Review Paper:
Technologies to Manage Used Automotive Oil Filters in Iran: A Review Study

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Please cite this article as Hassanpour M. Technologies to Manage Used Automotive Oil Filters in Iran: A Review Study. Archives of Hygiene Sciences. 2021; 10(2):97-110. http://dx.doi.org/10.52547/ArchHYgSci.10.2.97

doi: http://dx.doi.org/10.52547/ArchHYgSci.10.2.97

Article info:
Received: 16 Dec 2020
Accepted: 20 Feb 2021
Publish: 01 Apr 2021

Keywords:
Oil, Management, Technology, Industries, Recycling, Industrial waste

ABSTRACT

Background & Aims of the Study: Given that modern society is a rapidly moving civilization, the production of automobiles resulted in a massive quantity of Used Automotive Oil Filters (UAOFs). So handling the waste stream secures value-added to the national assets and underpins the demands in other sectors. The steel request is highly rising with the population growth, and dismantling and recycling UAOFs produces enough scrap steel to be retrieved in similar applications. Experts of this sector have forgotten this resource. The present review sought the UAOF recycling technologies from the initial step of the project to the recent developments in this area. Also, plasma technology application was addressed as the new technology posed and noticed its modern procedure in the UAOF recycling operation based on the existing technologies.

Materials and Methods: In this review, the related articles were searched and studied using key relevant words. Also, we used valuable existing references in this regard. 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.

Results: The collected results and concepts emphasized the redesign and reproduction of UAOF and employing frequently recycled scrap parts in the steel manufacturing operation.

Conclusion: The plasma technology enhances the adhesion, wettability, electro-conductivity, and many other characteristics of adsorbents within AOF and generates value-added products and nano-metal oxides from scrap metals of UAOF.

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1. Introduction

The invention of car engine oil filters dates back to 1923 when the first car oil purification system was designed. The inventors at the time chose the name "purolator" for their invention, which was abbreviated "pure oil later," meaning "next oil." In the early filters, textured fabrics were used. In 1946, the plastic paper technology that is still used was introduced in the oil filter [1, 2].

Engine oil becomes contaminated during lubrication and passing through different parts of the engine. These contaminations include blast debris at the top of the piston, particles collected by air filter which move towards the engine, and particles and chips due to the wear of parts inside the engine [2, 3].

It is obvious that the most important part of the oil filter is the adsorbent part. Most inexpensive filters are made of paper and cardboard and can absorb particles as large as 40 microns or more. Advanced filters are made from a combination of paper fibers, cellulose, and or fiberglass. These filters are capable of absorbing particles as small as 5 to 10 microns. They usually have a higher contact surface which increases the filter capacity. The contaminated oil passes the oil filter through the upper holes and, after passing through the safety valve (oil barrier gasket), enters the central part of the filter. Most counterfeit filters do not let the oil pass through the filter after a short time, and the oil moves directly through the safety valve. The counterfeit filter contaminates the oil quality due to the lack of purification in the shortest time. The new filters are also suitable for synthetic oils due to their higher capacity, as synthetic oils can lubricate the engine for a longer period (about 15000 km), while paper filters can eventually lubricate up to 6000 km [4-6].

Replacing the oil filter depends on the engine's operating conditions and the type of oil filter [7-9]. According to Iranian National Standard No. 2525, the following standards are required for the oil filter. The pressure drop of an oil filter in its nominal flow is less than 0.3 bar. Screw filters should withstand vibrations of up to 5000000 cycles. The filter should withstand up to 40000 cycles of impact against oil shocks (To ensure the filter's efficiency at the initial start of the engine, especially when the oil is cold and as soon as the car is turned on, the pumped oil hits the filter). The filter should withstand pressure up to three times more than the operating pressure of the oil pump [10, 11].

In China, the USA, Japan, Germany, South Korea, England, Italy, France, Sweden, Spain, and other European countries, as well as car-producing countries in South America such as Brazil and Argentina, the consumption of car filters is more than other countries and therefore the production of the Used Automotive Oil Filter (UAOF) is enormous and consequently more scrap and used oil are generated from these filters. It is worth mentioning that Iran is in the top rank of the world car industry producers, and therefore, it is one of the primary producers of UAOFs in the world. Regarding UAOF export, this product has no place in international exchange in the world. Considering that about 85% of UAOF (by weight) are made of iron or steel, in all countries of the world first procedure of recycling UAOF is to drain the oil and then to separate and produce scrap iron, and then if requested and desired, they are exchanged globally. Exporting and importing UAOF is not economical, and their scrap must be pressed to take up less space. According to information obtained from field activities of drivers of light and heavy vehicles as well as car service workshops (oil change centers and car filters in the country), all cars, whether light or heavy, usually replace the UAOF with a new filter over a distance of 10000 km [12-14].

