SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, and K_2O [2]. Saturated BE will turn into spent bleaching earth (SBE) solid waste.

SBE contains 20-40% residual oil, so it can oxidize quickly and reach the point of spontaneous combustion. While SBE gets a high temperature or exposes to the sun for a long time, it mights causing a fire hazard [3]. SBE is composed of several chemical compositions, one of them is SiO_2 with a percentage reaching 65-75% (w/w in ash) [2]. In Government Regulation number 22 of 2021 concerning Implementation of Environmental Protection and Management, SBE includes hazardous and toxic (B3) waste with residual oil content of more than 3%. SBE can turn into non-hazard and toxic waste if the residual oil is less than or equal to 3%, but this requirement is difficult to achieved. Based on these regulations, SBE must be treated appropriately, because so far SBE has been processed with incineration or directly disposed to the environment. These processes very risky because the SBE content is toxic and will pollute the environment without prior treatment [4].

Several research related to the utilization of SBE and residual oil were briquettes [5], biofertilizers [6], catalysts in transesterification [7], ceramics [8], biodiesel [9], lightweight concrete materials [10], and biodiesel using heterogeneous catalyst [11]. In addition, studies that have used reactivated bleaching earth (RBE) as adsorbent have also been carried out, such as the adsorbent of pigments [12], adsorbent of tetracycline hydrochloride [13], purification of glycerol [14], adsorbent of diclofenac [15] and catalyst supported for RWGS reaction [16]. Many studies have been carried out on the utilization of SBE and its residual oil, but only a few have analyzed the economic and environmental aspects of SBE processing. Some of the latest literature that discusses the techno-economics of SBE processing are [17][18], and [19] which explain the techno-economics of production bleaching earth. This paper aims to determine the best scheme for utilizing SBE and residual oil in terms of economic and environmental aspects.

2. Materials and methods

2.1. Materials

This study used reactivated SBE with the best results of the BET analysis. RBE-Ba and RBE with the best BET results were chosen to be the basis for economic and environmental analysis. SBE is obtained from a local edible oil refinery company.

2.2. Methods

2.2.1. Extraction of residual oil

The residual oil content in SBE was extracted using n-hexane, SBE to hexane ratio was 1: 2 (m/v). The extraction process used an ultrasonic cleaner at 55ºC for 45 minutes. Previously, SBE was sieved using a 100-mesh sieve.

2.2.2. Impregnation of $BaCl_2$

The residue of extraction was deoiled bleaching earth (DOBE) and the filtrate was a mixture of residual oil and hexane. DOBE was impregnated using $BaCl_2$ 5% solution by maceration method at 70ºC for 30 minutes, the ratio of DOBE and $BaCl_2$ 5% was 1:5 (m/v). The impregnation aims to fill the inter-layer and surface of DOBE with Ba^{+2} ions from the active metal $BaCl_2$ solution [20]. After maceration, the products dried in the oven at 105ºC for 24 hours. The products of impregnation were called DOBE and DOBE-Ba.

2.2.3. Reactivation of DOBE

The result of the reactivation process was reactivated bleaching earth (RBE). The reactivation process combines thermal and acid activation. Firstly, DOBE and DOBE-Ba were activated thermally at 600ºC in a furnace for 60 minutes and followed by chemical activation using HCl 10% solution at ambient temperature for 30 minutes. The ratio of sample and HCl 10% was 1: 5 (m/v). After being activated, RBE-Ba and RBE were rinsed by aquadest until the pH was neutral and dried in the oven at 105℃ for 24 hours.

2.2.4. Economic and environmental analysis

Investment is the funds or capital needed to build a factory until it is ready to operate and produce the products. Capital consists of total capital investment (TCI) and total production cost (TPC), while profit before taxes is obtained after total income minus operating costs. Economic evaluation is an instrument to see the feasibility of an investment plan. In this research, economic feasibility is reviewed from the return on investment (ROI), payback period (PBP), net present value (NPV), internal rate of return (IRR), and benefit to cost (B/C) ratio. The basis for calculating economic analysis is presented in Table 1. This work describes a benchmarking of the economic feasibility of the reactivation of RBE in a new plant at an existing factory (RBE NP), RBE-Ba in a new plant in the existing factory (RBE-Ba NP), and RBE in the new factory (RBE NF).

