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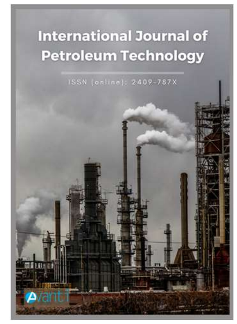

Transformer Oil Generation and Regeneration Techniques Based on Recent Developments (A Review)

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ABSTRACT

With regard to the wide application of Transformer Oils (TO) as an energy stream on an industrial scale with fast progress towards green TO generation and regeneration technologies, the current review takes into investigation the TO generation industries based on the screening step of industrial projects by Iranian evaluator teams of in-charge organizations. The present review encompassed the TO generation and regeneration technologies from traditional, typical, and recently developed practices in this regard. The technologies extended to introduce green TO generation practices in connection with fossil fuel resources. By the way, a comparison has been done based on technologies posed for TO with the used motor oil reprocessing techniques and used lubricant oil regeneration technologies. To sum up, the current review comprised basic knowledge to select the best technologies for decision-making models in future industrial developments. The prominent achievement of the current review can be mentioned to the aggregation of industrial data for further processing in decision-making theory, criteria, and alternatives selections.

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1. Introduction

The transformers have found a vast application in electrical equipment over the world. The transformer fluids used in respective years included petroleum-based oils, askarels, silicon oils, high-temperature hydrocarbons, chlorofluorocarbons-based fluids, isopropyl biphenyl hydrocarbon fluids, tetrachloroethylene-based fluid, and recently green TO. The outlays of replacing TO are very impressive. It reminds the considerations of reliable maintenance and service procurement. TO is a type of refined mineral oil obtained by the fractional distillation of crude oil, which is boiled at a temperature between 250 and 300°C. This oil is used as an insulation agent and is expected to consist of high insulating and cooling properties. The oil needs to have enough viscosity to present a high cooling property and a high dielectric coefficient to contain a good insulating property [1, 2]. High purity and long life are other important features of TO. The purity of TO is important in terms of being compatible with other components of a transformer. The most important causes of TO failure are oxidation and overheating. This oil has been one of the main components of transformers. However, it is also used in other electrical appliances such as circuit breakers, capacitors, bushings, and so on. This oil is chemically completely pure after refining and contains only liquid hydrocarbons. TO has two main functions: first, it acts as an electrical insulator, and second, it transfers the heat generated in the live parts of the transformer. With the high voltages currently present in the power transmission network, the need for TO as electrical insulation and cooling device has increased [3, 4].

The characteristics of ideal TO are as follows. (1) High electrical resistance, (2) high conductivity for heat, and (3) low specific gravity. In oils with low specific gravity, the suspended particles settle easily and quickly, and this property accelerates the homogenization process of the oil. (4) It has enough viscosity, the oil that has enough viscosity has better and good performance and as a result, will have better cooling properties depends on the type of application and location. (5) It has a low pour point. An oil with a low pour point will lose its motion at low temperatures. (6) It consists of a high flash point. Flashpoint indicates the tendency of the oil to be evaporated. The lower the flashpoint of the oil, the greater the tendency for the oil to evaporate. (7) It should not damage the insulation materials and metal structures. (8) It has a stable chemical property. This will make the oil last longer. TO characteristics: The oil used in the transformer must have the following two characteristics: (1) the oil must be clean. Suspended solids or harmful chemicals or water should never be present. (2) The oil must be chemically stable. The oil changes should be as small as possible at the normal operating temperature of the transformer due to the heat and oxygen that come in contact. In general, the main reasons for using oils in motor transformers can be stated as follows: Electrical insulation, control of the internal temperature of transformers and heat transfer, prevention of corrosion of insulation materials and metal parts of transformers, longer life, and the guarantee of chemical stability for transformers, sealing, collecting and transporting the impurities from operating outside the environment system, switching off the electric spark. The functions that a good oil should have as an insulating fluid and a heat transfer material are dielectric strength or high breakdown voltage, good heat transfer capability, enough viscosity, low pour point or flow, high flash point, the tendency to oxidation, and low sludge formation, low insulation loss coefficient, high specific resistance and oil working conditions [3-5].

The most important factors affecting the properties and conditions of the TO are: Changes in ambient temperature, system load and surfaces used, pollutants and impurities, the possibility of air presence and its penetration in the oil system, space and location of the transformer in terms of fire, operation and maintenance of units. To use TO as insulation agents, it must be free of moisture and suspended particles of impurities. Decreasing the dielectric characteristics due to moisture and foreign objects reduces the oil insulation voltage. Dielectric strength is the most important electrical characteristic of TO. Impurities mainly include; rotten shells covered oil tanks, fiber particles, and dissociated parts of insulating paper, and rotten oil particles in service, etc. Absorbed water particles are also the result of moisture in storage tanks and transformer installations location or through the breathing of motor transformers and even moisture is created by the oxidation of the oil. Moisture absorption by the oil significantly reduces its dielectric strength and increases its insulation losses. Due to the possibility of moisture absorption in oil transportation, storage, and charging of oil in the installation and operation stages, the dielectric strength of new oils should be considered more than the permissible level specified in the standard table [6,7].

By placing the insulators in the electric field, in addition to ohmic losses, a dielectric loss occurs due to the leakage current from the insulation. In electrical modelling, an insulator in the form of a series of capacitors with a resistor is shown to have a dielectric loss due to leakage in the insulation current range, which is also proportional to the frequency. Insulation resistance indicates the electrical quality of the oil and the efficiency of insulation oil. Measuring the electrical resistance of the oil, like measuring the loss coefficient, indicates the quality of the oil. During the operation of some transformer motors, many electrical stresses occur. From this point of view, the electrical resistance of oil is the first method in evaluating oil. The measurement method is by applying a voltage between the two electrodes and measuring the current flow [8, 9].

The chemical properties of motor TO generally include the amount of corrosive sulfur, the amount of water-soluble in the oil, and the stability of the oil to oxidation, which includes total acidity and sludge settling in the oil. During the operation of the oil for various reasons, the oil characteristics in the motor transformer change. One of the factors of this change is moisture absorption. The absorption of moisture by the oil significantly reduces its electrical resistance and increases insulation losses, and as a result, the insulating role of the oil is badly affected. Therefore, recording and measuring the amount of moisture in the oil is considered its chemical characteristics. The electrical resistance of the oil largely depends on the amount of moisture. The amount of water that the oil can dissolve at a temperature of 20°C is about 40 to 100 ppm [10].