Research shows that the AOF and UAOF have an average of 40% by weight of steel, 55% by weight of used oil, and 5% of other filter compounds immediately after separation. The average weight of new filters for light vehicles is 400 g, and for heavy vehicles, 900 g, which become 800 g, and 1910 g for used filters of light and heavy vehicles immediately after separation, respectively [4, 15, 16].

As we already mentioned, the estimations show that UAOF is made up of an average of 40% by weight (steel), 55% by weight of used oil, and 5% of other constituents of the filter [17]. Based on the most probable cause, the production of UAOF has grown by upper than 8% in Iran. It has been estimated that at least 20000 tons of scrap steel and about 25000 tons of used motor oil can be extracted annually from the collection and recycling of UAOF, which are dumped into the environment [18-25].

The typical recycling processes introduced for UAOF are gravity drained, crushed, drained, dismantling, pyrolysis, and shredding processes. The existing factories of melting UAOF in the USA are 1. Bayou Steel, Baton Rouge Louisiana, 2. Birmingham Steel, Birmingham, Alabama, 3. Lukens Steel, Allentown, Pennsylvania, 4. Structural Metals, Austin, Texas US Steel, Pittsburgh, PA, 5. Wheeling-Pittsburgh Steel, Wheeling, WV, 6. Structural Metals, Seguin, Texas, 7. TAMCO, Ranch Cucamonga, California, 8. U.S. Foundry and Manufacturing, Medley, and FL. Also, there are many other locations reported for processing, landfilling, incinerating, and other handlings positions of UAOF [4, 25].

By the present review, we tried to assert the typical recycling practices (management methods) of UAOF and the application of plasma technology in handling the UAOF stream. The typical, traditional, and novel implications of recycling UAOF will be explained to reach the plasma technology application finally. The industrial units of recycling UAOF were extracted from the screening step of industrial projects in the Environmental Impact Assessment (EIA) plan in Iran. The novelty of the present review is related to the possibility of underpinning the framework of decision theory in EIA for available and recently developed alternatives to manage UAOFs [26, 27]. The limitations in managing UAOF is insufficient science about UAOF handling technologies. The question is which technology is the relevant and proper alternative. The decision-making systems in the following steps of EIA can solve the problem.

2. Materials and Methods

In this review, the related articles were searched and studied using key relevant words (such as plasma technology, used oil, used automotive oil filter, project, EIA, recycling, etc.). The industrial data employed in the present review refers to the project identification steps expressed and investigated by the Iranian evaluator team of both the Iranian Industries Organization and Iranian Environment Protection in the EIA plan. EIA is an integral part of industrial projects in which in-charge organizations undertaken to prepare a report before the complete establishment of the projects in Iran and all over the world [28-31]. The research design included a single sample from each industrial cluster. We explored all critical articles published in the field of UAOF recycling technologies. The scope of the present review falls into waste management. Therefore, we tried to collect all concepts associated with the subject.