Table 1. Base of reactivation economic analysis

Item	RBE	RBE-Ba
SBE processing/batch (kg) :	250	250
Process time/batch (min) :	95	120
Batch/day (batch) :	15	12
SBE processing/day (ton) :	3.79	3.00
SBE processing/year (ton) :	1136.84	900
SBE to hexane ratio (m/v) :	1 : 2	1 : 2
SBE to HCl 10% ratio (m/v) :	1 : 5	1 : 5
SBE to $BaCl_2$ 5% ratio (m/v) :	-	1 : 5
Recovery hexane/batch :	98%	98%
Recovery HCl 10%/batch :	90%	90%
Recovery $BaCl_2$:	-	90%
Percentage of extracted oil :	91%	91%
Price of hexane/litre :	USD1.80	USD1.80
Price of HCl 32%/litre :	USD1.20	USD1.20
Price of $BaCl_2$/kg :	-	USD16.67
Potential energy of recovery oil/ton/year :	USD 350	USD 350

3. Results and discussions

3.1. Characteristics of spent bleaching earth

SBE were characterized using proximate analysis consisting of moisture content (MC), volatile matter (VM), ash content (AC), and fixed carbon (FC). Table 2 shows the results of the proximate analysis of BE, SBE, and DOBE. BE has a higher MC than SBE and DOBE because it has not adsorbed impurities and oil content from CPO. The high VM of SBE indicating that the residual oil and other impurities are quite high. VM indicates the reactivity of a material, so it means that SBE more reactive than others [21]. The AC value indicates the amount of inorganic material that turns into ash at high temperatures. While FC indicates the amount of carbon remaining after MC, VM, and AC evaporate when in the sink at high temperatures.

Table 2. Results of proximate analysis

Parameter (wt%)	BE	SBE	DOBE
Moisture content (MC)	3.12	1.4	1.3
Volatile matter (VM)	5.17	33.12	18.41
Ash content (AC)	91.44	64.91	78.72
Fixed carbon (FC)	0.27	0.58	1.57

3.2. Reactivation of SBE

The yield of recovered oil was 19.4 grams or equivalent to 90.76% residual oil. After extraction, the next processes were impregnation and activation. The results of BET analysis of RBE and RBE-Ba are presented in Table 3. RBE-Ba has a wider surface area than RBE, it relates to previous study [21] showed that $BaCl_2$ impregnation produced a wider area compared to impregnation using $MgCl_2$, $CaCl_2$, KCl, and NaCl solutions. Meanwhile, the average pore size and total pore volume between RBE and RBE-Ba were not too different. The results of BET analysis of SBE show that it can not be used as an adsorbent because it does not have a surface area and pore volume to adsorb impurities in CPO.

Table 3. Analysis results of BET

Sampel	Surface Area (m^2/gr)	Total Pore Volume (cm^3/gr)	Average Pore Size (nm)
FBE [9]	227.1	0.1	1.17
SBE	0	0	1.52
RBE	150	0.11	6.14
RBE-Ba	160,159	0,209	2.62

3.3. Detailed process design of reactivation SBE

3.3.1. Process description

The study of scale-up from laboratory to industrial-scale using the best result from this research with time optimization of up to 30%. Process of flow diagram of SBE reactivation is depicted in Figure 1. Firstly, the residual oil extracted with non-polar hexane solvent. SBE can be processed directly from the temporary waste storage using a vacuum system or belt conveyor. Each batch requires 250 kg (0.025 tons) of SBE and 500 litres of hexane, but hexane tank should be filled at least twice the capacity needed to anticipate delays in supply from recovery solvent [17].

SBE and hexane are mixed in the extraction tank for 25 minutes at 55°C. Furthermore, SBE and hexane slurry will be filtered and dried. The edible oil refining industry usually uses a Niagara filter with injected steam, SBE will be filtered and dried in one equipment, so the estimated time is around 10 minutes. In this process, the filtrate is a mixture of hexane and residual oil. The filtrate is transfered to holding tank and separated in the evaporator and condenser. Hexane is evaporated and the vapour is condensed and returned to the hexane tank. It is assumed that 98% of hexane can be recovered, as has been done by [17], so each batch only requires 5% fresh hexane. The recovered oil content was 91%. This yield is higher while compared to recovered oil produced by microwave method 20.97% [22].

