Plant Design for Regeneration of Spent Bleaching Clay by Boil-Off Method and Acid Treatment

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Abstract

There are significant economic and environmental benefits to the recycling of the waste generated by edible oil refineries, spent bleaching clay is one of the major ones. These spent bleaching clays are disposed into landfills which causes environmental pollution in addition to odors and fire hazards. The amount of fresh clay used in edible oil refineries in Saudi Arabia is estimated to be 6000 tons per year. Thus, boil-off method followed by acid activation is explored in this paper as a chemical recycling method for spent bleaching clay. This treatment can remove the adsorbed oil content and reactivate the clay to recover the bleaching ability where it can be sold again with a reasonable price. The proposed process handles a feed of 26 tons per day of spent bleaching clay, the suggested design achieves a deoiled and activated clay with bleaching ability as fresh one. The plant includes batch reactors to carry out the oil removal by boil-off method then followed by acid activation. After both reactors, filter presses combined with washing process to separate the filtrate and neutralize the products. Heat exchangers, dryers and storage equipment are also included in the design. The suggested design requires a capital investment of $2.079 MM and the cash flows of this plant suggests that it will break even by around 5.2 years.

Keywords— spent bleaching clay SBC, Boil-off, Acid Activation, crude edible oil, regeneration, financial analysis.

I. INTRODUCTION

Treatment of edible oil in refineries involves degumming and bleaching and generates plenty of spent bleaching clay (SBC). The amount of fresh earth been used by edible oil refining industries in Saudi Arabia is estimated at 6000 tons per year [Alhamed and Al-Zahrani, 1999]. The SBE resulted as waste which contains high percentage of oil. Edible oil is considered one of the essential elements in daily diets of people nowadays. Thus, producing high quality oil requires a multiple stage treatment for crude vegetable oil to remove impurities, free fatty acid, and coloring materials. Bleaching is used to removes colored matters by mixing bleaching earth with raw edible oil under controlled conditions of temperature and producing spent bleaching clay with oil content ranges from 20 to 40 wt%. The disposal of spent bleaching clay into landfills provides flammable hazards and causes environmental pollution. For that purpose, it is necessary to design a treatment process for recycling spent bleaching clay to eliminate the issue of disposal by removing adsorbed oil content. Also, performing regeneration of deoiled clay which can be reused in edible oil refinery will reduce the amount of imported fresh clay.

There are several methods mentioned in the literature to extract the oil contained in SBE. One of the methods is called boil-off method or lye extraction: It involves the oil removal from the spent clay by treatment with a boiling aqueous solution of sodium hydroxide and sodium chloride at boiling conditions. Also, reactivation of the deoiled clay is necessary to recover the bleaching ability of the clay; this is done by using inorganic acid to reactivate the internal pore surface where the adsorption is located; also, the acid treatment has the ability to leach the residual impurities that been left after oil removal. The optimum operating conditions for both treatments are recommended from the literatures and the design for the process is based upon them.

The design should achieve a deoiled and activated clay with bleaching ability as the fresh one. Reaching the goal of the process requires oil removal and reactivation units for the SBC, as well as proper separation units to achieve the desired product specification.

The paper will investigate if Boil-off method followed by acid activation is economically valuable or not. This is done by suggesting a process design and performing cost analysis to check the economic feasibility of the proposed design.

II. Methods to Recycle Spent Bleaching Earth

There are many methods to recycle spent bleaching clays. However, they all achieve the bigger goal of saving the environment and reducing the costs. In the next few points, are exploring the paths that have been proposed in the literature.