3. Results

Measures are taken to build capacity and fundamentally strengthen EIA in the United Nations Development Program in collaboration with the Environment Protection Agency. They include the development of Persian and English library of EIA, development of Environmental Assessment Training Program for various related levels, seminars, and workshops in Iran, development of environmental assessment model in the country, development of the assessment process in other countries, identification of special (sensitive) biological areas for environmental assessment, development of assessment guidelines for essential projects of the Supreme Council for Environment Protection, required regulations for the environment in Iran, the establishment of an evaluation database, and holding training workshops. The classification of projects for the need of evaluation based on the World Bank guidelines is as follows [26, 27]. First, projects that are likely to have significant environmental impacts and should be evaluated. These projects are marine agriculture, dams and water reserves; transmission lines, afforestation, factories, industrial estates; irrigation and drainage, cleaning and land leveling; mineral materials development (including oil and gas); oil, gas, and water pipelines development; port, and harbor development; land reclamation, resettlement; river and basin developments; electricity and power current demand development; tourism attraction activities; rural roads; water supply (on a large scale); construction, transportation and use of insecticides (or other toxic and hazardous substances), and projects in which the risk of hazards and accidents are serious. Second, projects that are likely to have specific environmental impacts and require more limited environmental analysis, such as agro-industries (large-scale), marine agriculture (small-scale), transmission lines (relatively large), industries (small scale), drainage and irrigation (small scale), small hydropower plants, public facilities, hospitals, housing, schools and so on. Also, it includes projects in the field of renewable energy, rural electricity, communications, tourism (small scale), urban development (small scale), water supply, and rural health. Third, projects that usually do not have the effects of environmental indicators, therefore, do not mainly need environmental analysis, such as educational projects other than school construction, family planning, health (except for hospital construction), nutrition, organizational development, and technical cooperation. Last, projects like the construction of a national park with a strong emphasis on environmental protection and may not require a separate environmental assessment [32-35].

The Iranian industries of UAOF recycling

Usually, with changing the oil of light and heavy vehicles, the oil filter is also changed, which during the change, some other waste materials remain. They are either accumulated or burned in many countries. The dumping of such substances causes surface water pollution, and their burning also led to the dissipation of very severe pollution (mainly acidic contaminants and compounds made of heavy metals). But today, the recycling operation has become cost-effective. The first step in UAOF recovery is to implement and open the

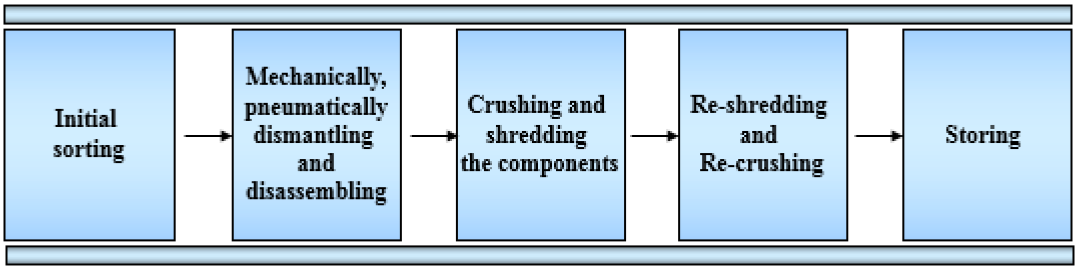

Figure 1. UAOF recycling process [27, 28]

filters automatically, in which the filters in different designs and sizes are disintegrated to the following components such as used oil, the internal filter of the metal body, the filter, and the lower parts of the steel and small parts according to the rotation before opening the filter. Gravity and rotation will remove most of the waste by centrifugation. In the second stage, the internal filter is come out. Then, the shredder crushes the filter into tiny pieces. In the third stage, the dismantler separates the metal body of the filter, which in turn shreds the pieces. A conveyor system transfers all the materials to the treatment, separation, and drying sections, during which all the remaining oil particles are removed, and the metallic and non-metallic materials of the oil filter are separated from each other. The parts which can be reused (like the bottom, the springs, and pressure plates) are removed and reassembled according to Figure 1 [26, 27]. Figure 2 displays the various parts of a UAOF. Table 1 shows the annual requirements of industries of UAOF recycling.

Iranian gaskets industries

A variety of rubber gaskets are processed in this unit. The gasket is used in sealing the AOF to the automotive body. Rubber alarm rings are rotating rings with different cross-sections, which are used as an intermediate product for sealing water, sewer, steam, oil, hydrocarbon, and many connections. The description of the rubber gasket production process includes mixing and molding as follows (1) raw rubber is cut into desired parts by hydraulic guillotine (2). Raw materials must be weighed by accurate and automatic scales before mixing (3). The first stage of mixing includes mixing rubber with soot, mineral fillers, and zinc oxide to improve and enhance the quality of the products for 10 minutes (4). By rolling the sheets, the mixtures are both cooled and take the form of sheets (5). To cool the sheets and prepare for the second stage of mixing, they are temporarily stored (6). At this stage, sulfur and accelerators are added to the mixture, and the rubber becomes a sheet (7). The sheets are cut with a knife by a skilled worker and are placed on the conveyor belt (8). Talcum powder is sprinkled between