The resistance of oil to oxidation is another important feature of TO. To understand this property, two values of the neutralization number and the amount of sludge in the oil must be examined. The stability of the fresh oil against oxidation is usually expressed in terms of the results of the oil ageing test, which is similar to the actual performance of the oil under service conditions during the useful life of the oil. The presence of sediment and sludge is compared with the standard values. It is important to know the degree of permissible oil degradation to the extent that sludge deposition in the oil does not pose a significant problem and is permissible, as scale formation is very detrimental due to reduced thermal conductivity [11].

Transformers that operate continuously at a slightly higher temperature than normal will experience a sharp reduction in insulation life and an increase in the degree of oil deterioration. Optimal maintenance of the entire transformer of network motors is considered and recommended. Measuring the total acidity of the oil is the most appropriate and fastest way to evaluate the oil capability for the absence of acid formation in the service and its rise indicates the need to reduce or change the engine TO [12, 13]. The neutralization number determines the amount of organic and inorganic free acids present in the oil and is needed to neutralize all of these free acids in one gram of oil. Oxidation of oil is the result of a reaction between the hydrocarbons in the oil and oxygen. Oxygen may be atmospheric due to contact of the oil with ambient air during respiration or tail of the engine transformer, or it may remain dissolved due to incomplete degassing of the oil. Oil ion oxidation is a chain reaction that results in the formation of organic and sludge acids. The addition of ion oxidation inhibitors, in addition to increasing the oil resistance to oxidation, neutralizes the catalytic role of metals such as copper coils in the oxidation action. At the end of this period, the oil is free of inhibitors and the oil begins to spoil, and its progress is just like the oil that has been free from the substance from the beginning [14, 15].

The rise of sediment from the standard level indicates the unsuitability of the oil used in the motor transformer [16]. The oil degradation products indicate sedimentable sludge. The quantity of these contaminants for oil in service is determined by sampling and testing. The resulting acids increase the level of sludge that will settle on the windings and other parts of the motor transformer. This also prevents the proper rotation of the oil and the natural transfer of heat and accelerates the deterioration of the insulation material, which will be very undesirable. To prevent these events, organic substances that prevent oxidation are added to the oil. They are called inhibitors or stabilizers of the oil against oxidation [17, 18].

Oils that are not flammable and do not age in special transformers are not formed sludge. But it is economically more expensive than ordinary oils. Considering the densely populated areas such as densely populated cities and even factory halls, the use of special transformers in basements and confined spaces is inevitable. Fire-resistant synthetic oils can be used for these transformers, but their electrical properties are not the same as insulating oils. These oils also dissolve insulating glazes as well as rubber, so they should not be used in containers containing these coatings. These special oils can be listed as follows; Ascarl - Clofen - Pyralen - Silicon

- Chlorinated hydrocarbons such as - Pentachloride - Diphenyl - Trichlorobenzene - Pirachlor - Tools and oil equipment [19, 20].

If the oil test results indicate the need for filtration of the TO, physical purification will be performed by transferring the oil purifier to the transformer installation site. In this device, which is usually used to capture suspended and impure materials using filters, a vacuum dewatering system is used to separate the oil moisture. This method is quite common in Iran. In this operation, oil purification is continuously started in a closed circuit from the bottom of the transformer with the help of a pump, sucked in and the filtering operation begins. The oil is first passed through a filter and the coarse particles are first purified. The oil is then placed in a relatively large chamber and heated. Since the excess heat causes the antioxidants to evaporate, they do not allow the heat to exceed 60 °C. To separate the moisture from the oil will be increased the contact surface of the oil and the air. This operation is done by pulverizing the oil and spraying it into the vacuum chamber. The said container is less than or equal to 1 mbar during vacuum filter operation. During this step, the gas and oil moisture is removed. The dried and degassed oil collects in the bottom of the chamber and is poured through the sand filter on the trays inside the vacuum filter chamber so that the gases dissolved in the oil evaporate at the same time as the water evaporates. The oil is then returned to the transformer. The silica gel device as a dehumidifier in the transformer is a function of the load and environmental conditions. In addition, the volume of the dehumidifier is determined by the same factors [21, 22]. The types of tests of these oils are divided into four categories including at least 28 typical tests according to the following cases.

- Insoluble gas analysis
- Furan analysis; to detect the furan components released into oil is employed the furfural test that is an indicator of cellulose dissociation. The test indicates the ageing conditions of insulation paper. The cellulose is used to form a solid insulation framework of the transformer as kraft paper, which is called electrotechnical paper, and pressboard to enhance the electrical and mechanical stability in power supply facilities.
- PCBs Analysis; Despite the prohibition of PCBs production all over the world, the lubrication storage locations and sites accumulated large quantities in transformers and capacitors [1, 23, 24].

Comprehensive electrical and physical tests which include: color and appearance of oil, breakdown voltage, water content, acidity, dielectric loss factor, flash point, drop point, density, and eruption, and dielectric loss factor tests are not only used to measure the quality of TO but also to diagnose general incompatibilities of internal transformer components or transformer insulation system problems, which cannot be detected without a complete overhaul of the transformer. It is generally recommended that comprehensive electrical and physical tests be performed twice a year, insoluble gas analysis once a year, and eruption tests once every two years for transformers that have operated for more than five years [25-28].

The industrial data employed in the present review refers to the project identification steps expressed and investigated by evaluator teams in the Environmental Impact Assessment (EIA) plan according to Figure **1**. Tables associated with project requirements are devoted to the screening step of EIA [29, 30]. To the best of our knowledge, this is the first report that shares the data and technologies of TO generation and regeneration industries in EIA across Iran. The current review targeted to explain the generation and regeneration technologies of TO in comparison with technologies outlined for drying oils, used motor oil, used lubricants, margarine oils, vegetable oils, and olive oil.

2. Typical to generation practices

2.1. TO generation technology

According to Figure **2**, the initial feedstock of TO gets back to crude oil for the petroleum-derived TO types. The crude oil employed for lubricating oils comprised 1% of whole applications of crude oil. It is a small proportion of crude oil feedstock [1].

