PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 25 No. 1 pp: 112-120

Environmental Impact of Oil and Soap Industry in Egypt: State of Practice

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Received 5-8-2021
Revised 31-9-2021
Accepted 27-9-2021

ABSTRACT

Oil and soap industries are considered inseparable industries, as the raw materials used in soap industry are oil and fats that are extracted from oil industry. Egypt has several private and public factories working in this industry to meet the demand, on the other hand, the pollution load resulting from both processes is huge and require attention as not to harm the environment. In this research, the production processes of both products are illustrated, after that the pollution sources are pointed out. The pollution control and mitigation techniques used to reduce the environmental impact are illustrated and represented as pre-process pollution prevention, in-process modifications and end of pipe treatment. In solvent extraction process; the widely used solvent is n-hexane, however it has several impacts such as toxicity, harmfulness, and high precautions in handling and disposal. Consequently; an eco-friendly alternative for solvent extraction is mentioned to reduce the negative impact of hexane.

Keywords: Edible oil, Soap, Environmental impact, Water treatment

1. INTRODUCTION

Oil and soap production processes are considered one industry and performed in the same plant. Egypt has a large number of oil and soap factories that are divided into public and private sectors. The public sector has about eight companies such as Salt and Soda Company, Alexandria Oil and Soap Company, … etc. The following table shows the distribution of oil and soap producing plants throughout Egypt [1, 2].

Table 1: Distribution of oil and soap factories in the Egyptian governates [2]

Governorate	Number of factories	Oil	Soap	Oil & Soap
Alexandria	24	8	15	1
Cairo	39	9	30	-
Gharbeya	26	16	6	3
Giza	24	12	12	-
Kalubeya	26	8	18	-
Sharkeya	26	18	8	-
Behera	6	1	5	-
Suez	4	2	-	2
Sohag	2	-	-	2
Suez	4	2	-	2

Edible oil has different types according to the source from which it is extracted. It may be separated from seeds such as cotton, sunflower, soybean, and palm seeds or fruits such as olive [1]. Despite this variety of oil sources, the production process is still nearly the same [2]. It is considered an essential product for life purposes, as it is used as it is in cooking purposes or it may be used as a raw material for soap [3].

Soap is alkali and ammonium salts of fatty acids that are produced continuously by saponification of triglycerides (fats and oils), neutralization of fatty acids, or by the saponification of fatty methyl ester. These processes are done in the presence of alkali as sodium hydroxide, potassium hydroxide, sodium carbonate and tri-ethanol amine, as shown in Figure 1 [3, 4].

In this research the production processes of both oil and soap are discussed in details, followed by the pollution streams and waste mitigation techniques.

2. OIL PRODUCTION PROCESS

Generally; oil processing steps are almost the same in case of extracting oil from seeds, while in case of extracting it from fruits the process changes. The following stages describe the processing steps in case of

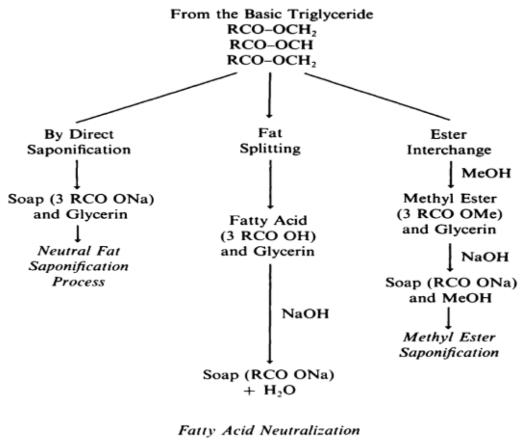


Figure 1: Three processes for making soap from triglycerides [5]

using seeds as raw materials as shown in Figure 2. The production process of edible oil passes through three main stages seed preparation, oil extraction and oil refining [1 – 4].

2.1. Seeds preparation

In the beginning, seeds are received and stored in stacks which are fully or partially covered, to avoid the deteriorative effect of rainfall or sunlight. Then they are cleaned through two steps by screening to eliminate foreign bodies such as stones, grit and dust followed by magnetic separation to get rid of metal contaminants [1, 2]. After that, drying of seeds is carried out to reduce the moisture content to about 10 – 12% before starting the extraction stage to enhance the efficiency of the whole process [6].