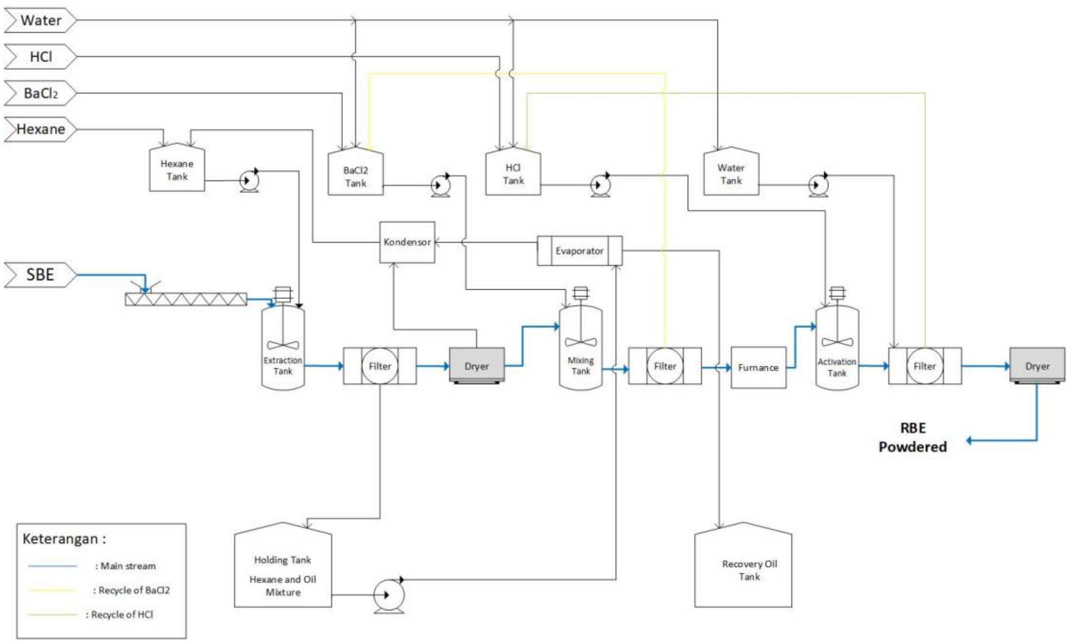

Figure 1. Process reactivation of spent bleaching earth with impregnation

DOBE was impregnated using $BaCl_2$ 5% solution by maceration for 20 minutes and it named DOBE-Ba. It is assumed that 90% of the $BaCl_2$ solution can be recovered, so it requires $BaCl_2$ 5% solution per batch. For the manufacture of RBE, after the first drying, DOBE is directly activated thermally in the furnace at 600 °C for 30 minutes, followed by acid activation using HCl 10% solution by maceration for 20 minutes. The products of the activation are called RBE and RBE-Ba. In the acid activation, it is assumed that HCl solution can be recovered 90%.

3.3.2 Process discussion

The best reactivation process is the most profitable and has minimum of environmental damage. Direct costs and indirect costs at TCI and manufacturing costs and general expenses at TPC were calculated use the assumptions that have been used [23] in calculating the techno-economic of bio-briquette from cashew nut shell waste, [19] in calculating the scale-up production of bleaching earth with bentonite from Ponorogo and Pacitan, and [24] in calculating the techno-economic of coconut coir bioadsorbent. The estimation of TCI is depicted in Table 4. The cost of the main equipment was calculated by equation 1 [25].

$$C = C_b \times \left(\frac{Q}{Q_b}\right)^{0.7} \quad (1)$$

Note.
C = capital cost of the equipment with desired size
C_b = base-case design cost (USD 235,822) [17]
Q = desired capacity of the equipment (1136.84 ton/year)
Q_b = capacity of the base-case equipment (664.62 ton/year) [17]

The value of scaling exponents between 0.6 and 0.7. In this study, a scaling exponent of 0.7 was used according to the latest study of techno-economic of coconut coir bioadsorbent [24]. Based on equation 1, the C value of RBE NP was USD 364.397. The value of C in RBE-Ba is smaller than RBE because the time per batch to produce RBE-Ba is longer. It caused by impregnation and filtering process. So, with the same basis of SBE (250 kg/batch) and longer time, RBE-Ba has smaller capital cost of equipment.

