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Multi-Criterial Analysis on Choosing Epoxidized Vegetable Oils for Insulation Material and Plastic Manufacturing

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Abstract:
In recent years, there is a rising interest on the use of insulation materials and plastic produced from sustainable sources because of the benefits of these technological materials, including their possible biodegradability and low manufacturing cost. The biodegradable materials from sustainable sources, such as epoxidized vegetable oils replacing fossil-based resins, can be used as agents in manufacturing fixed. Likewise, epoxidized vegetable oils can be used as intermediates in the manufacturing of polyols - polyurethane, synthetic starting materials, reactive diluents for paints, PVC-stabilizers and plasticizers, as well as components of adhesives and lubricants. The epoxidation of oils from vegetable resources contains numerous advantages. They are renewable, biodegradability, eco-compatible, cheap, harmless greenhouse effect, low toxicity, multi-functional molecules, small number of synthetic transformations, abundance in nature. The purpose of this study is to obtain the most appropriate triglyceride-based epoxidized oil for highly efficient technological material implementations. In this paper, the AHP method is performed to choose the most appropriate epoxidized vegetable oil to produce plastic and insulation material. Eight various epoxidized vegetable oil types were analyzed based on experts' opinions on eleven characteristics of these oils. Epoxidized vegetable oil data used in the study is obtained from the production firms.

Keywords: Epoxidized vegetable oil, Multi-criteria decision making, AHP, Insulation material, plastic manufacturing.

I. INTRODUCTION

Technological materials are used widely for isolating and plasticizing aims. Over the last decades, the use of sustainable resources in the preparation of diverse technological materials has been revived due to the environmental awareness. Life cycle of materials based on vegetable oils is displayed in Fig.1. The vegetable oils are noted to be the most significant group of sustainable resources. These oils can be supplied from plants such as linseed, cotton, and sunflower. The vegetable oils include mainly of triglycerides [1]. The triglycerides are ester production obtained from fatty acids' three molecules and glycerol's one molecule. By a complex reaction named 'epoxidation', the unsaturation present (with monomer) in vegetable oils can be chemically modified to a value added product. Thus, the double bonds in the vegetable oil can be functionalized by epoxidation [2]. Vegetable oil-based technological materials have numerous benefits compared to raw materials manufactured from fossil-based monomers. By their area of use, the vegetable oils should be anticipated that they present certain base technical features such as resistance to chemicals, flexibility, thermal stability, biodegradability, biocompatibility, non-flammability, gas permeability, adhesion to metallic substances, and electrical conductivity [3]. Generally, the obtained technological properties are important in specialty production. By transforming the vegetable oils into epoxidized vegetable oils, the economic value of the vegetable based oils could be raised. The diverse chemical form of vegetable oil monomers used in technological material preparation is directly effective on technique properties of materials as an economical alternative [4]. For this reason, the different material properties can be obtained from the different epoxidized vegetable oils.

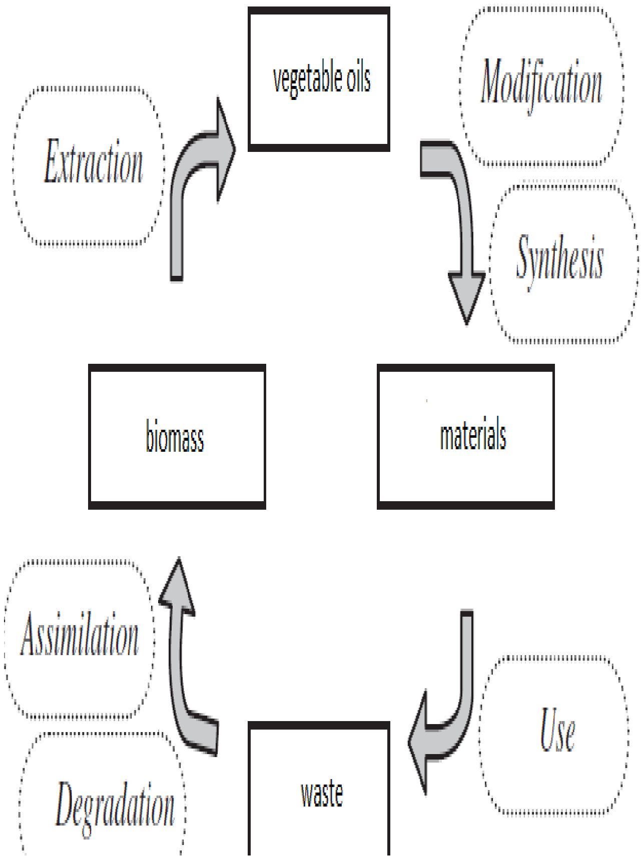


Figure.1. Life cycle of materials based on vegetable oils [1].