Seeds are tempered for two or three days to let these seeds to equilibrate with their new moisture content and to allow hulls to loosen to be easy to remove them in the de-hulling step. Oil content in the hulls is almost 1%, so it should be removed before oil extraction step to decrease the large size requirements of the absorption unit and increase the yield of the extraction process, as hulls absorb some of oil and reduce the ability of extraction of them again [2, 7].

Crushing of seeds is performed to increase the applied surface area by reducing seed particle size using crushing mills. Consequently; the efficiency of absorption of oil using a solvent is maximized as solvent adhere seeds easily [1, 6, 7]. Then conditioning using steam is performed to enhance the extraction process. This enhancement is done by increasing both the temperature and the moisture content of seeds. As by increasing the temperature of the medium, the viscosity of oil decreases and hence the fluidity of it increases, so the extraction process becomes easier [1, 2]. On the other hand; by increasing the moisture content, the seeds become softer, so low power will be required in the flaking step that performed to change the shape of seeds to decrease the distance that the solvent needs to reach the core of the seed, so the efficiency of the extraction process increases. [1, 6]

2.2. Oil extraction

Oil extraction from seeds may be performed by one of the following techniques [2]:

- **a- Mechanical pressing:** It is considered the oldest way of separation, in which seeds are pressed using a hydraulic or screw press to separate oil from cake. Its efficiency depends on the power supplied to the press, but in general; it has the lowest efficiency compared to the other techniques of extraction.
- **b- Solvent extraction:** n-hexane is the most commonly used solvent, because it reduces the pigment content of oil, in addition to its high absorption power of oil.
- **c- Prepress solvent extraction:** It's considered a combination of the previous two techniques, as mechanical pressing is applied followed by solvent extraction to increase the oil recovery.

Solvent extraction technique is the most commonly used in Egypt, as its efficiency is high when it is compared with mechanical pressing, also its operational cost is lower than that of prepress solvent extraction [2]. Solvent extraction process is performed through three steps oil absorption, filtration, and solvent recovery. A suitable solvent such as hexane that has high absorption capacity, high selectivity, and easily regenerated is applied to extract oil from seeds [7]. Then filtration is done to separate the raffinate (solids) from the extract (miscella / the mixture of oil and solvent) [1]. As a final step, the solvent is recovered to be used again through double-effect evaporation followed by a steam stripping or vacuum distillation [1, 7].

2.3. Oil refining process

The previous steps are just performed to separate oil from the solid part of seeds, but this extracted oil contains many undesired constituents, such as gums, waxes, pigments, phosphatides, free acids and odoriferous materials. Some of them affect human health and the other affects the physical properties of oil, such as color and odor. Consequently; their content is reduced to meet the required specifications [2].

2.3.1. Degumming

Gums and waxes content in oil depends on the type of oil, as soybean is richer in gums than cottonseed, while sunflower is rich in waxes. For this reason, the amount of chemicals added to remove gums is adjusted according to the type of oil. Separation of gums and phosphatides from