For the new plant (NP) scheme, it is assumed that it does not require costs to purchase land and construct new buildings for offices. The existing factory is assumed to have sufficient land reserves to build a new plant. Meanwhile, the new factory scheme requires costs to purchase land and buildings. The difference of initial chemical cost because RBE-Ba has to purchase $BaCl_2$. The contractor's fee is assumed to be 10% of the DC and IC. In the previous explanation, the assumptions for calculating other items use previous studies. The estimation of TCI is depicted in Table 4.

Table 4. Estimation of Total Capital Investment

Item	RBE NP (USD)	RBE-Ba NP (USD)	RBE NF (USD)
Direct Cost (DC)			
Equipments (arrived)	377,718	320,736	377,718
Installation cost	79,321	67,355	79,321
Instrumentation & control	45,326	38,488	45,326
Piping and electricity	49,103	41,696	49,103
Yard improvement	37,772	32,074	37,772
Land	-	-	22,663
Building & maintenance	-	-	83,098
Initial chemical cost	2,400	3,667	2,400
Total DC	591,640	504,015	697,402
Indirect Cost (IC)			
Engineering & supervision	56,658	48,110	56,658
Construction	113,315	96,221	113,315
Total IC	169,973	144,331	169,973
Contractor’s fee	76,161	64,835	86,737
Fixed Capital Investment	837,775	713,181	954,112
Working Capital (15% of TCI)	147,843	125,855	168,373
Total Capital Investment (TCI)	985,618	839,036	1,122,485

The estimation of TPC is depicted in Table 5. The most expensive raw material is $BaCl_2$, even though it can be recovered. In RBE NF, the cost of SBE comes from the cost of transporting SBE to the new factory. Labour expenditure in the NP scheme is smaller than NF, because it only requires 3 new operators, while for RBE NF needs at least 15 persons [19], consisting of factory managers, process engineers, salespersons, administrative staff, and operators. In the NP scheme, there are no costs for laboratory and R&D because it is assumed that they can use existing facilities. The NF scheme requires marketing costs because they have to sell its products to consumers, while the NP uses all of its products for its own needs.

Table 5. Estimation of Total Production Cost

Item	RBE NP (USD/year)	RBE-Ba NP (USD/year)	RBE NF (USD/year)
Direct Manufacturing Cost (DMC)			
Raw Materials			
SBE (Transportation)	-	-	75,789
N-Hexane	81,853	64,800	81,853
HCl 32%	213,158	168,750	213,158
$BaCl_2$	-	375,000	-
Labor	7,200	7,200	46,400
Maintenance	16,756	14,264	19,082
Plant Supplies	2,513	2,140	2,862
Utility	37,895	30,000	37,895
Total DMC	359,374	662,153	477,039
Indirect Manufacturing Cost (IMC)			
Payroll overhead	1,080	1,080	6,960
Laboratory	-	-	4,640
Plant Overhead	-	-	23,200
Total IMC	1,080	1,080	34,800
Fixed Manufacturing Cost (FMC)			
Depreciation of equipments	34,338	29,158	34,338
Property taxes	8,378	7,132	9,541
Insurance	8,378	7,132	9,541
Total FMC	51,094	43,421	53,420
Total MC = DMC + IMC + FMC	411,548	706,655	565,260
General Expenses (GE)			
Administration expenses	12,346	21,200	16,958
Marketing Expenses	-	-	28,263
R&D Cost	-	-	19,784
Total GE	12,346	21,200	65,005
Annual TPC = MC +GE	423,894	727,854	630,264

After the FCI and TPC are obtained, the next step is to analyze the economic feasibility return on investment (ROI) and payback period (PBP) using equations 2 and 3.