The epoxidized vegetable oils have been the subject of many industrial and academic researches. The mechanical characterization and fabrication of reinforced composites from epoxidized vegetable oils are researched by Crivello et al. [5]. Ligadas et al. investigated the diols suitable to produce polymers and monomers from vegetable oil for polyurethane technology. For use in structural applications, Knot et al. produced soybean oil to a few monomers and prepared rigid thermosetting resins with styrene [7]. Tsujimoto et al. produced biodegradable nanocomposites from plant oils. These materials showed good mechanical strength, thermal stability, and coating properties, which fixed by incorporating the network into the polymer (organic matrix). Richard et al. (2007) obtained plastic composites from Soy/Corn Oil. The resulting composites have shown useful thermal stability and mechanical properties and very high potential for industrial applications. Balo et al. manufactured building-insulation materials with fly ash-clay-diverse epoxidized vegetable oils (such as olive oil, soybean oil, palm oil, castor oil, sunflower oil, linseed oil, tall oil, and canola oil) and analyzed the physical–thermal-mechanical properties of these materials. Combining fly ash, clay with epoxidized vegetable oil to produce a potentially useful building-insulation material shown to be feasible. When the epoxidized vegetable oil rate increases, low thermal conductivity, low tensile - compressive strength and high abrasion loss are obtained. The results showed that tensile-compressive strength of the insulation material diminished when the low epoxidized vegetable oil rate used in the preparation of the insulation material composition. The epoxidized vegetable oil not only served as binding, but also appeared to serve as heat conductor [10-17]. In this paper, AHP method is used to select the most appropriate epoxidized vegetable oil to manufacture plastic and insulation material. Literature review and expert opinions have been used to reach at qualitative and quantitative evaluations. The comparative assessment of diverse epoxidized vegetable oil types is implemented. Each of the epoxidized vegetable oils is compared based on eight different characteristic properties. Among chosen epoxidized vegetable oil types, the most appropriate epoxidized vegetable oil choice is obtained.

II. EPOXIDIZED VEGETABLE OIL SELECTION METHOD

The reason for using an AHP-based decision analysis approach in this study is that it allows decision makers to analyze complex decision-making problems using a systematic approach that breaks down the main problem into simpler and affordable sub-problems. In an AHP hierarchy for choosing a vegetable oil, the objective would be to choose the best alternative towards the overall goal. This study aims to contribute to the existing literature significantly by helping decision makers in selecting the best alternative based on various criteria. First, a set of criteria are evaluated to be the factors reflecting the effects of oil on insulation material. A similar set of criteria is also determined for the choice of oil in plastic manufacturing. These criteria are evaluated within the same category, thus there is no sub-criteria defined in the decision hierarchy. Eight alternative oil types are compared using AHP technique.

2-1-The Selection Vegetable Oil for Insulation Material

The structure of the problem composed of the criteria for insulation material is constructed as shown in the figure below:

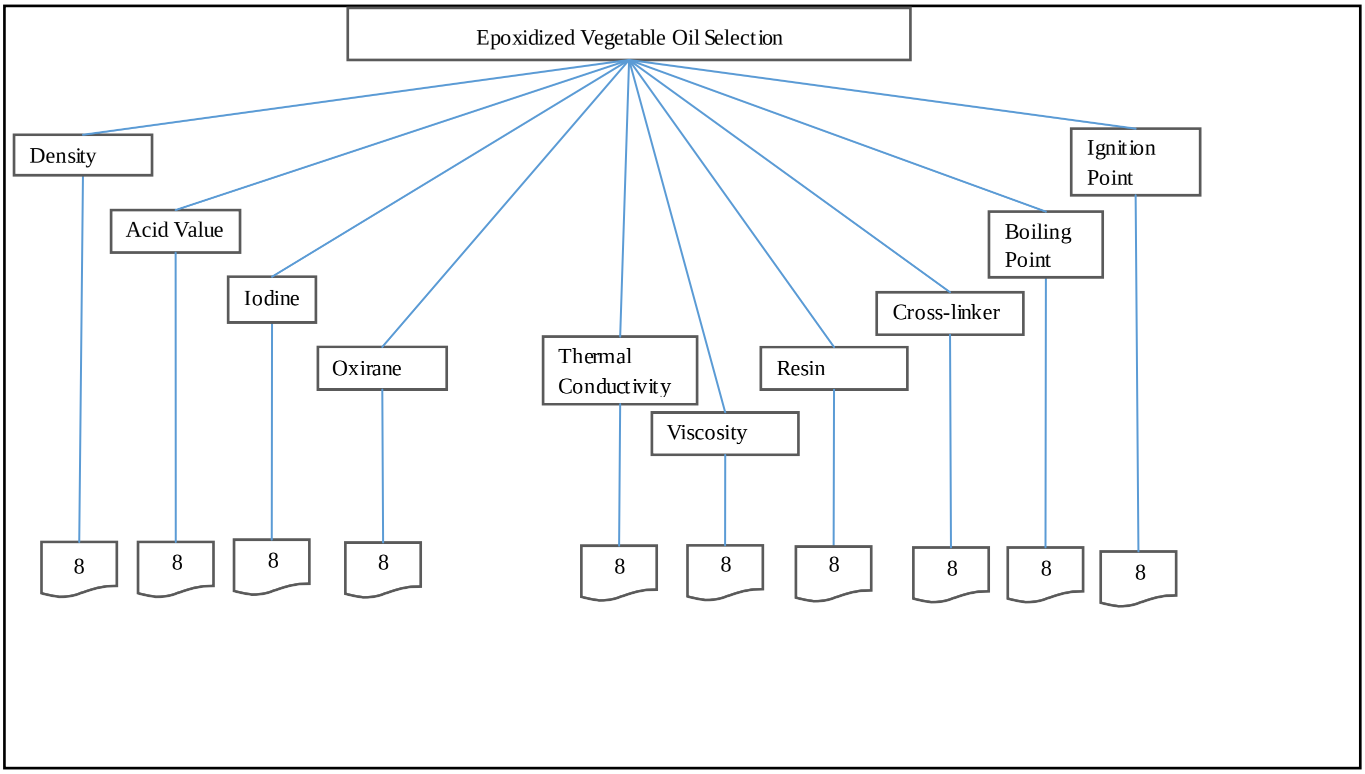


Figure. 1. Hierarchy of Criteria for Insulation Material

As it is the case in all multi-criteria decision making methods, the relative weights of criteria need to be determined. In AHP, this is accomplished by pairwise comparison of the elements. Below are the resulting priorities of 10 criteria for insulation material. These are the resulting weights for the criteria based on pairwise comparisons.

