Jatropha Oil in Spotlight for The Production of Bioresin & Sustainable Polymer

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Introduction

Most polymeric products are produced from non-renewable petroleum oil, which is unpredictable in terms of price and availability. Enforcement of a sustainable development pressures the chemical industry to move towards a bio-based product, which is synthesised from renewable resources such as vegetable oil. This could lead in reducing environmental impacts associated with the waste of petroleum based products such as a greenhouse gas emission (Desroches et al., 2012). Figure 1 shows the life cycle of polymers based on vegetable oils. For instance, the biomass from plant-derived resources is extracted in order to yield the vegetable oil, which is subject to chemical modification to improve the reactivity towards a given type of polymerisation approach. The polymers are then made available to the consumers, and once used, they become waste. After degradation and assimilation, they are reused as biomass and the cycle starts again (Samarth & Mahanwar, 2015).

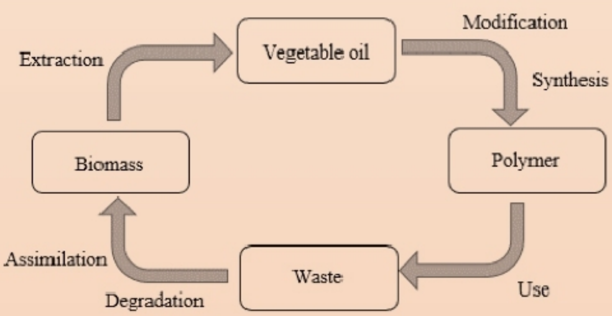

Fig. 1. Life cycle of materials based on vegetable oil (Samarth & Mahanwar, 2015).

Vegetable oil is predominantly made up of triglyceride molecules with varying fatty acid composition depending on the plant, the crop, the season, and the growing conditions. The word ''oil'' is used for triglycerides that are liquid at ordinary temperatures (Seniha et al., 2006).

Table 1 shows detailed fatty acid compositions of some types of vegetable oil. It showed that jatropha oil consists of 78.9 wt.% of unsaturated fatty acids, mainly oleic acid (43.1 %) and linoleic acid (34.4 %), which is relatively higher than palm oil. The triglyceride structures in vegetable oil vary from molecule to molecule. Fig. 2 shows a general jatropha oil structure consisting of a glycerol backbone attached to oleic, linolenic and stearic acids.

From the polymer point of view, the difference of the degree of unsaturation percentage presented in a variety of vegetable oil leads to the classification of the oil in drying (IV > 130), semi-drying (100 < IV < 125) and nondrying (IV < 100) oils according to their iodine value (IV). Iodine value (IV) is a measure of unsaturation content, which represents the amount of iodine (in mg) that can react with the carbon-carbon double bond presence in vegetable oil. The iodine value of some vegetable oil is listed in Table 1. In this work, some of advancement in polymer synthesis from vegetable oil preferably for coating applications will be highlighted. The spotlight will be on jatropha oil as it is a non-edible oil with 78.9% of unsaturation, suitable for chemical modification to afford polymeric materials. In Malaysia, Jatropha has become one of the most important crops after palm oil and rubber.

Vegetable Oil-based Polymer and Coatings

Vegetable oil has been used and studied as a raw material for the synthesis of various polymer products. This is a merit of the various functional groups available in the fatty acid chain. Figure 2 shows common functionalities of vegetable oil such as allylic carbon, double bond, alpha carbon and ester groups (Wool, 2005). These characteristics are special in differentiating the properties of one vegetable oil to another, as well as providing a platform for further chemical modification in polymer synthesis.

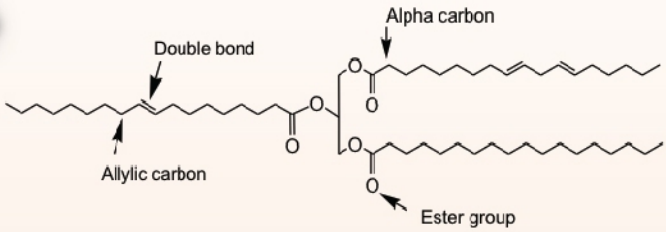

Fig. 2. Functional groups in triglyceride structure of jatropha oil

Table 1. List of fatty acids compositions in some vegetable oils (Sarin et al., 2007 and Lee et al., 1998).