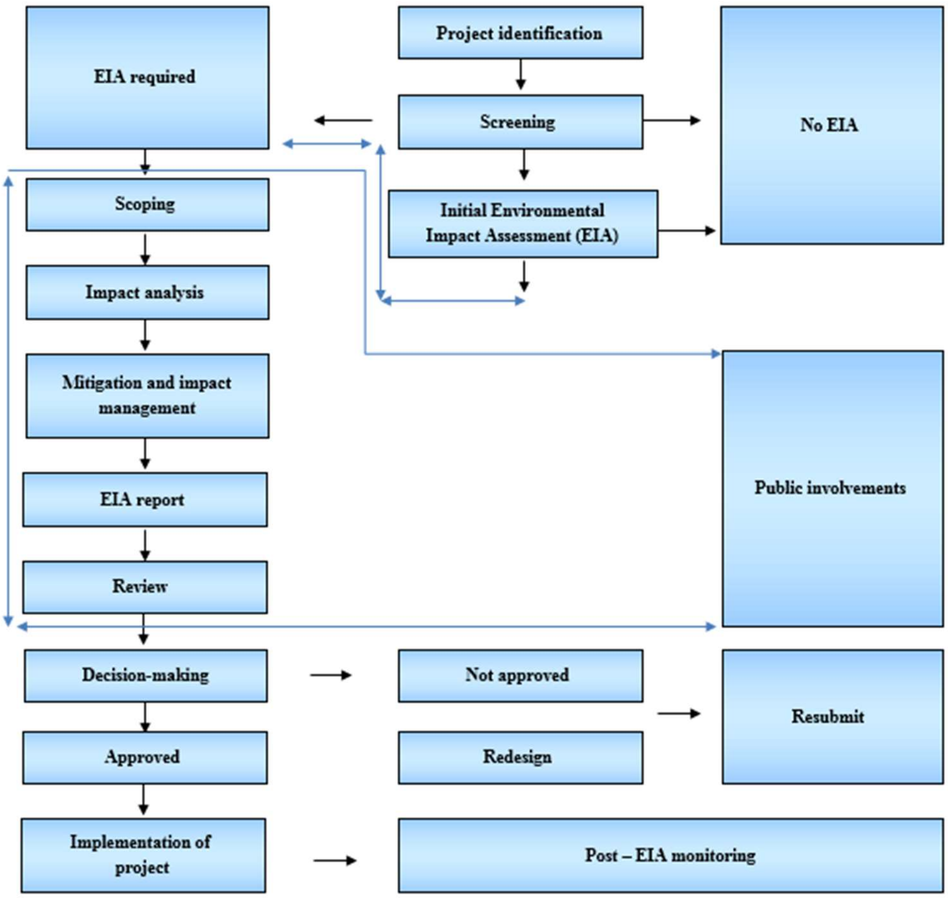

Figure 1: The evaluation steps of EIA [29].

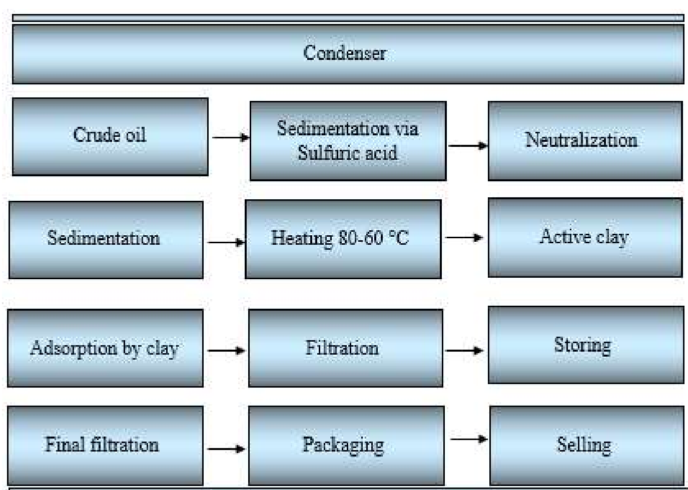

Figure 2: Typical TO generation processes in Iran [30].

Petroleum-based oils have long been used as an insulating medium as well as a heat exchanger in high voltage electrical devices. The production of such oils in recent years using raw oils free of wax has been accomplished and thus its use in the winter will be easily possible. TO generally requires it to be well refined and appeared free of any impurities that cause damage to facilities and has high resistance and excellent cooling ability. The general properties of the product obtained in the unit are as follows: (1) Superior electrical properties (high electrical resistance, low power factor, high dielectric power), optimal physical and chemical stability (oxidation and non-corrosion in the long run) (2) Optimal cooling effect (rapid heat absorption and instantaneous transfer) (3) High flash point and low loss against evaporation. The process of producing TO consists of a number of following steps. Purification process with sulfuric acid; by adding sulfuric acid, impurities will be removed such as aromatic substances, resins, asphalt, and nitrates in the raw material. To settle impurities; at normal temperature, the solution is left alone. Neutralization process; after the purification step with sulfuric acid is carried out in order to remove naphthenic acid and other remaining free acids. The neutralization is done by caustic soda. The product of this stage after heating to about 80-60 °C is sent to the adsorption stage with pigmented soil. Adsorption process; using active soil and in conditions that the product is still heated to separate the remaining impurities or water is performed. The treatment is done by using active soil. Vacuum filtration; to completely remove moisture, ozone, and other impurities that have not yet been separated. Filtration is performed in a vacuum filter and the product is directed to the packaging after this step. There are several types of adsorbent materials such as Fuller's earth, Kaolin, activated alumina or bauxite, and molecular sieves. The main drawbacks of mineral TO can be noticed in its low flammability and cellulose paper water absorption possibility [31]. Table **1** displays the annual requirements of transformer oil generation industries.

Table 1: Annual requirements of TO generation industries (nominal capacity of 8100 m^3) [30, 31]

The materials and equipment	Total annual rates
Equipment and devices	
Steel tank of 5 m^3	4 No
Gear pump	3 No
Filter press	1 No
Water storage tank, 8 m^3 stainless steel	1 No
Purification tank, with acid, 8 m^3 of stainless	1 No
Neutralization tank, 8 m^3 of stainless steel	1 No
Alkaline storage tank, 3 m^3 of stainless steel	1 No
Activated soil preparation tank, 10 m^3	2 No
Vacuum filtration 2 kW	1 No
The automatic filter of 11/5 kW	1 No
The compressor of 6 atmospheres, 500 liters tank	1 No
Laboratory requirements for testing and controlling	1 No
Repair and workplace requirements as needed	1 No
Materials demands	
Crude oil	8392 tons
NaOH (40%)	72 tons
H_2SO_4 (98%)	7.2 tons
Active soil (clay 92%)	569 tons
Filter paper (special mingled to chemicals)	10000 No
Filter texture	2000 No
Additive	8100 Kg
Barrels of 160 and 220 liter	43000 No
Products	
Transformer oil (Surface tension at 25°C equals 45°C, viscosity at 100 °C equals 2.5 stock resistance and water content in oil 20 ppm)	8100 m^3
Employees	
Staffs salary	18 Persons
Energy consumption	
Required water	5 m3/d
Power consumed	191 kW/day
Required fuel (Stoves)	36 Giga Joule/day
Required land and landscaping	
Required land	3900 m2
Construction of infrastructure (Buildings)	1110 m2