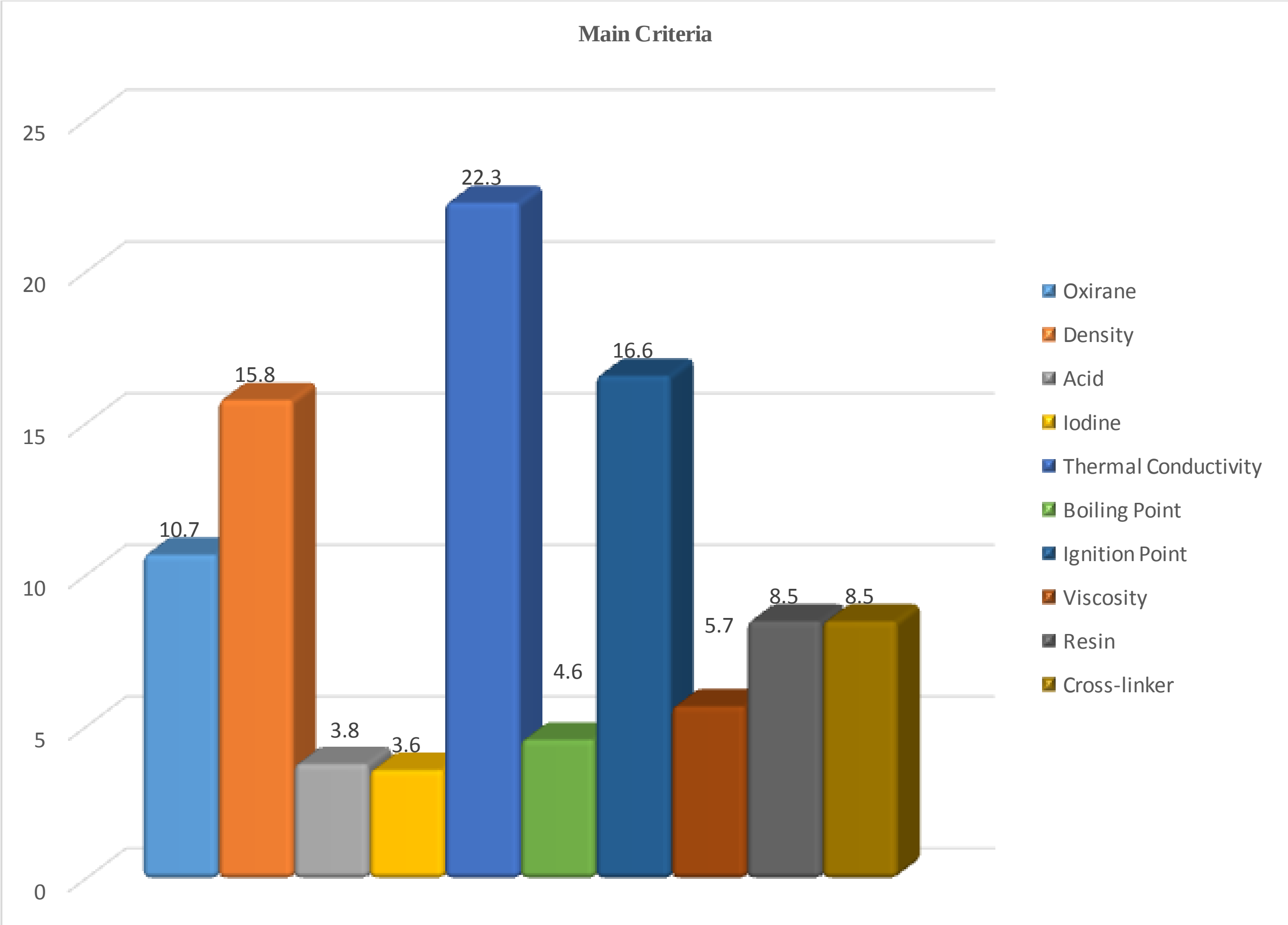


Figure.3. Weights of the selected criteria

The resulting weights are based on the principal eigenvector of the decision matrix.

Table. 1. Decision Matrix

	1	2	3	4	5	6	7	8	9	10
1	1	0.33	2.00	3.00	0.20	3.00	2.00	2.00	1.00	1.00
2	3.00	1	5.00	3.00	0.50	5.00	0.33	3.00	2.00	2.00
3	0.50	0.20	1	1.00	0.20	0.50	0.25	1.00	0.50	0.50
4	0.33	0.33	1.00	1	0.14	0.50	0.33	0.50	0.50	0.50
5	5.00	2.00	5.00	7.00	1	4.00	1.00	3.00	2.00	2.00
6	0.33	0.20	2.00	2.00	0.25	1	0.33	0.50	0.50	0.50
7	0.50	3.00	4.00	3.00	1.00	3.00	1	2.00	2.00	2.00
8	0.50	0.33	1.00	2.00	0.33	2.00	0.50	1	0.50	0.50
9	1.00	0.50	2.00	2.00	0.50	2.00	0.50	2.00	1	1.00
10	1.00	0.50	2.00	2.00	0.50	2.00	0.50	2.00	1.00	1

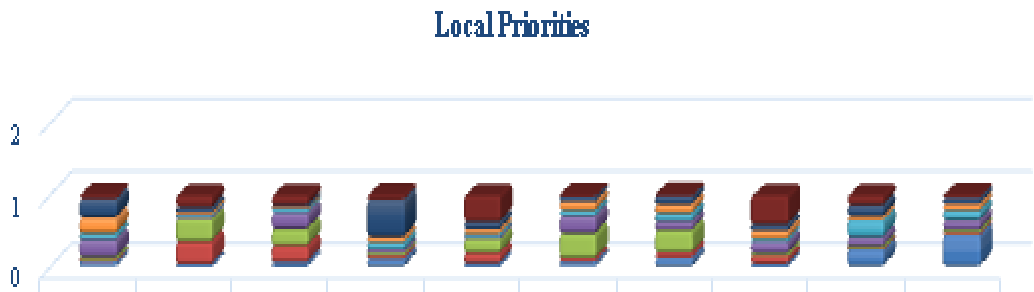
Consistency Ratio CR = 5.0%

Pairwise Comparison of the Alternatives with Respect to the Criteria After determining the priorities of each criterion with respect to the overall goal of determining the best oil for insulation material, the alternatives need to be compared two by two with respect to each criterion. The properties of the selected oils are presented in the table below:

Table. 2. Properties of epoxidized vegetable oil

PROPERTIES		ESO	EPO	EZO	ELO	ESFO	EHO	EKO	ETO
Appearance at normal temperature	*colour*	Clear to yellow liquid	Thick to orange liquid	Thick To green liquid	Thick To yellow liquid	Clear to yellow liquid	Thin to Brown liquid	Thin to green liquid	Thick to yellow liquid
Acid value	*(KOH/g):max. mg*	*2*	1.14	*1.21*	*1.32*	*2*	*3.01*	*2.97*	1. 545
Iodine value	*< max. % [mg I_2 per 100g]*	*3*	0.44	*0.85*	*0.62*	*3*	*1.44*	*131.4*	1.55 - 1.67
Oxirane value	*%*	*6.4*	3.15	*4.14*	*9.4*	*6.4*	*9.93*	*9.96*	4.43 - 5.36
Thermal conductivity coefficient	*W/mK*	*0,156*	0,144	*0,14*	*0,163*	*0,156*	*0,151*	*0,147*	0,133
Density (25 ^{o}C)	*g/cm^3*	*0.985 - 0.995*	0.897 - 0.941	*0.903-0.926*	*0. 991 – 1.002*	*0.985 - 0.995*	*0.976–0.997*	*0.966–0.985*	0.919-0.962
Boiling point	*^{o}C*	*150*	145	*167*	*163*	*150*	*155*	*153*	136
Ignition point	*^{o}C*	*310*	304	*359*	*321*	*310*	*316*	*311*	212
Viscosity	*MPa.s (25^{o}C)*	*325*	390	*276*	*430*	*325*	*400*	*370*	510
Resin	*g*	*145*	42	*56*	*131.5*	136.2	*76*	*131.9*	127.3
Cross-linker	*g*	*15*	6.7	*7.1*	*11.0*	10.8	*9.89*	*9.77*	7.90

The next step in applying the AHP technique is pairwise comparisons of the alternatives with respect to each criterion. Remainder of this section presents the priorities obtained using this technique. Below are the resulting weights of the oil alternatives for the criteria based on pairwise comparisons.



	Oxirane	Density	Acid	Iodine	Thermal Conductivity	Boiling	Ignition	Viscosity	Resin	Cross-linker
8	0.058	0.182	0.153	0.067	0.386	0.02	0.019	0.424	0.151	0.04
7	0.261	0.064	0.019	0.521	0.096	0.075	0.12	0.076	0.151	0.088
6	0.221	0.028	0.019	0.067	0.063	0.121	0.12	0.115	0.047	0.088
5	0.077	0.028	0.058	0.113	0.041	0.075	0.12	0.035	0.244	0.14
4	0.261	0.028	0.231	0.039	0.022	0.249	0.12	0.177	0.123	0.14
3	0.025	0.321	0.231	0.039	0.208	0.348	0.315	0.024	0.024	0.027
2	0.019	0.321	0.231	0.039	0.143	0.035	0.069	0.115	0.018	0.027
1	0.077	0.028	0.058	0.113	0.041	0.075	0.12	0.035	0.241	0.449

Figure.4. Local Priorities

The obtained priority values need to be multiplied by the weights of each criterion in order to calculate the global priorities. Based on the calculations above, the relative priorities corresponding to the attractiveness of each vegetable oil about all factors are presented below. The table below indicates that the third alternative is the one that contributes most to the overall goal in terms of the criteria considered.