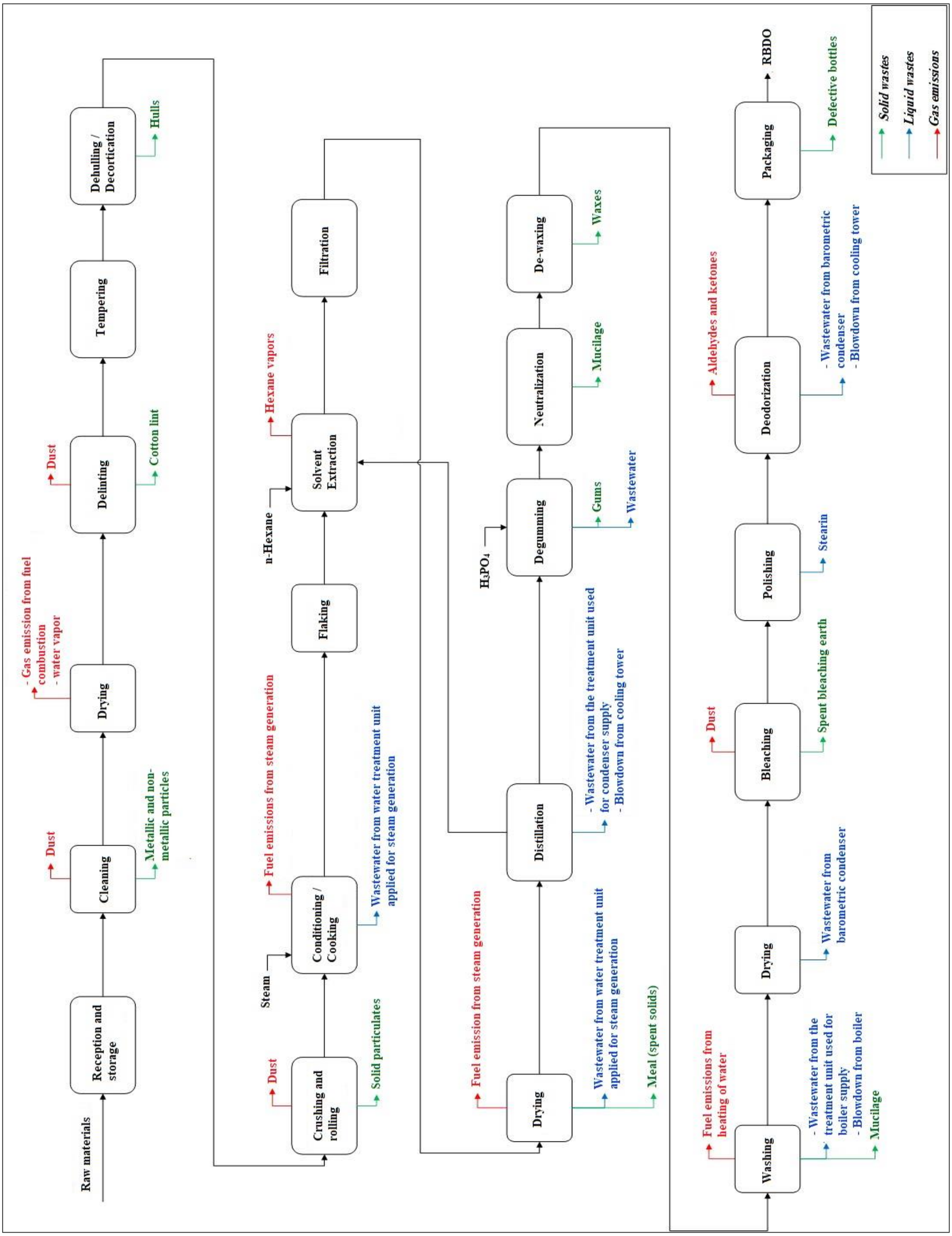


Figure 2: Process flow diagram of oil manufacturing from seed

oil occurs by adding phosphoric acid solution (H_3PO_4) [1, 2, 7]. The reaction between oil and phosphoric acid is performed to convert the phosphatides which are un-hydratable to hydratable compounds to be able to dissolve them in water. Then a centrifugal separator is applied to eliminate water and gums from oil [1, 2].

2.3.2. Neutralization

In another reaction tank the saponification reaction is performed by injecting caustic soda solution (NaOH) to react with the free fatty acids (FFAs) and the acidic pigments to form soap as seen in the following reaction. Soap surrounds the residual gums and form mucilage that is easily removed from oil by settling or using a centrifugal separator, due to the density difference between oil and the formed mucilage [7].

$$FFA + NaOH_{sol.} \longrightarrow Soap + Water$$

2.3.3. De-waxing

Waxes are suspended matters have a boiling point lower than that of oil, so they precipitate upon cooling to about 10°C to form solid crystals, then filltration is done to remove the formed solid crystals. This technique removes only about 85% of waxes content [1, 2]. While the residual 15% are removed via washing of oil using dilute citric acid solution and hot water followed by centrifugation to eliminate any residual amount of soap in oil centrifugal separator is applied to separate mucilage from oil. After eliminating soap, drying at 90 – 100°C under vacuum is performed to remove water as water content affect the efficiency of the bleaching step. [1]

2.3.4. Bleaching

It's an adsorption process in which the bleaching earth is added to adsorb pigments and colored materials, such as carotene. Bleaching earth is added in small amount w.r.t. the amount of oil about (1 – 2%) of the oil amount. This process is performed in the bleaching kettle at about (90-110°C) under vacuum [1]. After the adsorption of the undesired pigments using the bleaching earth, it's eliminated from oil by passing through a filter. The cake produced from filtration is blown with air and steam to recover oil as much as possible and reduce oil losses in the spent bleaching earth. Finally, the spent bleaching earth leaves that process with about (30-35%) of its weight oil. [1]