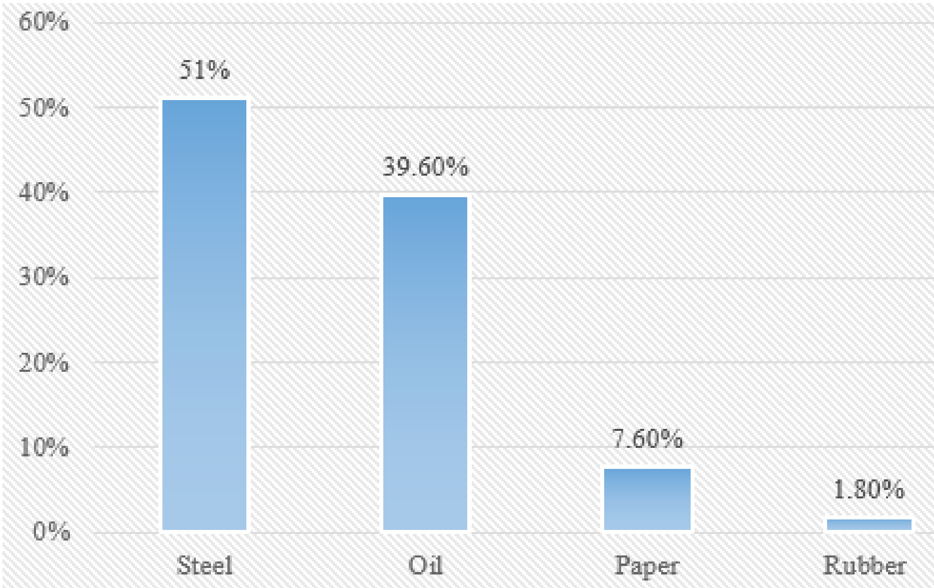

Figure 2. UAOF partitions [4]

Table 1. The annual requirements of industries of UAOF recycling (nominal capacity of 2000 tons) [27, 28]

Main Annual Materials and Equipment	Total Annual Rates
Equipment and devices	**No.**
Initial sorting machine, with a length of 3 m	1
Disassembling machine with a capacity of 10 number/minute as mechanically and pneumatically	1
Dismantling machine (with a capacity of 10 number/minute)	1
Shredding and crushing machine (with a capacity of 10 number/minute)	1
Treatment machine	1
Drying machine (length of 2 meters)	1
Sorting machine (length of 3 meters)	1
Conveyor system (length of 3 meters)	1
A storage tank of separated parts (2 m^3. Steel)	1
Materials demands	
Used oil	1200 tons
Metal and non-metal waste materials	800 tons
Solvent (HF = Hydrofluoric Acid)	20 Liters
Products	
Oil waste, the internal filter of the metal body, the filter and the lower parts of the steel, and small parts	2000 tons
Employees	
Staff	16 persons
Energy consumption	
Required water	4 m^3/d
Power consumption	71 kW/d
Required fuel (stoves)	3 GJ/d
Required land and landscaping	
Required land	2400 m^2
Construction of infrastructure (Buildings)	695 m^2

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the sheets and is kept on metal shelves for 8 hours. Now the sheets must be cooled quickly and reach a temperature of 20 °C (9). The sheets are reheated and softened and turned into similar sheets, and skilled workers cut and place them on a roller conveyor (10). The prepared rubber sheets are weighed and molded on a press machine. The washing of the washers is done by this machine with the help of heating elements, and then the washers are removed by the workers (11). The washers are placed in plastic bags and packed in cardboard boxes. The main raw materials used in the production of rubber gaskets (the type of Rubbers of SBR (Styrene-butadiene Rubber); NBR (nitrile butadiene rubber); CR (Chloroprene rubber); NR (Natural Rubber) are polybutadiene, accelerators, activators, curing agents, soot for filling and strengthening rubber, and other additives [36, 37]. The