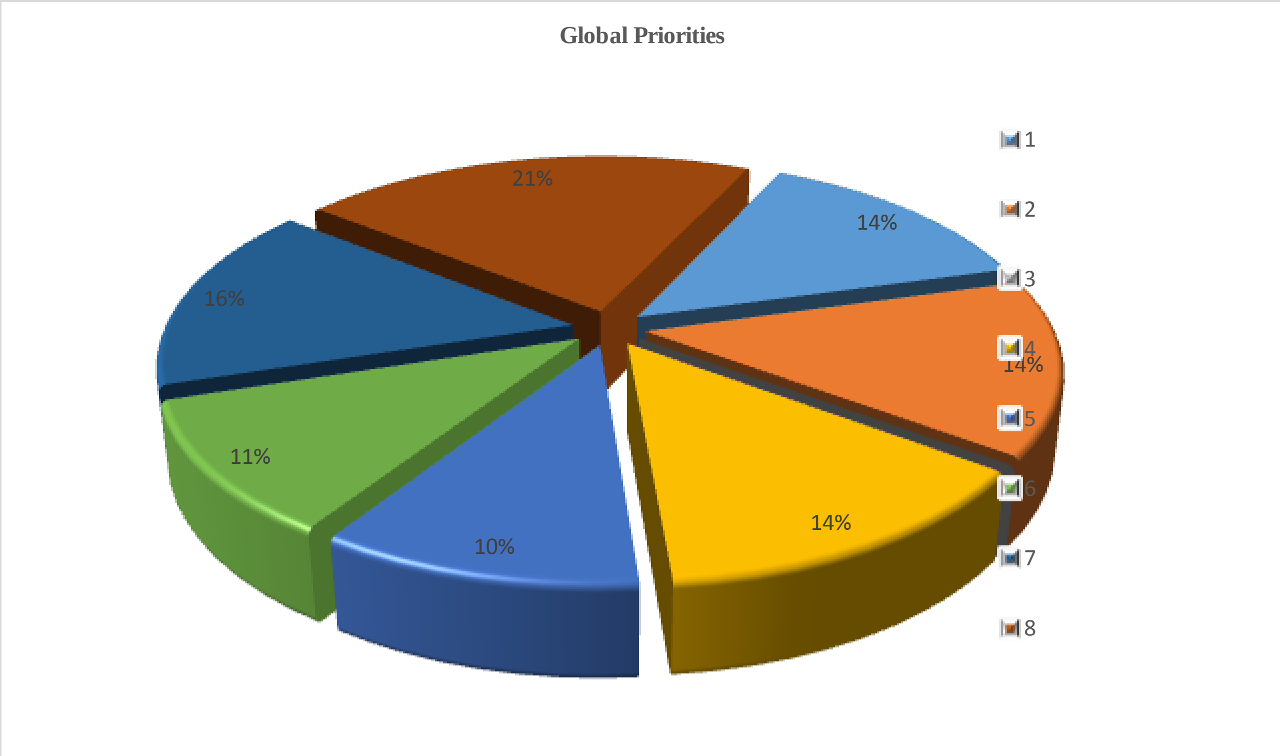


Figure.5. Global Priorities

The table above indicates that EZO has the highest total global priority of 0,184 while the second alternative ETO has a value of 0,174. On the other hand, ESFO is ranked the last based on the criteria evaluated. In overall, adding the global priorities in terms of all factors, the obtained results indicate that the material EZO is the alternative that contributes the most to the goal of choosing the best vegetable oil that satisfies all the criteria selected for insulation material.

2-2- The Selection Vegetable Oil for Plastic Manufacturing

As it was the case in the previous section where the oil alternatives were compared for the purpose of insulation material, the relative weights of criteria need to be determined in this section for the purpose of using vegetable oil alternatives in plastic manufacturing. However, due to the importance of "appearance" of the oil, this factor is also added into the set of criterion to be evaluated. Below are the resulting priorities of 11 criteria.

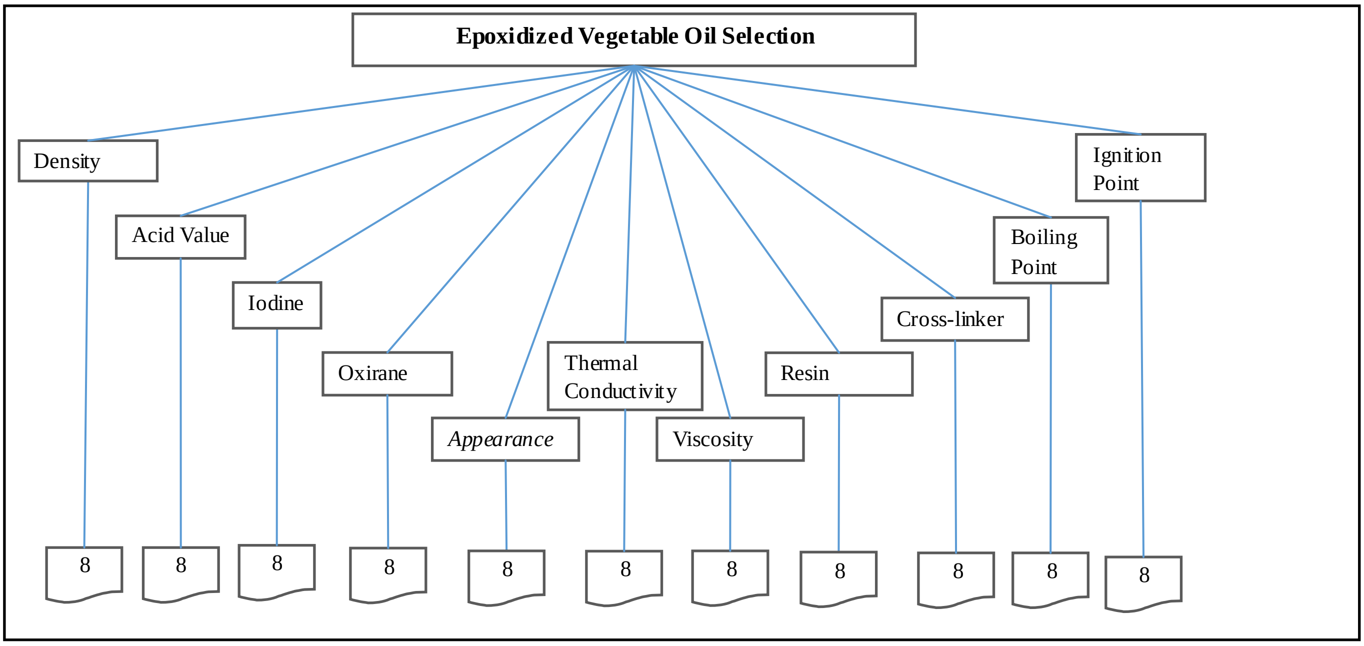


Figure. 5. Hierarchy of Criteria for Plastic

These are the resulting weights for the criteria based on pairwise comparisons.