2.3.5. Winterization and stearin removal (polishing)

This step is performed in case of oil with high stearin content, such as cottonseed and olive oil which contains up to 18% stearin. This process is done by decreasing the temperature of oil and maintaining it at 4°C for three daysto allow stearin to settle and form crystals that is separated by filtration. The filter is cleaned by applying steam to melt stearin crystals off. After that step the residual waxes from the de-waxing unit are removed, so the appearance of oil is improved [2].

2.3.6. Deodorization

The existence of aldehydes and ketones is the main reason for the undesirable smell. These compounds are removed by increasing the temperature of oil to about 250°C. This elevated temperature is reached under very low pressure (6 – 8 mmHg) to avoid decomposition of oil at this very high temperature. After this step, oil becomes refined, bleached and deodorized oil (RBDO) which is ready to be used in edible purposes [1, 2].

3. SOAP PRODUCTION

Triglycerides used in soap production are formed from oil and fats from either vegetable or animal sources. The properties of soap depend on the type of fats and oils used and the fatty acid composition forming these fats and oils. consequently, the properties of finished soap are adjusted by carefully selecting the fatty acids composition. The production process involves the following steps is shown in Figure 3 [5].

3.1. Saponification

In this process fats/oils (triglyceride), caustic soda are introduced into a reactor at 120°C in order to produce soap as shown in Figure 4 [8]. Saponification reaction is generally performed at elevated pressure (200kPa) and high mixing rate to prevent vaporization and to ensure immediate homogenization of raw materials respectively. Since saponification reaction is autocatalytic, a portion of the produced soap is recycled back to the reactor to increase the rate of reaction. Salt solution is added to enhance the separation of soap from spent lye (a mixture containing glycerin, salts and caustic soda); as soap has low solubility in salt while glycerin is highly soluble in it [3, 4]. Then the product is cooled to enhance the separation efficiency [3].

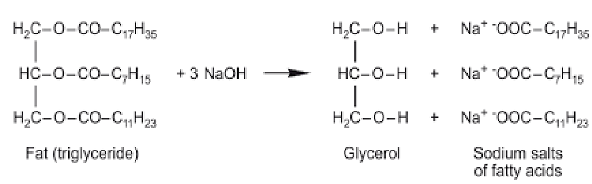
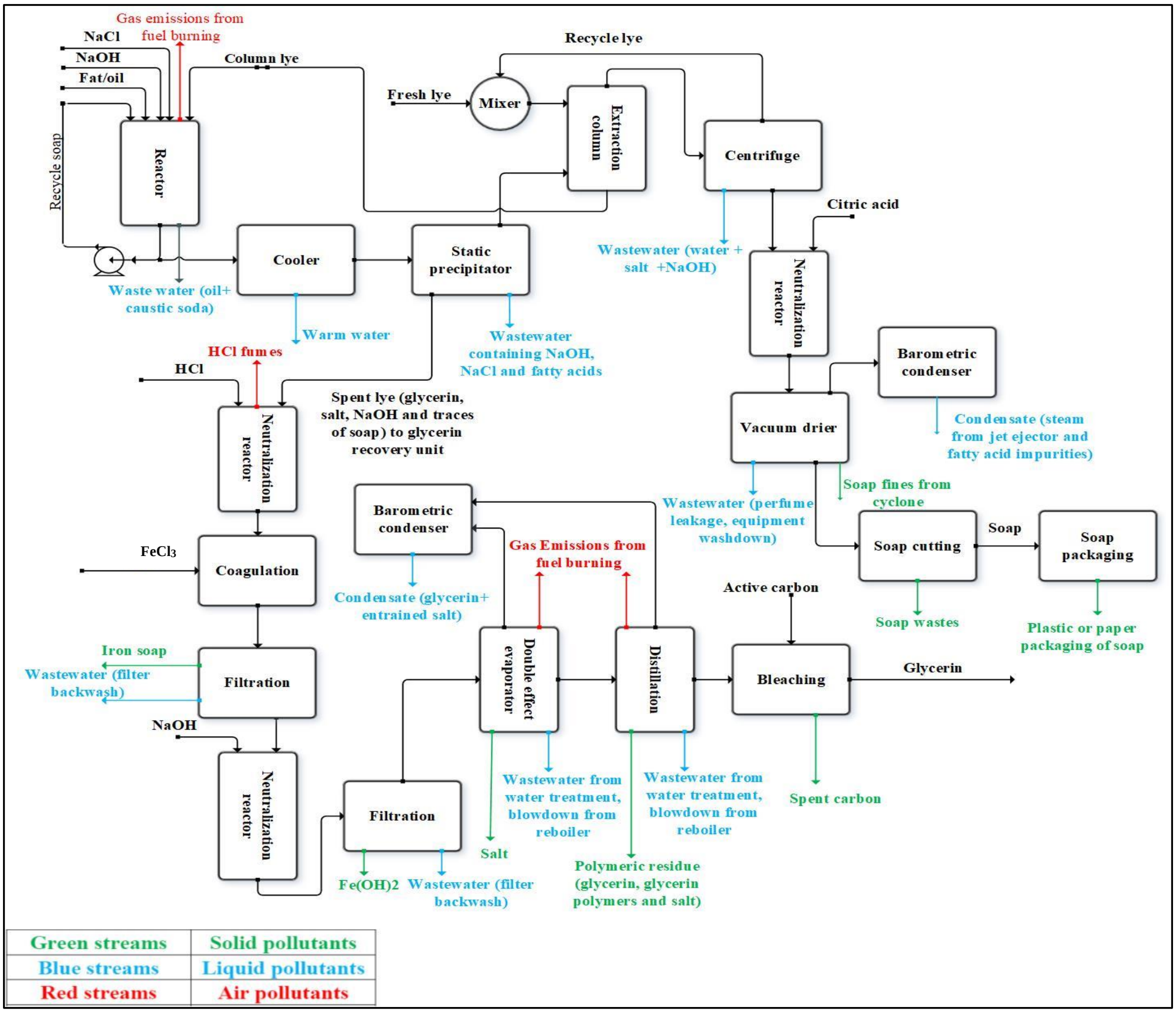