A. Spent Clay Regeneration by Solvent Extraction

This method entails the removal of oil by solvents. The factors affecting solvent extraction are as follows: [1]

1. Solvent type. (methylethylketone > and benzene-ethanol mixture > acetone…)
2. The temperature during processing. (room temperature= 25 ^oC)
3. Solvent to clay ratio (SCR) 4 to 5.
4. Mixing rate (150 to 200 RPM)
5. Extraction time (5 minutes)

B. Spent Clay Regeneration by Boil-off Method

Regeneration using this method entails the oil removal from the spent clay by chemical treatment. The factors affecting Boil-off method as following:

1. Boiling aqueous solution of sodium hydroxide (1-10% NaOH of the clay weight) under total reflux.
2. NaCl (1-8% of the clay weight) is added to the mixture in order to lower the surface tension between the oil and the clay.
3. The effects of NaOH and NaCl concentrations, water to clay ratio (WCR) and time of reaction on POE were investigated." [2]

C. Spent Clay Regeneration by Calcination

Calcination method entails the removal of the oil by heating. The factors affecting Calcination method are as follows:

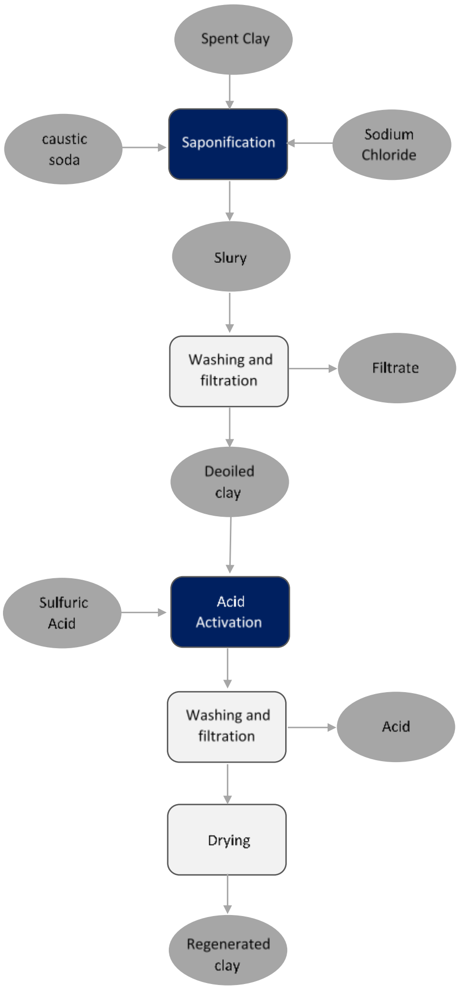
1- The temperature during processing. (400-550 oC)
2- Remoisturizing of the earth (to at least 10%)
3- In this method, about 98-99% regeneration is achieved. [3]

III. Reactivation of deoiled SBC

Deoiled SBC has limited adsorbing capacity. Therefore, reactivation by hot mineral acid solution such as H_2SO_4 or HCl enhance the adsorption, where hydrogen ions from mineral acid attack the structure of cationic sites and exfoliate layers from the surfaces which will cause changes in chemical composition and physical properties of the clay by exchanging Ca^{++} and Mg^{++} with H^+ that are good leaving group, thus will increase the adsorption capacity (Wang and Lin, 2000; Mokaya et al., 1993), also, which will increase pore volume. Activated Bleaching clay is capable of absorbing polar compounds, where the acid treatment role is to remove residual organic compounds, impurities and leaching Al^{+3} Ca^{2+}. Further acid treatment could leach more of Al^{+3} which will cause collapsing of the clay lattice structure" reducing active surface or bleaching efficiency [4].

IV. PROCESS INFROMATION

The recommended process involves two major parts namely oil recovery by boil-off method using caustic soda (NaOH) and reactivation of the deoiled clay by sulfuric acid treatment. Through boil-off, the Spent Bleaching Clay (SBC) is delivered into a jacked vessel which operated in a Semi-batch mode; the amount of SBC that required to be regenerated approximated around 7792 tons per year, 23 wt% of feed is fatty oil (1792 tons) is removed, which gives a product of 6000 tons of regenerated clay. SBC in the boil-off reactor is mixed with an alkaline solution 5 wt% NaOH to remove the oil content in the clay, also, WCR = 4 should be achieved. Moreover, 3 wt% NaCl is added to enhance oil removal. The whole mix is heated until it reaches the boiling point (above 100 ^oC, at 1 atm). Agitation is merely helping to mix the solution for better heat distribution with no effect on oil removal efficiency. Reaction time is 30 minutes and the discharge from the vessel is a slurry with soapy water which is fed to plate heat exchanger to cooldown to 60 ^oC; It is then directed to filter press for draining the soapy water. Also, the clay is kept inside the filter while pressing for further washing with hot water to remove residual soaps attached with the clay. Then, the Cake (filtered clay) is delivered into acid activation by using Sulfuric Acid. The operating conditions are: H_2SO_4 concentration is 15 wt%, WCR = 5 and reaction time is 15 minutes at boiling point of solution (103 ^oC, at 1 atm). The activation step is performed inside a jacked vessel operated in a semi-batch mode. The discharge from the jacked vessels is an acidic slurry which delivered to plate heat exchanger to cooled down to 60 ^oC, then, the slurry is directed to a filter press to sperate the acid from the cake followed by hot water washing to neutralize the clay. Finally, the deoiled acid free clay is sent to a (tray dryer) which operates by passing a hot air to evaporate the residual water content. Now the clay is ready to be commercially used.