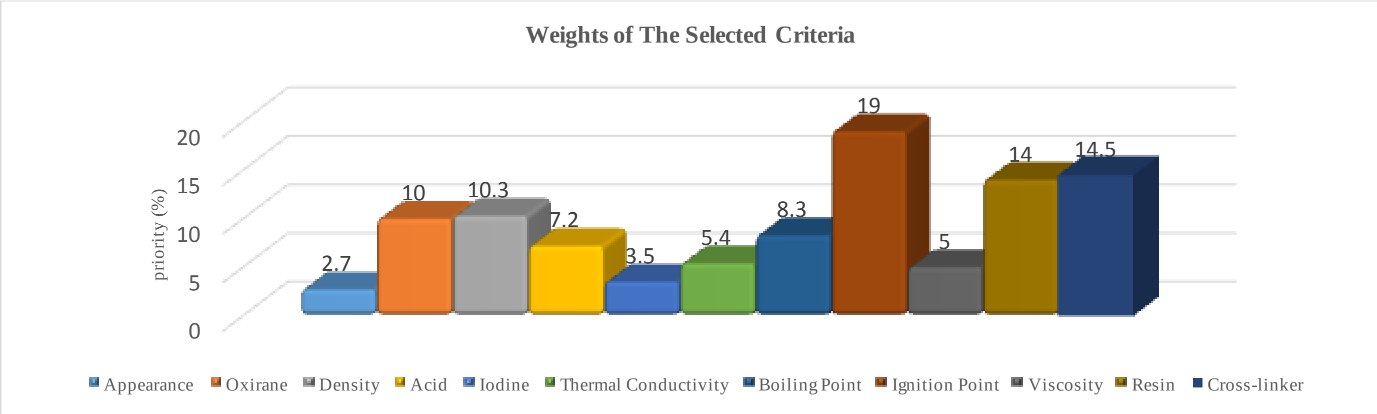


Figure.7. Weights of the Selected Criteria

The resulting weights are based on the principal eigenvector of the decision matrix.

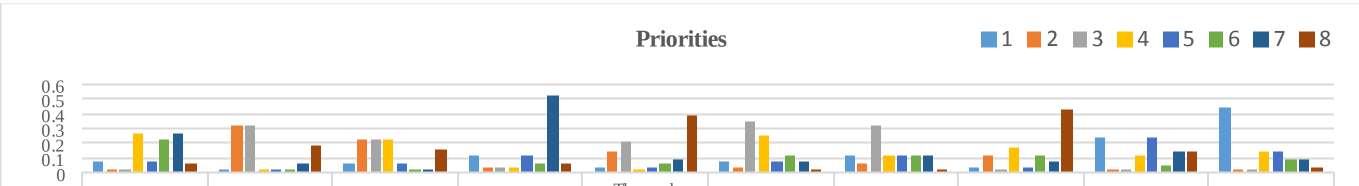
Table. 3. Decision Matrix

	1	2	3	4	5	6	7	8	9	10	11
1	1	1.00	0.33	0.33	0.50	0.33	0.20	0.14	0.33	0.14	0.11
2	1.00	1	2.00	1.00	2.00	2.00	2.00	0.20	2.00	1.00	1.00
3	3.00	0.50	1	2.00	3.00	2.00	2.00	0.33	2.00	1.00	1.00
4	3.00	1.00	0.50	1	3.00	2.00	0.50	0.50	2.00	0.33	0.33
5	2.00	0.50	0.33	0.33	1	0.50	0.50	0.25	0.50	0.25	0.25
6	3.00	0.50	0.50	0.50	2.00	1	0.50	0.33	1.00	0.50	0.50
7	5.00	0.50	0.50	2.00	2.00	2.00	1	0.50	2.00	0.50	0.50
8	7.00	5.00	3.00	2.00	4.00	3.00	2.00	1	3.00	1.00	1.00
9	3.00	0.50	0.50	0.50	2.00	1.00	0.50	0.33	1	0.33	0.33
10	7.00	1.00	1.00	3.00	4.00	2.00	2.00	1.00	3.00	1	1.00
11	9.00	1.00	1.00	3.00	4.00	2.00	2.00	1.00	3.00	1.00	1

Consistency Ratio CR = 5.0%

Pairwise Comparison of the Alternatives with Respect to the Criteria

After determining the priorities of each criterion with respect to the overall goal of determining the best oil for insulation material, the alternatives need to be compared two by two with respect to each criterion. The next step in applying the AHP technique is pairwise comparisons of the alternatives with respect to each criterion. Remainder of this section presents the priorities obtained using this technique. Below are the resulting weights of the oil alternatives for the criteria based on pairwise comparisons.