2.2. TO regeneration technology

The oil recycling industry is not a new industry and originated in Europe in the early twentieth century. Where the cost of imported crude oil was very high and as a result, such industries had good economic acceptance. In the United States, too, the experience of using recycled engine oil in military vehicles has been a success since the beginning. The industry began to grow and grew further with the outbreak of World War II during the 1950s and 1940s, when used oil was subjected to a process of heating, settling, and centrifuging and then activating its lubricants. The layout of units of used motor oil reprocessing industries and used lubricant oils are similar to the TO regeneration units and technologies. The differences refer to the heating unit and the concentration of pollutants in waste oils collected. So, depending on the mentioned cases the layout of processes (heating, filtering, etc) will change but the treatment technologies are the same [32-38]. In the power transformer facilities, the service life of mineral insulating oils is up to 40 years typically. So, due to the vast application of these oils, the regeneration operation is emphasized for the recycling aims. Generally, there are two types of regeneration technologies for TO (1) percolation (via gravity or pressure), and (2) contact. Their processes are analogous depend on the concentration and type of pollutants as an arrangement of units according to Figure **3** [39].

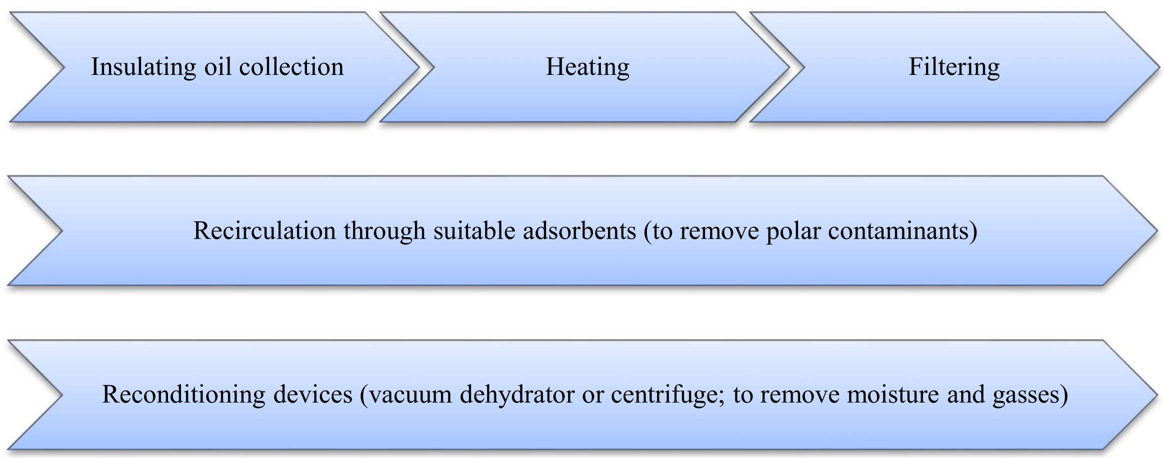

Figure 3: Regeneration technology of used TO in Iran [31].

The most common oils regeneratable and non-regeneratable are as TO, all diesel and gasoline crankcase oils, hydraulic oils (non-synthetic), high viscosity index oil, gear oils (non-fatty), compressor oils, dryer bearing oils, machine oils (non-fatty), quenching oils (non-fatty), grinding oils (non-fatty) and LVI, MVI oils, biphenyls; and polynuclear oils, halids, oils containing polychlorinated, brake fluids, synthetic oils, asphaltic oils, fatty oils, bunker oils, form oils, any kind of solvent respectively [40-42].

The TO is similar to cellulose oil in terms of compatibility. The TO is also produced from natural esters like sunflower, soybean, and rapeseed. The natural esters are generated in a different way of mineral-based TO. The initial feedstock is not crude oil and needs some primary steps to reach that such as delull or crack of crude vegetable oil. The following steps end up to crushing, extraction, degumming, neutralization (if it is refined chemically), deodorization, RBD oil, and TO generation via additives [38-42].

3. Comparison of generation and regeneration technologies

3.1. Drying oils

The techniques applied to generate the drying oils comprised below steps: at first, it is necessary to heat and cook the grain, because by performing this operation, the separation of the oil is facilitated due to the coagulation of the grain protein; increases the fluidity of the oil and moistens it during pressing. The operation of cooking the grains is done in heating chambers equipped with an oven and a stirrer. Then, the oil extraction of the grain is done by a vane press. In these presses, the increase in pressure is done by the rotational movement of a helical shaft inside a chamber. The applied pressure in the chamber is 1360 to 2720 atmospheres, which is handled by an adjustable pressure valve, and the cake is discharged from the end of the path. The oil obtained by compression in this machine has solid particles that must be separated from the oil by a solid particle press filter, and the oilseed cake generally has less than 4% oil. The purification operation is performed in the staining step by adding water or saltwater in the amount of 2 to 3% of crude oil and heating it to a temperature of 30-50°C, mixing and then separating the aqueous layer (bottom) by centrifuge. Neutralization with caustic soda is completed to remove the fatty acids in the oil as converting them into the soap to be removed. Success in the neutralization process depends on the proper concentration of the alkaline solution, temperature, stirring, and flushing. For oils with a fatty acid content, about 1 to 3% of the caustic soda will be used. The decolourization is carried out via clay in the amount of 5 to 10% of oil volume. The process of mixing the soil with oil takes 15 to 20 minutes and takes place at a temperature of 110°C. Then, the process is conducted towards the deodorization of oil by water vapour at a temperature of 170 to 230°C and under a vacuum of 5 to 20 mm in a tray tower. Improving the drying properties of each of the mentioned products is done in two steps. (1) Castor oil: In order to improve the drying property of this oil, by extracting a molecule of water from it, the number of its double bonds is increased to become a drying oil. About 17 to 25% of the unsaturated acid molecule is conjugated. The dehydration process is carried out at a temperature of 280°C by sulfuric acid, and by the way, the weight of the oil is reduced by 10%. Dehydrated castor oil can be heated. From this operation, a product will be obtained that has excellent resistance to water. (2) Barzak oil: Improving the drying property of oil is done by blowing air at a temperature of 70 to 120°C. This causes the oil to be rapidly oxidized and as a result, its viscosity increases very quickly. The improved oil has a very good polish and also has a very good lubricating property and has many applications in some special enamels and surface paints according to Figure **4**. The annual requirements for drying oil generation industries have been shown in Table **2**.