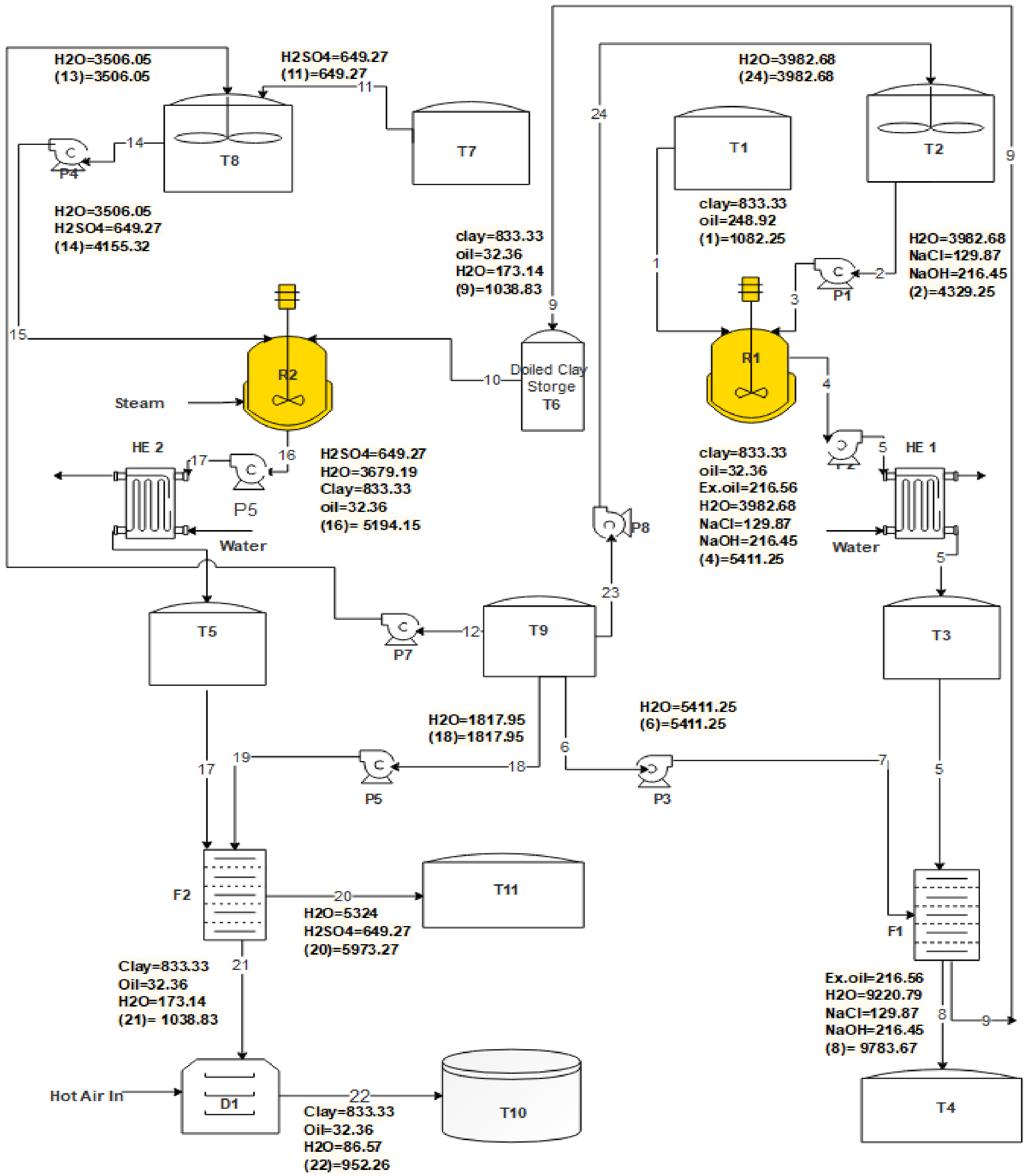


Figure 2: Process flow diagram

Key: -

T1: Spent Clay Tank. **T2**: NaOH+NCL Mixing Tank. **T3**: Slurry Tank (2). **T4**: Filtrate Holding Tank. **T5**: Slurry Tank (1). **T6**: Deoiled Clay Storage Tank. **T7**: Concentrated H2SO4 Acid Tank. **T8**: Dilute H2SO4 Acid Tank. **T9**: Washing Water Tank. **T10**: Regenerated Clay (Product) Tank. **T11**: Neutralization Tank. **R1**: Boil-off Reactor. **R2**: Activation Reactor. **F1**: Filter Press (1). **F2**: Filter Press (2). **D1**: Tray Dryer. **HE1**: Plate Heat Exchanger (1). **HE2**: Plate Heat Exchanger (2). **P**: For pumps.

Note: All the flow rates are in Kg/hr.

V. COST ANALYSIS

The cost estimation was made for plant processing of 7,792.21 tons of spent clay per year to produce 6000 tons of regenerated clay. the purchase cost based on the equipment in the process flowsheet Figure (2) is shown in Table (1). The design specifications were calculated based on information obtained from (Peters, Timmerhaus and West, 2006) [5] to find out the total capital t and product costs; the information is listed in Table (2) and (3). The selling price of the regenerated clay is assumed to be $US 420/ton.

Equipment cost estimation was based on data available in the literature. Each equipment in the process is designed according to the required capacity of the process the price is set accordingly to the size of the equipment. [6]