Figure 4: Saponification of triglycerides [8]

3.2. Soap Separation



The mixture of soap and spent lye are separated from each other through three steps in series. At first; gravity separation is applied by providing sufficient residence time and by decreasing the velocity of flow to produce neat soap as the top product and spent lye as the bottom product. Then the extraction column is applied to meet the color and odor specifications, and to ensure high efficiency of separation, as the density difference between neat soap (0.97g/cc) and spent lye (1.05g/cc) is small. Separation proceeds in a countercurrent manner, where the fresh lye (mixture of salt and caustic soda) entered from the top of the extraction column comes in contact with the soap that introduced from the bottom. The fresh lye that became enriched with glycerin is discharged from the bottom as spent lye, which in turn is recycled back to saponification reactor to utilize the remaining alkali in the lye. Finally; to reduce salt and moisture content in soap, centrifugal separation is done. The separated fresh lye is recycled back to the extraction column and neat soap is sent to a neutralizer [3, 4, 8].

1.1. Neutralization

Although the caustic soda levels in the neat soap is limited, yet they are still unacceptable for toilet soap and laundry soap [8]. Weak acids such as coconut oil fatty acids, citric acid or phosphoric acid are introduced into a CSTR type neutralization reactor to neutralize any caustic soda present. Preservatives are also added to minimize the degradation of the neutralized soap. This reactor operates under atmospheric pressure and temperatures of 80-90°C, producing neat soap at suitable conditions for storage [3].

1.2. Soap drying

The purpose of this step is to reduce the moisture content present in the neat soap from 30-35% to reach 8-18% [3, 8]. Drying is achieved using single or multistage vacuum spray drying systems which are easy to operate and flexible to all formulations and to different moisture contents [3, 9].

1.3. Glycerine recovery

Glycerin is a very valuable byproduct produced from soap making process, so it is separated from the spent lye and purified in order to be sold [1, 8]. The steps required for glycerin recovery are described in the following section.