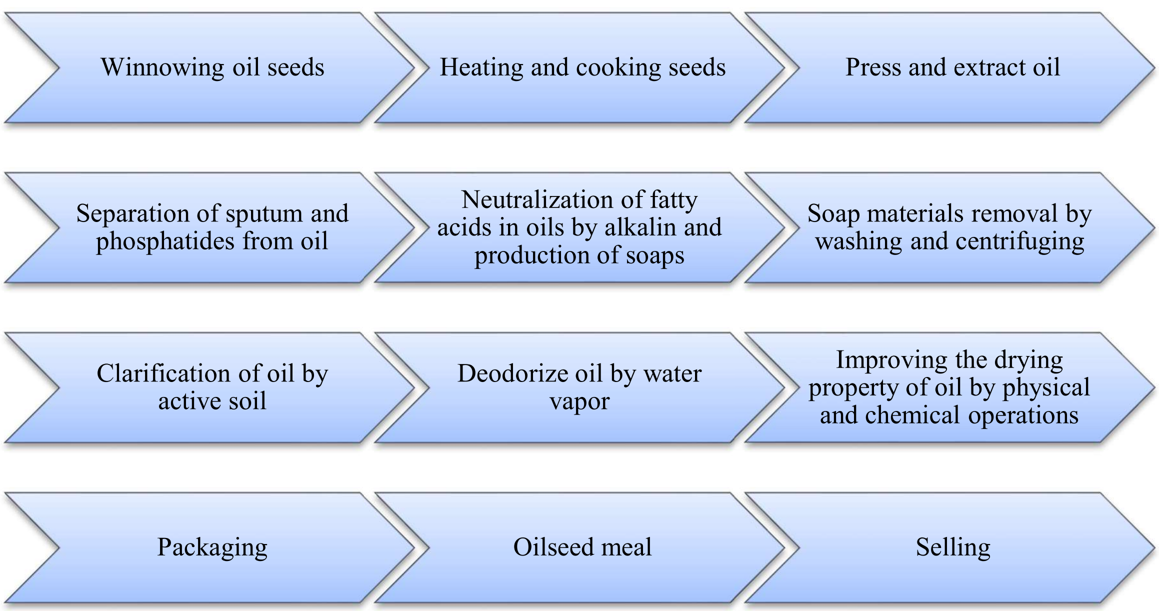

Figure 4. Drying oil generation steps [30]

3.2. The generation and regeneration units of used motor oil and used lubricants oils

The basis of the technologies applied in lubricant oil production comprised of a series of relatively uniform and unique processes. There are some differences in the type of press filter operation, additive employed, temperature run-up in processes but it is generally the same as indicated in the diagram of production processes presented according to Figures **5** and **6**. It needs to explain that Figure **5** shows the acid/clay technique for recycling the used motor oil.

Table 2: Annual requirements of drying oil generation industries (nominal capacity 1000 tons oilseed meal + 500 tons drying oil) [30, 31]

The materials and equipment	Total annual rates
Equipment and devices	
Storage tanks, vane presses, heaters, filter presses, and oilseed meal packaging	1 No
Neutralization tanks, Sputum, wash, bleach, Deodorizer, and centrifuge tanks	1 No
Aeration reactor, storage tank, and filling machine	1 No
Repair and workplace requirements as needed	1 No
Materials demands	
Small (30%) and coarse oilseeds	1500 tons
NaOH (99%)	8 tons
H_2SO_4 (98%)	60 tons
Active soil (bentonite)	4 tons
Cans, 20 liters	27000 No
Polyethylene sacks, 50 kg	20000 No
Products	
Oilseed meal + drying oil	1000 tons + 500 tons
Employees	
Staffs salary	22 Persons
Energy consumption	
Required water	15 m^3/d
Power consumed	213 kW/day
Required fuel (Stoves)	89 Giga Joule/day
Required land and landscaping	
Required land	2000 m^2
Construction of infrastructure (Buildings)	570 m^2

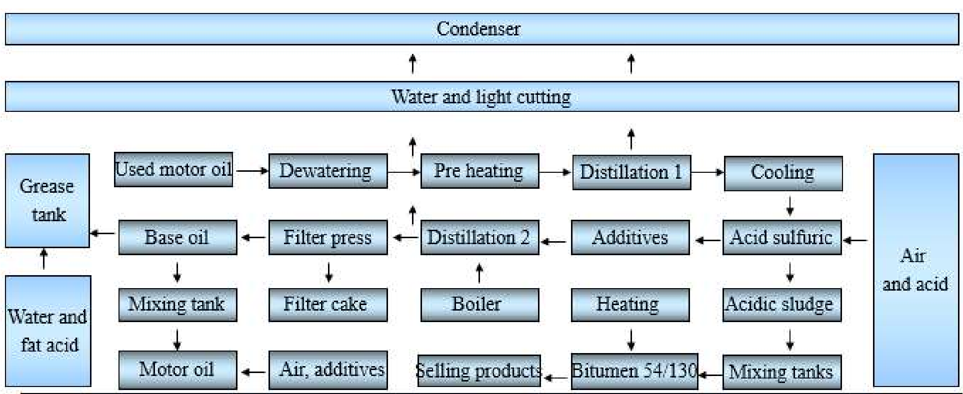

Figure 5: Diagram of layout acidic sludge recycling units and reprocessing industry of used motor oil in Iran [37]

The layout of processes in each technology depends on the concentration of existing pollutants in used oils, quantity, and quality of products ordered. For example, a clay filter is a common unit among all technologies discussed in the current review. But the heating unit differs in technologies discussed. For instance, the acid/clay technology needs a heating degree of around 400℃ mostly. But the same units (heating units) of TFE and TDA need high temperatures. The temperatures applied in preliminary distillation units are the same with acid clay technology. To generate high purity products and different derivates the vacuum distillation is a common and urgent unit of all technologies mentioned. The stripping and extraction of solvents is also a type of generation and regeneration technology that can be accommodated in the lines of operation depends on the quality and quantity of influent used oils. But it needs to be paid attention to the costs required. It is applicable to all mentioned technologies. All mentioned technologies demand an additive unit to supply the quality requested for products [43-50].