The capital needed to supply the required manufacturing and plant facilities is called the fixed-capital investment (FCI), while that necessary for the operation of the plant is termed the working capital (WC). The sum of the fixed-capital investment and the working capital is known as the total capital investment (TCI). The fixed-capital portion may be further subdivided into direct cost and indirect cost.

Table 1: Equipment Cost Summary

Code	Equipment	Size m^3	No. Of Units	Purchase Cost $/Unit	Spec
R1	Boil-off Reactor	7.48	1	$48,000	Glass-Lined Mild Steel
R2	Acid-Activation	6.79	1	$40,000	Glass-Lined Mild Steel
HE1	Plate Heat Exchanger (m^2)	37.88	2	$1,100	316 SS
HE2	Plate Heat Exchanger (m^2)	38.81	2	$1,100	316 SS
F1	Filter-Press After boil-off (m^2)	3.95	2	$9,660	Mild-Steel
F2	Filter-Press after Acid Activation (m^2)	2.78	2	$12,000	PVC-coated carbon steel
D1	Dryer	(355 ft^2)	2	$21,600	Carbon Steel
T1	Spent-Clay Storage	65	3	$30,000	Milled Steel
T2	Boil-off Solution	4.76	1	$1,950	Rubber-Lined Mild Steel
T3	Slurry Tank-1	6.33	1	$3,336	316 stainless steel
T4	Filtrate Tank	1,176.39	1	$135,000	Rubber-Lined Mild Steel
T5	Slurry Tank-2	5.75	1	$2,919	316 stainless steel
T6	Deoiled Clay Hold up Tank	1.57	1	$500	Mild Steel
T7	Concentrated Acid Tank	42.36	1	$6,250	316 stainless steel
T8	Diluted Acid Tank	4.24	1	$1,650	Rubber-Lined Steel
T9	Water Tank	16.19	1	$3,200	Mild Steel
T10	Product Tank	76	2	$20,000	Milled Steel
T11	Neutralization Tank	749.36	1	$120,000	Rubber-Lined Steel
			Total	**$458,265**	

DIRECT COST COMPONENTS WERE ESTIMATED AS A PERCENTAGE OF THE PURCHASED EQUIPMENT COST, AND THE INDIRECT COSTS WERE CALCULATED AS A PERCENTAGE OF THE DIRECT COST.