1.3.1. Salt Removal

The soap- free lye solution is sent to a double effect evaporator operating under vacuum, to separate salt and to concentrate glycerin solution to reach 80- 85% crude glycerin. The 80-85% crude glycerin is pumped to crude settling tank to separate more salt. The salt withdrawn from the settling tank and from the bottom of the second evaporator is washed, dried and sent to storage drums in order to be used again in the process. In order to remove the small amounts of salt, organic, and inorganic impurities from glycerin to produce it with high quality, fractional vacuum distillation using superheated steam followed by bleaching of it using activated carbon are performed [1, 8]:

2. WASTE MITIGATION TECHNIQUES

Different pollutants from oil and soap industry apperar in Figure 2 and Figure 3. The treatment of different wastes can be classified into pre-process prevention, in process modifications, and end of pipe treatment.

2.1. Pre-process pollution prevention

Good housekeeping can represent significant pollution prevention opportunities and reduction of waste through [10]:

- storage the raw materials in closed tanks to minimize weather damage of seeds and accidential spillage of chemicals.
- Transportation of raw materials using belt conveyors.
- Performing preventive maintenance for cooling towers to reduce the hydraulic load of wastewater.

2.2. In Process Modification

It represents the modifications that may be done in the process itself to reduce wastes. It includes [10]:

- Reduction of washing water by applying primary and secondary washing steps or reusing it in preparation of caustic soda solution used for the neutralization of crude oil. This procedure can reduce the hydraulic load of the wastewater from the neutralization plant by almost 50%.
- Reduction of oil spillage by performing regular maintenance for pipelines to minimize leakage.
- Prevention of clogging of pipelines by appling steam jackets to avoid clogging of pipelines that transfer the molten soap.
- Recycling of indirect steam to be reused in the steam boiler unit.
- Accurate adjustment of temperature and pressure in glycerin distillation unit helps in reduction of polymer formation that contributes in increasing the loads of chemical oxygen demand (COD) and biological oxygen demand (BOD) [1, 11].

2.3. End of pipe treatment

It represents the treatment performed after releasing wastes. The following section involves the explanation of end of pipe treatment for solid and water.

2.3.1. Solid waste treatment

Solid waste from oil and soap industry includes: hulls of seeds, oil-cakes (meal), gums, spent bleaching earth, waxes, and soap fines from cyclone.

- Hulls of seeds are used as animal fodder or used in flour production for human consumption [1].
- Oil-Cakes are rich in protein and most are valuable food for farm animals, but some seeds such as castor seeds contain toxic substances. Consequently; acceptable feeds can be produced by blending about 30% of oil-cake with other local ingredients such as cereals and bran [12].
- The produced gum could be a useful by-product from which lecithin, a natural emulsifier can be obtained [7].
- Spent bleaching earth contains 30-50% oil, so its disposal causes bad impact on the environment, since it is prone to catching fire, besides polluting the underground water. Also the disposal of it in landfills requires high cost, so solvent extraction process is applied to be able to landfill the de-oiled bleaching earth, or using it as a source of fuel, or it may be applied in cement/ fertilizers industries as it contains silicates. While the recovered oil may be used in non-edible applications such as feed stock for production of biodiesel, a lubricant base for bio-lubricants, or as a feedstock to the oleo-chemical industry as it becomes high in FFA and peroxide value [13].
- Waxes may be used in building materials and coatings as they are considered water repellent materials, also they are widely used in cosmetics, pharmaceuticals, inks, Poly vinyl chloride (PVC), tires, rubber and candles production. [14]

2.3.2. Wastewater treatment

It's performed by applying pre, primary, secondary and tertiary treatment according to the application in which water will bw used. In most applications only pre, primary and secondary treatment are performed.

A. Pre-treatment

Wastewater stream passes through two steps before being treated to be able to perform that treatment perfectly that are:

a) Equalization

Wastewater streams are collected from different equipment and supplied to the equalization tank to get uniform flow rate, contaminant concentration, pH, and temperature to avoid variations in treatment procedure [15].

b) Neutralization

It is performed to adjust the pH value to make wastewater biologically treatable and comply with discharge standards in which sodium hydroxide or calcium hydroxide are used to increase the pH, while sulfuric acid, hydrochloric acid or CO_2 are used to decrease [16].