Fatty acid	Palm oil	Jatropha oil	Soybean oil	Canola Oil	Linseed oil	Rapeseed oil	High oleica
Myristic ($C_{14/0}$)			0.1				
Palmitic ($C_{16/0}$)	40.3	14.2	11	8.08	5.5	**3**	6.4
Palmitoleic ($C_{16/1}$)		1.4	0.1			**0.2**	0.1
Stearic ($C_{18/0}$)	3.1	6.9	4	1.69	3.5	**1**	3.1
Oleic ($C1_{8/1}$)	43.4	43.1	23.4	57.09	19.1	**13.2**	82.6
Linoleic ($C_{18/2}$)	13.2	34.4	53.2	23.12	15.3	**13.2**	2.3
Linolenic ($C_{18/3}$)			7.8	10.02	56.6	**9**	3.7
Arachidic ($C_{20/0}$)			0.3			**0.5**	0.2
Gadoleic ($C_{20/1}$)						**9**	0.4
Behenic ($C_{22/0}$)			0.1			**0.5**	0.3
Erucic ($C_{22/1}$)						**49.2**	0.1
Ligoceric ($C_{24/0}$)						**1.2**	
Saturates	43.4	21.1	15.5	9.77	9	**6.2**	10
Unsaturates	**56.6**	**78.9**	**84.5**	***90.23***	**91**	**93.8**	***89.2***
IV (mg)	**44-58**	**102**	**117-143**		**94-120**	**117**	

[a] Genetically engineered high oleic acid content soybean oil

Various approaches have been identified for chemical modification of vegetable oil as well as the polymerisation of unmodified and modified vegetable oil such as by free radial, cationic or olefin methathesis as the synthesised polymers could be thermoset and composites. On the other hand, condensation polymerisation could produce polyesters, thermoplastic, polyamides and polyurethane (Xia & Larock, 2010). Epoxidised vegetable oil has the potential to be used as plasticizer to toughen a brittle polymer (Tan & Chow, 2010).

In coating industries, the use of drying oil for surface coatings applications has dated back since a hundred years ago. The film formation of drying oil assisted by free radical polymerisation in which auto oxidation of the fatty acid double bond takes place with the help of oxygen in the atmosphere, produces a crosslinked polymer. However, these processes are very slow. Besides, the unsaturation on the fatty acid is not sufficiently reactive to allow homo-or copolymerisations directly to produce resins with good mechanical performance as well as chemical resistance (Wool, 2005).

Due to the advancement in chemistry knowledge on modifications of vegetable oil, it is possible to produce vegetable oil based coatings materials from semidrying and nondrying oil with higher drying rates. Besides being renewable, vegetable oil provides the flexibility to the coating due to their aliphatic fatty acid composition. In addition, the polar groups such as epoxide, hydroxyl, carboxyl and urethane were introduced to the fatty acid to act as adhesion promoters (Alam et al., 2014). Some possible polymerisation of modified vegetable oil and its derivatives to afford polymeric materials for coating application is illustrated in Figure 3.