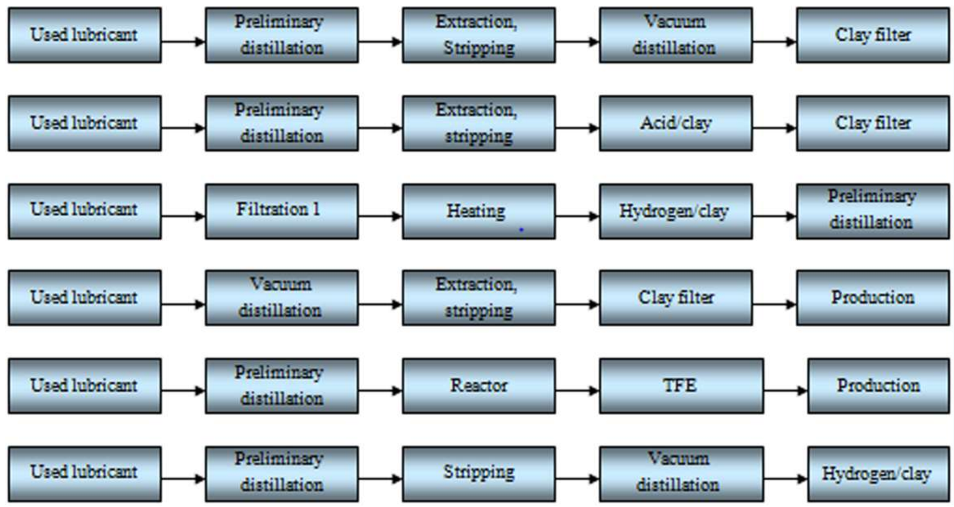

Figure 6: Layout variety of industrial and semi-industrial practices from regeneration lubricants in the world, Bartlesville, solvent extraction in Europe, Phillips process, RTI in Norway, Recyclon process, KTI in America, respectively. No 1 presents filtration unit; and extraction and stripping are joined to the solvent; TFE; thin-film evaporation [37]

3.3. The generation units of margarine oil

Margarine production technology consists of two main parts. The first stage is the treatment of crude oil (fat) through common processes such as deacidification, decolorization, hydrogenation, and decontamination. The second step involves mixing and adding special additives to the refined oil (or fat) and adjusting the melting point of the oil to the appropriate properties. This step can be done by mixing, making emulsion, cooling, shaping, and packaging processes. While being stored in storage tanks, it is gradually directed to the margarine production stage. The properties of margarine oil, especially the type of melting point, are determined in advance. Color and emulsifiers are heated. On the other hand, water, skim milk powder, salt, and other water-soluble additives are also pasteurized in a pasteurization machine. In the next stage, the aqueous phase of the material and the oil phase are mixed together and its temperature is adjusted and the mixture is conducted into the emulsion tank. In this stage, all the materials are mixed together and make an emulsion up. After cooling and rubbing the paste is flown to the packaging machine according to Figure **7**. The annual requirements of margarine oil generation industries have been shown in Table **3**.

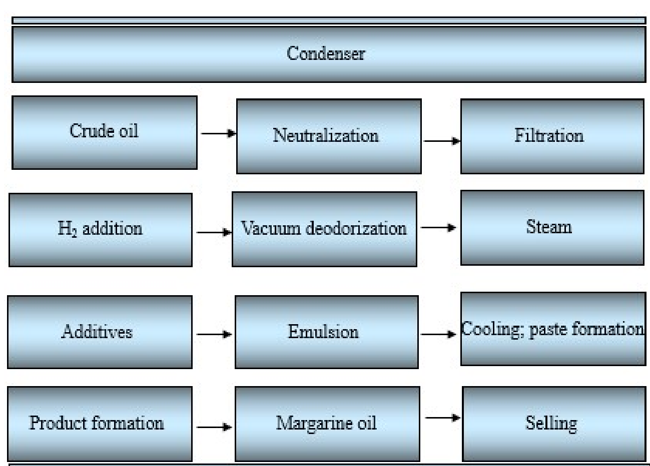

Figure 7: Diagram of layout Margarine oil generation units in Iran [31]

Table 3: Annual requirements of Margarine oil generation industries (nominal capacity of 12000 tons) [30, 31]

Main annual materials and equipment	Total annual rates
Equipment and devices	
Storage tanks, transfer pumps, pre-treatment oil tanks	2 No
The acidification section includes separators, mixers, Tank oil purification tank and all belongings	1 No
Bleaching machine, filter press, mixers, pumps, piping, decolorized oil tank	1 No
The main device, pumps, heaters, related piping, steam oil storage tank	1 No
Hydrogenation unit equipped with stirrer, heat coil of relevant filters	1 No
Sterilization section (2 tons)	1 No
Additive mixing tanks 50 cubic meters of stainless steel	2 No
Cell electrolysis to produce hydrogen by capacity 50 m^3/h and its belongings with purity 99.9%	1 No
Packaging machine (with a capacity of 250, and 500 g)	1 No
Ammonia refrigerator with full equipment	1 No
Electrical control panels	5 No
Materials demands	
Crude oil or fat (Sunflower, cottonseed)	9600 tons
Salt (2-3%)	360 tons
Lecithin	24 tons
Beta carotene	12 tons
Emulsifier	36 tons
Active soil (clay) + supplementary additive	50 tons + 8 tons
H_2SO_4	18 tons
Anti-oxidane	550 Kg
Catalyst	5 tons
Paper containing cover, aluminum foil, and cellophane	300000 No
Products	
Margarine; Fat and oil content (80% by weight), 2-3% salt, 0.2-0.5% monoglyceride, Other additives such as beta-carotene (vitamin A), anti-oxidane, and lecithin.	12000 tons
Employees	
Staff	51 Persons
Energy consumption	
Water	5 m^3/d
Power	320 kW/day
Fuel	217 Giga Joule/day
Required land and landscaping	
Required land area	8600 m^2
Construction of infrastructure (Buildings)	2455 m^2

3.4. The generation units' of vegetative oils

Oilseeds are controlled under temperature and humidity conditions and are stored in storage silos. First, the oilseeds are sieved, which removes impurities such as dust, small twigs, bark, and hollow grains, then separates them in a sanding machine. The cleaned grains are stored in the dryer silo and from there they are conducted to the grain dryer. In this dryer, by blowing hot air to the oilseeds, their humidity is adjusted to the appropriate level. For cottonseed grains, the fibers are taken from the grains using a linting machine. Before the oil grains are fed to expeller machines they underwent thermal operations that are called cooking units. The cooked grains are conducted to mechanical oil extraction machines. The most common type of machine is a spiral or blade press. Inside this press, the grains are pressed and extracted by the oil by screw circulation. In these press machines, is extracted the oil in the grain up to 90-97%. The obtained oil by pressing the grain via a spiral press contains solid materials that are separated from the materials and the oil is injected into the press filter by a pump. In this filter, particles and various other solids are separated from the oil. The oil from this filter is transferred to the weighing tank and from there to the crude oil storage tanks. The produced meal in the press machine, after aeration and dehumidification, is stored in the right silo and then bagged and embroidered, and used for animal feed according to Figure **8**. The annual requirements of vegetative oil generation industries have been shown in Table **4**.