B. Primary treatment

The main purpose of that procedure is to eliminate oil droplets from wastewater stream. One or more of the following techniques is applied to remove oil from water according to the difficulty degree of separation [17].

a) Physical treatment

It is performed in a setlling tank where oil droplets float at the top then skimmers are used to eliminate that layer. The efficiency of separation is mainly affected by the density difference between oil and water and the size of the suspended particles. Consequently; it requires large area with high settling time [18].

b) Chemical coagulation

It's the most widely used technique due to its high efficiency and the availability of the used chemicals. Different coagulants may be used such as alum ($Al_2(SO_4)_{3.16}$ H_2O), ferric chloride ($FeCl_3$) or lime ($Ca(OH)_2$) depending on the pH of the medium [19, 20].

c) Electrocoagulation

This technique is performed in an electrochemical cell. By applying electrical current, species react with negatively charged particles to form flocs, while the released gases at the cathode carry these flocs to float at the surface to be easy to be removed. It has some advantages over the previous two techniques as it requires low retention time, produces low amount of sludge, causes rapid sedimentation, requires simple equipment with easy operation. The reactions carried out are shown below [21]:

At the anode: $Al \rightarrow Al_{aq}^{3+} + 3e^-$

At the cathode: $3H_2O + 3e^- \rightarrow \frac{3}{2} H_2 + 3OH^-$

In the solution: $Al_{aq}^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+$

d) Air floatation

Air floatation is considered an accelerated gravity separation. In which air is supplied to decrease the specific gravity of oil droplets to allow them to float at the surface of the tank to be skimmed [18]. Air floatation is performed by one of the following techniques:

Dissolved air floatation (DAF): There are different schemes of DAF, as it may be done by appling pressurized air from the bottom or applying pressuized wastewater that is previously saturated with air. When these streams enter the floatation chamber that operates at atmospheric pressure through an orifice the applied pressure is released and allow oil droplets with the entrained air to float at the surface. This technique is performed by The full flow pressurization system, the partial (split) flow pressurization system, and the recycle flow pressurization system [18, 15]

***Induced air floatation (IAF*):** Air is supplied downward to a central rotating shaft conducted with a pipe contains a number of nozzles. In this technique, the contact between water and air occurs at atmospheric pressure, so the generated air bubbles are found to be larger than that formed in DAF by about 1000μm. Consequently; DAF is more effective in oil removal, but it requires higher residence time to purify the produced water stream [18, 15].

C. Secondary treatment

The aim of this process is to decrease COD and BOD load of wastewater to comply with the environmental standards. It is performed by applying biological treatment. It involves the degradation of dissolved bio-degradable organic materials present in wastewater through the action of microorganisms. Organic nitrogen and phosphorus are added to serve as nutrients for microorganisms' growth. There are two types of metabolic processes that are mentioned in Table 2. The efficiency of both processes depends on the amount of biodegradable materials present. Consequently; to ensure better results BOD/COD ratio must be equal or higher than 0.4 [16]. It is followed by sedimentation to eliminate the acivated sludge, then part of this sludge is recycled back to ensure proper food/microorganism (F/M) ratio, while the excess sludge is sent to sludge dewatering processes [22]. The produced sludge contains only 0.25wt% - 12wt% solid materials that are mainly bacterial tissues and heavy metals, so elimination of water content decreases helps in easy disposal [16].

D. Tertiary treatment

This treatment is applied only when a high degree of purity is required. It involves some techniques such as ultrafiltration and carbon adsorption [15].

a) Ultrafiltration

Filtration using membrane is used in cases when complete removal of insoluble heavy metals is desired. It depends on the material from which the membrane is manufactured. Polymers are the commonly used material in membrane with pore diameter in the range of 0.001-0.1μm. The wastewater stream is allowed to flow through the pores, where oil droplets or other solid particles are held back. It operates under pressure of about 0.2-1MPa [16]. The life time of the membrane is affected by the flow rate, temperature, pH, the degree of dirtiness of the water stream and the frequency of cleaning of the membrane, so it requires extensive pre-treatment. This application is not applied to large-scale operations [15].

b) Carbon adsorption

It's an advanced way to eliminate soluble oil droplets using activated carbon. It also requires extensive pre-treatment as ultrafiltration. Activated carbon requires replacement or reactivation periodically, as deactivation of it occurs. It's not applied to large-scale operations [15].