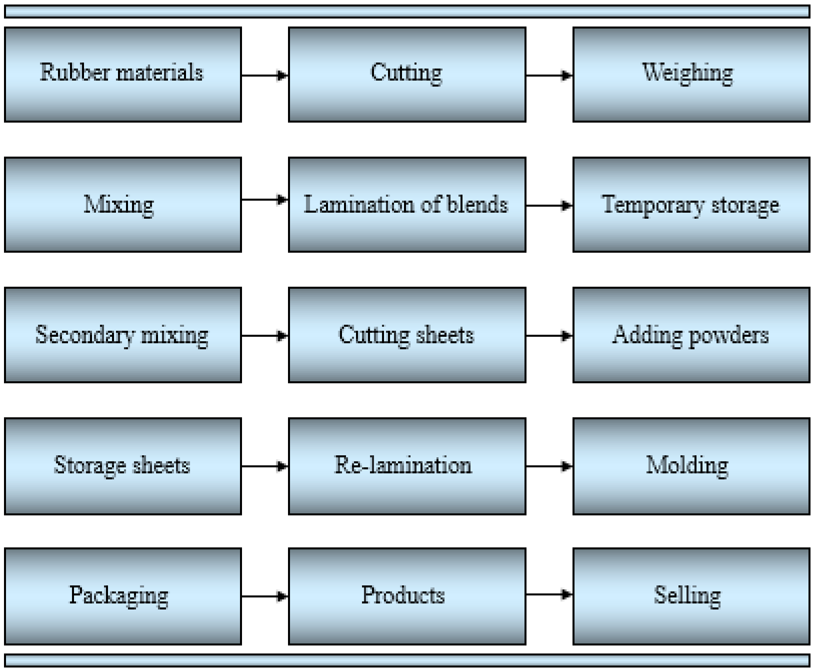

Figure 3. The layout of processes of gasket production industries [29, 30]

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procedure of gasket generation has been shown in Figure 3. Table 2 presents the annual requirements of gasket generation industries.

4. Discussion

The recycling processes for UAOF are gravity drained, crushed and drained, dismantling, pyrolysis, and shredding processes. Table 3 has summarized the effect of various processes on UAOF recycling operation.

Used motor oil handling released from UAOF recycling operation

Because of releasing a massive quantity of used motor oil during the recycling process of UAOF, the strategy of handling waste is to transfer it to used motor oil reprocessing or re-refining plants. The methods associated with the used motor oil recycling depend on the quantity of product, quality of retrieved product requested, and quality of used oil collected. There are many recycling methods used motor oil, such as acid/clay, distillation, solvent de-asphalting, Thin Film Evaporation (TFE) with hydro finishing, TFE with clay finishing, TFE with solvent finishing, solvent extraction hydro-finishing, and thermal de-asphalting [38, 39]. The dominant technology in many non-civilized nations is acid/clay technology. The recent developments for managing used motor oil moved towards the use of ultrasonic irradiation by producing free radicals to decontaminate pollutants [40-42].

The study of Van Zyl [43] ascertained to generate light motor oil by valorizing used motor oil. The exploitation of used motor oil has not been encouraged in composting, mulching, landfilling, and incineration due to wastage of resources and producing secondary pollutants. The recent technologies recommended employing plasmatron reformation of used motor oil to generate added-value gaseous products such as H_2, CH_4, CO_2, CO, etc. The gaseous products can be used in other sections of the recycling unit, such as finishing and reformation operations [44-48].

Plasma technology

Plasma is the fourth state of matters that induces forces in the hot and cold states on the framework of matters. Also, plasma possible motivated outcomes are complete disposal, alteration, phase conversion, polymerization, and modification. The interfering forces in a plasma phase can be allocated as mechanical, thermal, chemical, radiation, rays, electrical, nucleus, energies, and integrated forms of them are used in various reactors. The application of plasma technology in UAOF is defined as the regeneration of steel parts with high-quality products with regard to its ability to develop functional bonds, multiple layers, cross-linking agents, etching, and modification of surfaces. The variety of adsorbents employed in AOF will be encountered to plasma forces via alteration in the wear resistance, porosity, wetting characteristics, adhe-

Table 2. The annual requirements of gaskets industries (nominal capacity of 200 tons) [29, 30]