	Oxirane	Density	Acid	Iodine	Thermal Conductivity	Boiling	Ignition	Viscosity	Resin	Cross-linker
1	0.077	0.028	0.058	0.113	0.041	0.075	0.12	0.035	0.241	0.449
2	0.019	0.321	0.231	0.039	0.143	0.035	0.069	0.115	0.018	0.027
3	0.025	0.321	0.231	0.039	0.208	0.348	0.315	0.024	0.024	0.027
4	0.261	0.028	0.231	0.039	0.022	0.249	0.12	0.177	0.123	0.14
5	0.077	0.028	0.058	0.113	0.041	0.075	0.12	0.035	0.244	0.14
6	0.221	0.028	0.019	0.067	0.063	0.121	0.12	0.115	0.047	0.088
7	0.261	0.064	0.019	0.521	0.096	0.075	0.12	0.076	0.151	0.088
8	0.058	0.182	0.153	0.067	0.386	0.02	0.019	0.424	0.151	0.04

Figure. 7. Priorities

The obtained priority values need to be multiplied by the weights of each criterion in order to calculate the global priorities. Based on the calculations above, the relative priorities corresponding to the attractiveness of each vegetable oil about all factors are presented below. The table below indicates that the fourth alternative is the one that contributes most to the overall goal in terms of the criteria considered.

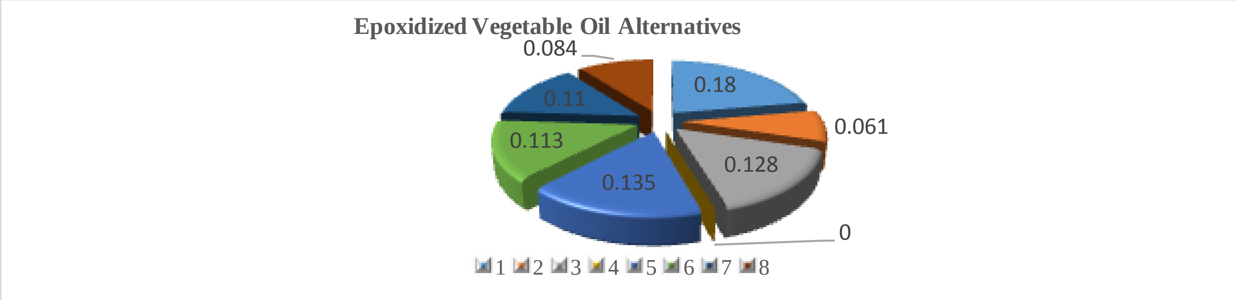


Figure. 8. Global Priorities

The figure above indicates that ELO has the highest total global priority of 0,185 while the second alternative ESO is close to the first alternative with a value of 0,180. The material ranked the last is EPO with a priority value of 0,061 based on the criteria evaluated. In overall, adding the global priorities in terms of all factors, the obtained results indicate that the material ELO is the alternative that contributes the most to the goal of choosing the best vegetable oil that satisfies all the criteria selected in plastic manufacturing.

III. RESULTS AND CONCLUSIONS

The vegetable oils are lipids and fats including triglycerides. Most vegetable oil has the high unsaturated fatty acids. They can be transformed into epoxy acid by classic epoxidation or chemo enzymatic epoxidation. Recently, the epoxidized vegetable oil is having increasing concern as they are environmental friendly and produce from renewable, sustainable natural source. Epoxidized vegetable oils can be used as a raw material for required synthesis along with different chemicals. These oils are source chemicals for manufacturing diverse types of polyurethane, polyether, polyolefin, and polyester due to their high reactivity of epoxy ring and respectable epoxy oxygen content. In the same way, the building insulation materials can produce with the porosity properties at obvious temperatures of epoxidized vegetable oils. In this paper, the AHP methodology for epoxidized vegetable oils evaluation model is applied by using available parameters of different epoxidized vegetable oil types for produce of the insulation and plastic materials. Among the most widely used epoxidized vegetable oil types, the most appropriate epoxidized vegetable oil choice is determined thorough eight diverse categories for epoxidized vegetable oils. This paper claims to fill in a gap in the field of selection of the epoxidized vegetable oils for produce of the insulation and plastic materials. The aim of present article is to determine the most appropriate epoxidized vegetable oil by evaluating the multi-directional properties of different epoxidized vegetable oil types applied into the actual produce systems.

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