Table 2: The two metabolic processes in biological treatment [16]

	Anaerobic treatment	Aerobic treatment
Definition	It is the conversion of organic substances, in the presence of microorganisms and absence of air, to produce variety of products as methane, CO_2, sulfides etc. The treatment process takes place in an airtight stirred tank reactor, where microorganisms are retained in the tank as biomass.	It is the conversion of dissolved organic substances, in the presence of microorganisms and air (or pure oxygen), to produce CO_2, water biomass (activated sludge).
Techniques	• Anaerobic contact reactor • Upflow anaerobic sludge blanket (UASB) reactor • Fixed bed reactor • Expanded-bed reactor.	• Complete mix activated sludge process • Membrane bioreactor process • Trickling or percolating filter process • The Expanded-bed process • Fixed-bed biofilter process
Applicability	It's used for high BOD loads.	It's used for low to moderate BOD ranges.
Advantages	• Energy consumption rates is low compared to aerobic treatment • Energy rich-gas (biogas) is produced which is used as a fuel • Low amount of activated sludge is produced, 10% lower than that produced from aerobic treatment	• Large amount of wastewater can be treated, • Relatively high energy efficiency compared to non-biological treatment • Mainly harmless compounds are produced from degradation process • COD removal efficiency can reach higher than 85%
Disadvantages	• Due to high sensitivity to toxic substances, increased amounts of activated sludge can be discharged when toxic substances enter • Very slow start up • COD removal is lower than 85%, thus requiring further treatment.	• Due to the supply of oxygen in water, high energy is consumed • High amounts of activated sludge is produced (except with membrane bioreactor or fixed-bed biofilter process) • Volatile compounds, as odor, is released due to the aeration effect • In the case of poor sludge-settling quality, the sludge handling can be a problem.

3. NEW TREND IN OIL INDUSTRY

Solvent extraction is the main technique used for oil extraction from seeds. n-hexane is widely used due to its benefits such as simple recovery and high selictivity, on the other hand there are some drawbacks such as toxicity. A new alternatives are found to replace the usage of n-hexane such as green solvents and aqueous assisted enzyme extraction. Green solvents such as terpenes and ionic liquids can extract the oil in an eco-friendly manner as shown in Figure 5, these solvents are derived naturally or from agriculture residues. Both green solvents and enzyme technology are beneficial due to their higher yields, cost effictiveness and less harmful to the environment [23].

4. CONCLUSION

Oil and soap industry is one of the industries that produce industrial wastes that affect the environment. For this, different pollutants from each equipment were highlighted and treatments were applied for some of the mentioned pollutants. Wastewater, gums, waxes, bleaching earth and oil cake were treated. A new trend of

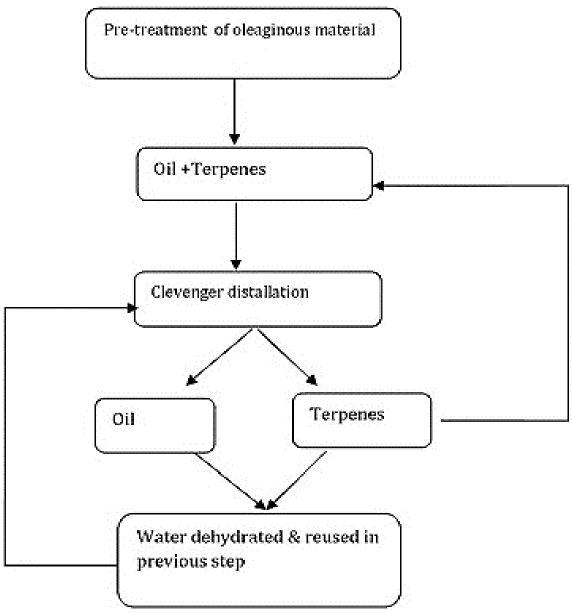


Figure 3: Block flow diagram of green solvent technology [23]

using green solvent rather than n-hexane in oil extraction showed to be a better solution for oil extraction as it is eco-friendly, can obtain higher yields, cost-effective and aids in obtaining co-products without any damage.

Credit Authorship Contribution Statement

The authors of this research cooperated together to carry out this work and formulate it as a review. Author contribution was as follows:

Amal M. El-Sayed: Data acquisition regarding oil industry and waste mitigation techniques in this industry.

Aya M. Gomaa: Data acquisition soap industry and waste mitigation techniques in this industry

Kareem H. Hamad: Data analysis, revision and editing this research.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Funding

No fund was needed to carry out this work

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