Main Annual Materials and Equipment	Total Annual Rates
Equipment and devices	**No.**
Hydraulic guillotine, width= 60 cm, 500 kg/h, 7.5 kW	1
Mixer, 15-20 L	1
Roller, w and L= 30 and 70 cm	2
Hydraulic press, 100 tons, 55 kW	2
Balance, 3, 15, and 30 kg	3
Four-layers metal shelf	2
Compressor, 60 kW, 1 m^3/min	2
Tables with various sizes	3
Conveyor in size of 2*0.7 m^2	2
Hardness measurement machine, Shore A	1
Digital balance	1
Materials demands	
NBR-SBR-UR CR rubbers	115.4 tons
Plastic reactive	1390 kg
Stearic acid of technical properties (TBBS-MBT TMTD)	2980 kg
ZnO 95%	4500 kg
Antioxidant of technical properties (BLE-25)	1340 kg
Anti O3 of technical properties (DPPD)	1735 kg
Camaron resin	2310 kg
The soot of technical properties (U550)	59.6 tons
Oil dioctyl phthalate	11.5 tons
Sulfur	2285 kg
MgO	775 kg
Talk powder	2 tons
Single-layer cardboard boxes	13300 No
Tape	120 No
Plastic bags of polyethylene	8 tons
Products	
Rubber gaskets in the sizes of 30-150 mm according to Iranian standards 1990,1989, and 1988	200 tons
Employees	
Staff	52 persons

Main Annual Materials and Equipment	Total Annual Rates
Energy consumption	
Required water	12 m^3/d
Power demand	193 kW/d
Required fuel (Stoves)	5 GJ/d
Required land and landscaping	
Required land	4900 m^2
Construction of infrastructure (Buildings)	1405 m^2

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sion, surface tension, grafting, refractance, transmittance, reflectance, and compatibility [49-51]. The submerged glow-discharge plasma is a proper technology for nano-materials synthesis. The scrap metal (consist of 6.45% carbon and 93.55% Iron compound) has been examined by this technique to produce nano-iron oxides via vapor deposition operation. After processing, a rise has been observed in carbon content and a fall in iron combination as 34%-35% and 15%-49%, respectively. But products had a good quality appearance [52]. Rani et al. [53] promoted the adhesion properties of cotton fabrics and raise the electro-conductive characteristics via plasma modification. So, the adsorbents employed within the AOF can pass through the same process and enhance the adhesion in texture or its structure. The activation of the adsorbent surface escalates the breakdown of contaminants composed due to long-time use of oil [54]. The plasma technology has been used to induce a graft of acrylic acid on bentonite to enhance the performance of adsorbents in aqueous ambient. The appearance of a proper efficiency proved the promotion in adsorbent performance via thermodynamic investigations [55].

The wide application of plasma technology proved that it is not comparable with conventional processes to generate environmentally-friendly products via conversion of matter states with modern and promoted characteristics in solid surfaces. The conversion of various waste materials into any state of matter mixed with raw materials in specific ratios can generate highly efficient products, nanomaterials, and composites using plasma reactors. Plasma reactors are initiated via raising the energy levels of feedstock's introduced into various configurations of reactors via thermal energy, chemical reactants, rays, electrical forces, nucleus energy. Also, their integration was based on the kind of exploitation

Table 3. Effect of different processes on UAOF recycling [4]

Process	Used Oil	Filter Media	Ferrous Scrap
Unprocessed	Non recovered	None recovered	Unacceptable as scrap (30-50 wt.% steel)
Gravity drained	30%-70% recovered	None recovered	Unacceptable as scrap (50-60 wt.% steel)
Crushed and drained	50%-98% recovered	Usually remains with ferrous scrap	Inconsistent scrap quality (60-85 wt.% steel and 2-20 wt.% oil making fume from melting
Dismantling	50%-90% recovered	Disposed of in landfill or waste to energy when available or required	Good scrap quality (95+wt% steel but lower overall recovery because significant steel is disposed of with the filter media
Pyrolysis	60%-85% recovered (additional 5%-25% combusted as fuel)	Vaporized and combusted, ash remains with the scrap	Excellent scrap quality (95%+wt.% steel but low density)
Shredding	75%-95% recovered	Fluff is disposed of in landfill or waste to energy when available or required	Excellent scrap quality (95+wt.% steel)
Plasma technology	-	-	-

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as cold or hot plasmas reactors [56-60]. The conversion of miscellaneous scrap metals led to the development, modification, coating, thin film deposition, embedding for controlled release, immobilization, layer-by-layer deposition, and photo grafting and synthesis of various valuable products via physical and chemical vapor deposition techniques in low to high pressures. The pressure adjustment in the case of product quality demands applying high pressures that depends on the type of products requested and its application against corrosion, erosion, and similar damaging conditions. The feedstock's (precursors) of coating operation comprised a wide range of materials forms as powders, wires, melted materials, solutions, or suspensions depend on the type of plasma reactor employed. The main field of exploitation of coating operation is aeronautics, energy, automotive, mining, biomedical, and electronics. The process can make products of sizes with micrometers up to millimeters.