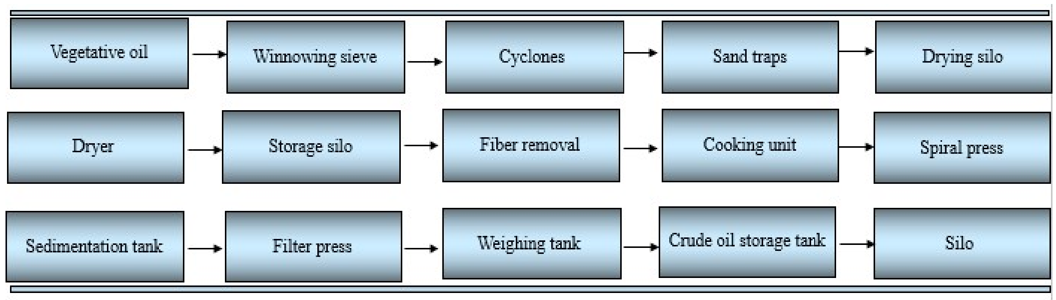

Figure 8: Diagram of layout vegetative oil generation units (except soya and olives) in Iran [31]

Table 4: Annual requirements of vegetative oil generation industries (nominal capacity 3375 tons crude oil + oilseed meal 5625 tons) [30, 31]

Main annual materials and equipment	Total annual rates
Equipment and devices	
Silo equipped with hygrometer and thermometer	2 No
conveyor belt	3 No
Winnow and sand trap machine	1 No
Carbon steel silo, convex lens roof, and funnel end	1 No
Preheater, 250 kg grain per hour, equipped with burner	1 No
Cyclone	2 No
Loaders with cylindrical saws to the diameter 20-20 cm wiper blade	1 No
Cooking tower	1 No
Spiral press, with horizontal cylinder, axle with screw blade, capacity 230 kg per hour	1 No
Steel chamber	1 No
Sedimentation tank, flat roof, funnel floor, with inlet filter, one cubic meter	1 No
Centrifugal pump, stainless steel	2 No
Filter presses, carbon steel and stainless steel mesh plates	1 No
Oilseed meal storage silo, carbon steel, 10 cubic meters	1 No
Packaging facility (for a capacity of 50 Kg)	1 No
Materials demands	
Sunflower seeds contain 40% oil and 12% moisture	4550 tons
The cotton grain contains 20% oil and 15% moisture	4550 tons
Polyethylene sacks (50 Kg)	112000 No
Additives of filter press	2700 Kg
Products	
Crude oil (Acidity 0.2%, moisture 0.5%, phosphatides 0.3% and waxes 0.3%)+ oilseed meal	3375 +5625 tons
Employees	
Staff	33 Persons
Energy consumption	
Water	10 m^3/d
Power	128 kW/day
Fuel	60360 Giga Joule/day
Required land and landscaping	
Required land area	3600 m^2
Construction of infrastructure (Buildings)	1025 m^2

3.5. The generation technology of olives oil

In the beginning, the centrifuge machine separates the leaves and debris from the olives, then the olives are introduced into the tub for washing to remove the dust. The oil extraction is done by a hot pressing method. To do the oil extraction, both the seeds and the kernels are crushed to form a homogeneous mixture. Then the olive paste is kneaded in a tub. After this step, it goes to the three-phase separators and part of the oil is separated. The remaining water and oil are transferred to two-phase separators and due to the difference in density and volumetric mass, the oil and water are separated and introduced into the neutralization part. In this place, free fatty acids are neutralized and this is done by adding a weakly alkaline solution that is made at a temperature of 90°C and the resulting soap solution is gradually precipitated. The bleaching operation is done after neutralization to remove the dye of the oil. The oil is dried at 80-85℃, then soil and colorant are added and stirred at the same temperature for a while. It is then purified with a flat plate. Now it is time to deodorize. The purpose of this step is to remove the substances that give a special taste and aroma to the oil. In this system, the oil is heated with the help of steam and bypassing the steam. The oil becomes odorless, the heat is brought to 135℃, and in the second stage, the heat is reduced to 60℃, then the oil enters into a tank and from there moves towards the filling machine according to Figure **9**. The annual requirements of olives generation industries have been displayed in Table **5**.

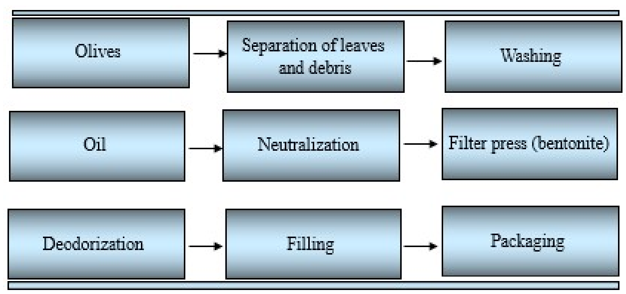

Figure 9: Diagram of layout olives generation units in Iran [31]

4. Plasma technology and recent developments

A mixture of gases in which ions are discharged in opposite directions, resulting in zero pure electrical discharge, is called the plasma state. Hot plasma has a very high energy content, which intensifies the rupture of all organic molecules at the atomic surface. As a result, these plasmas can only be used to produce very high-calorie energy. Electric discharge with a visible arc is called static electrical discharge or cold plasma discharge. Plasmas play an important role in environmental chemistry. Production of durable but chemically degradable organic and inorganic compounds, non-toxic or very toxic substances, and compounds can be considered in green chemistry. The unique properties of plasmas reduce adverse environmental effects and environmental analyzes and are important tools in environmental research. Many detection and monitoring systems in well-equipped laboratories are associated with plasma technology. Plasmas can reduce pollutants several times less than the approved standard. Many pollutants can be recycled at the same time. Materials that are recycled with the help of this technology can be very valuable materials, and can also be exploited in various forms and shapes. They are also an effective way to reduce the volume of pollutants even to zero emissions. They are very effective in removing hazardous waste in three states of matter and are used locally or mobile to avoid the costs and potential risk of toxic and hazardous materials. Plasmas are a way to produce nanostructured materials and coating the substrate. In this method, the precursors evaporate and enter the reactor [51]. The adsorbed molecules decompose either by heat or react with other gases and vapors to form a solid film on the substrate. Research into additives to various lubricants has been underway since the 1940s. Nano lubricants are the first synthetic oils based on spherical inorganic nanoparticles. Like other lubricants, their role is to reduce wear and friction between moving parts, increase performance, and create higher efficiency. As a result, it prevents energy consumption and pollution, and fuel consumption is significantly reduced. The search for a perfect lubricant that does not need to be replaced is a long-standing one. In the last century, synthetic additives have increased the performance of conventional lubricants such as oils. Most of these additives are toxic and environmentally hazardous [52].