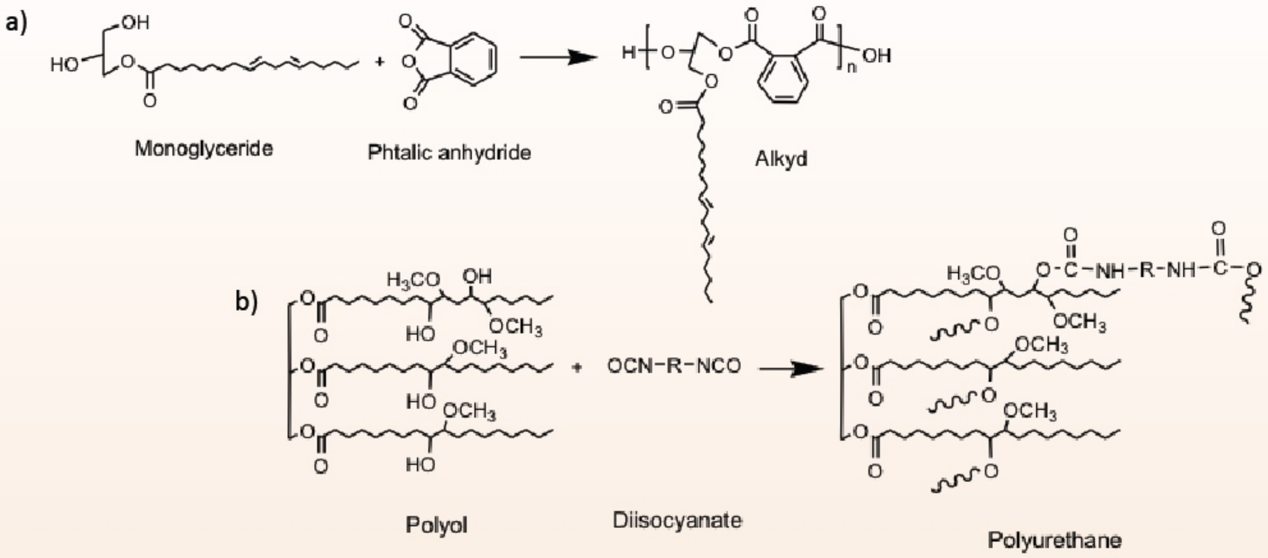

Fig. 3. Possible transformation of modified vegetable oil to polymeric coating materials (a) alkyd and (b) polyurethane.

Previous Research on Jatropha Oil-based Polymers

Previous research concerning the modification of jatropha oil to afford various types of polymers is summarised in Table 2. Recently, the physicochemical properties of jatropha oil-based polyol with potential to be used as raw material for polyurethane has been reported (Abdullah et al., 2017). A polyurethane (PU) and alkyd resin were successfully produced for adhesives, coatings, and flexible polymer applications. Previous work conducted by Aung et al. (2014) indicated a high performance of PU wood adhesives derived from jatropha oil. They showed excellent shear strength with no adhesive failure of the resin that was used to bind wood substrates. These useful findings suggest the potential of producing PU coatings from jatropha oil since adhesion is one of the most important characteristics of a good coating material.

Overall, the PU adhesive and coating as well as the alkyd resin were reported to have good thermal stability and excellent adhesion to the substrate (Aung et al., 2014; Boruah et al., 2012; Harjon et al., 2012; Saravari & Praditvatanakit, 2013). The coating products demonstrated a high gloss. Previous work by Harjono et al. (2012) on a PU acrylate coating indicated high optical properties of the product. Interestingly, waterborne polyurethane dispersion was successfully synthesised from jatropha oil. This would be more environmentally friendly coatings as it considered as VOC free coatings.

Table 2. Previous research on jatropha oil-based polymer.

Product	Remarks	Reference
Polyol for polyurethane	•Low viscosity, high molecular weight	Saalah et al. (2017)
Waterborne PU dispersion	•Good thermal stability, Hydrophobic	Saalah et al. (2015)
Wood adhesives	•Good chemical resistance	Aung et al., (2014)
Polyol for flexible PU	•Low viscosity polyol allows more time for molding and additives addition during polyurethane production	Hazmi et al. (2013)
Urethane alkyd	•Good adhesion, excellent resistance to water and acid •Low hardness, long drying time (>1h at 120°C)	Saravari & Praditvatanakit (2013)
PU acrylate coating (paint)	•High Gloss, hardness, adhesion on ABS substrate	Harjono et al. (2012)
Alkyd resin for surface coating	•High gloss, hardness, adhesion and chemical resistance properties •Thermally stable up to 330°C	Boruah et al. (2012)
Alkyd resin for electrical insulation	•The physical and electrical properties meet the standard requirements	Patel et al. (2008)

Conclusion

Some of advancement in polymer synthesis from vegetable oil preferably for coating applications has been highlighted. The spotlight is on utilization of a non-edible jatropha oil as starting materials for production of bio-based polymers such as polyurethane (PU), alkyd resin, waterborne PU for adhesive and coating applications.

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