Because a considerable quantity of different metals are disposed of industrial and municipal resources, and lots of them are valuable and expensive as initially, the application of plasma technology is encouraging alone or combined with other techniques using raw and waste materials proportions. The plasma jets are nominated to be a relevant reactor for the coating operation to recycle the scrap metals from the waste stream with a high capacity to make up nano to micro sizes products. Plasma jets are special facilities for producing high-temperature ambient. This reactor is configured from two systems of transferable and non-transferable arcs [61-64]. The transmission system requires very high currents (one hundred thousand amps). Critical industrial applications of plasma jets include synthesis (such as the production of SiC, Si_3N_4, ALN, and acetylene, etc.) include melting such as metal heating process, refining of metal mixtures to separate specific metal, reactive melting, industrial waste treatment, decontamination incinerators, radioactive waste treatment, metal recycling, sedimentation (fabrication of composite metals, extraction, and smelting of powder metals, high conductivity metal oxide processing, ceramic/metal materials generation, etc.) and coating operation can be mentioned. One of the most successful applications of hot plasma is the "plasma-sprayed coating" technology, which has been used for the last 20 years. Some difficulties have been reported in injecting nano-metal powders to the reactor as initial precursors, but the various configurations of injection devices receded the challenges experienced. Therefore, this technique is a cycle for generation and regeneration operation. The generated products can be regenerated after dismantling [65-68]. The demanding cases must be taken into consideration in the development stage or newly implemented plants. Therefore, the use of plasma torches, plasma spray, and jets demands an indispensable consideration to generate highly efficient materials and overwhelming technology for developing nations. The plasma jet plants can implement a circular economy framework for the rising needs [68-73].

5. Conclusion

The recycling plan for UAOF is one of the projects that, besides the direct added value created, has very valuable and long-term profitability for the environment, especially agricultural lands. The infiltration of oil from the UAOF and iron oxide formation due to the long shelf life of iron and steel scrap in the soil damage its fertility quality and produces poor quality products. As the price of steel in the world market is increasing, the price of scrap steel will also increase to such an extent that this trend will affect the Iranian market. According to the above explanations, our country needs both iron and steel scrap and industrial lubricant oils. From an environmental point of view, the fewer number of UAOF, the less waste it is to the environment and is desirable for society. But from the point of view of using recycled materials, using scrap steel, lubricant oil and creating added value, certainly procures the country's rising need. This project can cover the needs of the domestic market to some extent. Meanwhile, the supply of scrap steel and scrap iron is much more critical compared with oil demand. Plasma technology is a boost to the circular economy and its application in phase alteration of materials.

The available inventory tabulated for the Iranian industries based on initial screening of industrial projects by the Iranian evaluator team paves the way to estimate the financial and economic aspects of projects. It also directs the projects for the next stage of EIA and clarification of implementation costs. Using a data envelopment analysis also provides relevant media to make a firm decision by experts and managers to thrift the outlays and move towards sustainable development of industrial units in the post-EIA plan. As we know that data envelopment analysis is a strong decision-making instrument in EIA to find the efficiency of industrial and engineering projects and plants. The mentioned cases can be studied for further understanding of sustainability in future developments and studies.

The main achievement of the present review is to introduce alternatives for recycling UAOF that have been allocated as standard technologies and recently posed techniques. In the next stage of EIA, the decision-making theory underpins the matrix of criteria against alternatives introduced. So, the decision theory helps the experts to figure out which technology is relevant and holds cost-effective aspects. The criteria selection can be made considering the concept used to explain the recycling techniques, materials, and energy streams employed.

Ethical Considerations

Compliance with ethical guidelines

Any opinions, findings, and conclusions expressed in this publication are those of the author and necessarily reflect the current views and policies.

Funding

This research was extracted from the PhD. dissertation of the author at the Department of Environmental Science, University College of Science (UCS), Osmania University, Hyderabad, Telangana State.

Conflict of interest

The author declared no conflict of interest.

Acknowledgments

The author want to thank the colleagues and evaluators of both the Iranian environment protection agency and Iranian Industries Organization for the data assessed.

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