Table 5: Annual requirements of olive oil generation industries (nominal capacity 70500 bottles + molasses 210 tons) [30, 31]

Main annual materials and equipment	Total annual rates
Equipment and devices	
Silo 4.8 m^3	5 No
Sweeper	1 No
Soap tank, 3.14 m^3	2 No
Active soil of filter tank, 3.14 m^3	1 No
Packing and filling machine for the cap of 50 to 4000 cc, 2000 No/h	1 No
Filter press, 200 tons/h	1 No
Olive washing chamber	1 No
Olive mill	1 No
Olive curing machine	1 No
Three-phase oil-water separator	1 No
The storage tank of olive, steel	4 No
Two-phase oil-water separator	1 No
Deodorizer	1 No
Materials demands	
Olive	352.5 tons
Bottles (1000 cc)	72000 No
Cardboard (25*35*45 cm^3)	3000 No
Labels	74300 No
AL caps (30 mm)	74300 No
Products	
Olive oil with a yellow to yellowish-green color with special smell and taste of olives and free of any external odor and taste, clear and free of any sediment. In glasses with a volume of 1000 cc with the specifications of the Iranian National Standard No. 1446	70500 +210 tons
Employees	
Staff	19 Persons
Energy consumption	
Water	55 m^3/d
Power	269 kW/day
Fuel	62 Giga Joule/day
Required land and landscaping	
Required land area	3400 m^2
Construction of infrastructure (Buildings)	965 m^2

Nanomaterials and potential nanofluids are considered additives for several different reasons. These fluids are used in polymers to enhance the gel-forming ability. Converting friction from slippery to rolling, reducing wear and friction coefficient, increasing engine production and torque, reducing engine emissions and wear, and finally reducing fuel consumption are among the most important advantages of nanoparticles used in engine oil. Another important factor attracting the market for nanoparticles and nanomaterials is that they are "green" lubricants. As concerns about environmental pollution increase, there will be a greater tendency to use environmentally friendly materials. The production of nanoparticles with suitable properties is on a large scale in the research stage [53, 54]. The magnetic nano-fluids layer enhances the dissociation period, dielectric performance, thermal conductivity, and heat-transfer characteristics, dispersing agents, and viscosity of oils [55-58].

The membrane technology is also employed in impurities removal of lubricants with regarding passing a narrow flow through the membrane. The membrane technology needs a pretreatment unit before and an additive addition unit after that. The waste lubricating oils examined for the removal of water-soluble salts generated by mixing the additives, colloidal particles, asphaltenes, and carbon black via ultrafiltration. By the way the efficiency of impurities removal obtained with a decline of 14% of polar substances and 32% of oxides in polymer organic membranes applications. The advantages of employing the ultrasonic separation technology refer to wide and continuous applications, high efficiency, low contact, and low pollution but it demands a microfluidic chip and acoustic radiation force (generator) [57-64].

The recent studies developed towards gas conversion to liquid TO, mixing both natural esters (plants, vegetable oil-based natural and seeds like soybean, sunflower, coconut, rapeseed, olive, Pongamia, palm nuts, canola, flax, etc.) and synthetics esters and producing green TO [65-70]. The natural esters are completely biodegradable and a proper insulating matter. So, studies are expanding towards the implantation of substances in the mineral oil content and integrating the ways for generating green products of them [71-75].

5. Guideline for TO utilization of TO in facilities

To exploit the To in the best possible way some guidelines need to be considered in transformers and related facilities considering equations 1 to 6 and according to Tables **6** and **7**.

Table 6: Guidelines for dissolved decay products in TO [7]

Oil condition	Dissolved decay products (mg/l)	Turbidity (NTU)
Good oils	0-10	0-1
Proposition A oils	10-25	1-4
Marginal oils	4-10	4-10
Bad oils	25-50	10-30
Very bad oils	50-300	30-150
Extremely bad oils	> 550	> 150

Table 7: Criteria for judging the aging status of traction transformers based on furfural concentration and aging degree of solid insulation materials of transformer based on the degree of cellulose paper polymerization [61]

Operational life (year)	Different aging criteria (mg/L)	Degree of polymerization	Life (%)
1~5	≥0.1	1000~1200	100
10~5	≥0.2	500	50
10~15	≥0.4	300	0
20~15	≥0.75	50	-

$\mathrm{Log\ (Furfural)} = 1.065 - 0.0027\ \mathrm{DP}$	DP= degree of polymerization	(1)
$\mathrm{Ln\ L1} = \mathrm{Ln\ A} + (\frac{\mathrm{B}}{\mathrm{T}})$	L_1= thermal aging model T= absolute temperature A, B= constants of the specific working environment of the transformer	(2)
$\mathrm{L2} = \mathrm{Kg\ E}^{-\mathrm{n}}$	L_2= Electrical aging model K, n= constants of the specific working environment of the transformer E= external electric field	(3)
$\mathrm{L3} = \mathrm{Kg\ E}^{-\mathrm{n}}$	L_3= Electrothermal aging model	(4)
$\frac{1}{\mathrm{DPt}} - \frac{1}{\mathrm{DP0}} = \mathrm{kt}$	DPt and DP0 represent the current value and initial value of DP, t is the aging time, and k is the constant of any particular aging environment	(5)
$\mathrm{Ft} = \mathrm{bt} + \mathrm{ct}^2$	Ft is the current concentration of furfural, t is aging time, b and c are constants of the specific aging environment	(6)

The information offered by tables, equations, catalogues of TO, and transformers helps the users to thrift costs, avoid conducting damages to their facilities, etc. However, the stakeholders holding well-equipped and furnished lab facilities may recede the simple checking in this regard.

6. Conclusion

Pollutant concentration is an indicator of technology and process selection in the generation and regeneration practices of TO. The acceptability of products by stakeholders gets backs to the type of use and circumstances of use. The technology selection is in high dependence on the type of collection method of used TO from the industrial waste stream. The regeneration technologies will be different for the integrated management practice of the industrial waste stream. It means mixed-used lubricant oils collection system is not encouraging in non-civilized countries due to access to old, traditional, and typical regeneration technologies. By the current review, our effort jumped to update the knowledge for the data devoted to the initial screening step of TO generation and regeneration techniques. Future research can consider the efficiency assessment of TO generation and regeneration technologies based on data envelopment analysis, economic estimation and look forward to extracting significant criteria for the decision-making theory and select the best technique through the various options.

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Conflict of interest

There is no conflict of interest.

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