Table (2) summarizes the different components of capital investment and the percentages used in their estimation. The total capital investment estimated to be $US 2,329,064.47 as shown in Table (2).

Total product cost is divided into two categories: manufacturing costs and general expenses. Manufacturing costs are also referred to as operating or production costs. Further subdivision of the manufacturing costs is somewhat dependent upon the interpretation of variable, fixed, and overhead costs. Total product cost estimated as $2,078,642.94 per year where the income of the process is estimated as $2,520,000 per year. Thus, the gross earning equal to income minus total product cost and estimated to be $441,357.06 per year. Thus, the return investment of total capital will be 18.95% and the breakeven point will be reached after 5.2 years.

Table 2: Estimation of total capital investment costs.

Estimation of Total Capital Investment (TCI)

Table 3: Total Product Cost

Product Kg/year	6,000,000	**Operating Time (hr/year)**		7200
FCI $	1,979,704.8			
I. Manufacturing cost				
A. Variable Production Cost				**Calculated Values $/year**
1.Raw material	**ton / year**	**$/ton**		
NaCl	935.06	70		65,454.48
NaOH	1,558.44	100		155,844.00
H2SO4	4,674.73	75		350,604.86
Spent clay	7,792.21	-		-
Water	105,969.09	0.67		70,999.29
Total				642,902.63
2.Opraiting labor	15 Labor, 5 $/hr			165,000.00
3. Operating supervision	0.15 of Operating labor		0.15	24,750.00
4. Utilities	0.15 of Total Product Cost		0.15	311796.44
5. Maintenance and repair	0.07 of FCI		0.07	138579.336
6. Operating supplies	0.15 Of Maintenance and repair		0.15	20786.9004
7. Laboratory charge	0.15 of Operating labor		0.15	24,750.00
8. Patents and royalties	None		0	0
Variable production cost =				1,328,565.30
B. Fixed Charges				
1.Depreciation	0.1 of FCI			197,970.48
2.Local taxes	0.05 OF FCI			98,985.24
3. Insurance	0.01 of FCI			19,797.048
4. Rent	None			0
Fixed Charge=				316,752.768
C. Plant-Overhead Costs (POC)	0.6 Of Labor+ Supervision +Mint.			196,997.60
Total Manufacturing Cost=				1,842,315.67
II. General Expense				
A. Administrative costs	0.15 Of Labor + Supervision +Mint.			49,249.40
B. Distribution and selling costs	0.05 Of Total Product Cost			103,932.15
C. R&D costs	0.04 Of Total Product Cost			83,145.72
D. Financing	0.00 Of Total Capital Investment			0
General Expense =				226,385.33
III. Total Product Cost				
Manufacturing Cost + General Expense =				2,078,642.94
IV. Gross Earning				
Total Income - Total Product Cost =				441,357.06

VI. CONCLUSION

Thorough analysis of the proposed design indicates that boil-off method followed by acid activation to produce regenerated and activated clay which is a valuable product. In accordance with the project objective, 7,792 tons per year of spent bleaching clay are processed to produce a clay with 100% of bleaching ability is recovered. Economic analysis estimates a net profit value of $0.441 MM per year with an investment return rate of 10.24%.

VII. RECOMMENDATON

The financial viability of the proposed design was found to depend heavily on market prices of fresh bleaching clay. Cost analyses revealed that the minimum requirement for profitability of this project under the current design is a cost of product equal or greater than $346.4 per ton. Prior to further development of the process, additional studies should be undertaken to confirm the results presented in this project. One should estimate the selling prices of fresh clay at present time and other should also confirm the accuracy of design calculations, or revisit the assumptions made.

VIII. ACKNOWLEDGMENTS

The authors express their gratitude to Prof. Abdulrahim Al-Zahrani for his guidance and assistance and he helped us in doing a lot of research and we came up with many new things. Secondly, we would also like to thank the faculty members in our department for their consultancy in many project stages .

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