$$\text{ROI} = \frac{\text{Profit}}{\text{FCI}} \times 100\% \quad (2)$$

$$\text{PBP} = \frac{\text{FCI}}{\text{Profit} + (0.1 \times FCI)} \quad (3)$$

The ROI and PBP of RBE NP, RBE-Ba NP, and RBE NF are presented in Table 6. RBE NP has the highest net profit (USD 175,714 per year) while compared to RBE-Ba NP and RBE NF. The ROI of RBE-NP is 20.97% (min 10%) and PBP is 3.23 years (max 5 years). Based on ROI and PBP, RBE-NP is the most profitable scheme, but it should be analyzed by net present value (NPV), internal rate of return (IRR), and benefit to cost (B/C) ratio with considering the concept of time value of money.

Table 6. Benchmarking of economic analysis RBE and RBE-Ba

Item	RBE NP	RBE-Ba NP	RBE NF
FCI (USD)	837,775	713,181	954,112
TPC (USD/year)	423,894	727,854	630,264
Income (USD/year)			
Avoided purchase of BE	378,947	300,000	378,947
Avoided disposal of SBE	75,789	60,000	0
Potential energy of residual oil	144,871	114,689	144,871
Net profit (USD/year)	175,714	-253,165	-263,592
ROI (%)	20.97	-35.50	-27.63
PBP (years)	3.23	-3.92	-5.67

$$\text{NPV} = \sum_{n=0}^{n=t} \frac{Cf_n}{(1+r)^n} \quad (4)$$

NPV is calculated by equation 4 [24], Cf is cash flow in year n and $(1+r)^n$ is discount factor. Interest rates (r) in this study is assumed 5%. IRR is interest rates (r') while NPV is zero. The value can be found by trial-and-error calculations or using IRR function in spreadsheets. The B/C ratio can be calculated by NPV divided by FCI. The discounted cash flow of RBE-NP is depicted in Table 7. The NPV of RBE-NP is USD 446,633.71, IRR is 15%, and B/C ratio is 53.31%. If the NPV is positive and IRR is greater than zero, it means that the investment scheme (RBE NP) is profitable and feasible to further study.

Table 7. Discounted cash flow of RBE NP

Year	Net Cash Flow (USD)	Discount Factor	Present Value (USD)
0	-837,775.08	1.00	-837,775.08
1	159,167.15	0.95	151,587.76
2	160,916.24	0.91	145,955.77
3	162,665.33	0.86	140,516.43
4	164,414.42	0.82	135,264.15
5	166,163.51	0.78	130,193.45
6	167,912.60	0.75	125,298.96
7	169,661.68	0.71	120,575.39
8	171,410.77	0.68	116,017.56
9	173,159.86	0.64	111,620.39
10	174,908.95	0.61	107,378.92

RBE NP has a positive impact on the environment while compared to traditional processing such as landfill, incineration, compost and other schemes. Disposal of SBE by landfilling causes secondary pollution because the oil content can contaminate water sources and soil, incineration causes emissions of NOx, SOx, and fly ash, and composting make heavy metals to become more concentrated if the recalcitrant organic matter cannot be decomposed [26]. The silica content in SBE can increase the risk of exposure to hazardous chemicals [27]. Usually to transport of SBE is using an open dump truck which is very high risk of falling or being carried away by the wind. LCA for palm oil refining and fractionation was done by [28], it show that reactivation of SBE contributes to make environment be better by reducing of GHG emissions, ionizing radiation, formation of PM 2.5, terrestrial acidification and ecotoxicity.

4. Conclusions

SBE can be reactivated into RBE by the recovery method, utilizing RBE to become a new adsorbent and utilizing the potential energy of residual oil. The activation and impregnation have been carried out to obtain characteristics similar to fresh BE, but after an economic feasibility analysis, the RBE NP scheme was the most profitable. Based on environmental aspects, the RBE NP scheme can reduce air pollution resulting from SBE transportation, reduce the risk of water and air contamination, less chemical waste, and RBE will reduce the mining of bentonites to prevent environmental damage. The optimal processing of SBE is processing it directly on-site, minimizing the chemical consumption and utilizing RBE and residual oil.

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