Potential of Palm Oil as a Renewable Material for Radiation Curable Coating

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INTRODUCTION

Research on bio-based polymers and resins in industrial applications has seen some progress as well as the products facing competition with their petroleum-based counterparts. The demand for bio-based polymers and resins is due to their property of environmental friendliness as they are made from renewable resources (Ashraf *et al*., 2015). Additionally, human health is compromised when using traditional coatings which utilise high molecular weight polymers that release volatile and toxic solvents when crosslinked with heat, or when coalesced dry, resulting in serious hazards to human health. The hazardous air pollutants and volatile organic compounds (VOCs) released into the atmosphere during manufacture and application of coating materials lead to environment contamination. Environmental regulations and government legislations towards zero waste generation during the development as well as application of coating materials have been the dominant driving force in advances in bio-based polymers. Due to their abundance, palm triglycerides provide a renewable alternative to petroleum-based coating. Palm oil is the leading vegetable oil in terms of production volume as the oil palm produces between eight and 10 times more oil per hectare per year compared with annual oilseeds such as rapeseed or soyabean (Basiron, 2007). In fact, palm oil accounted for 32.0% of the global oils and fats output in 2012 (Sime Darby, 2014) and 30.1% in 2016 (Mielke, 2016).

Triglycerides from palm oil can be converted chemically to be incorporated into radiation or ultraviolet (UV) curable formulations, which are used in electronics, inks, coatings and adhesives, so that they can be crosslinked by high-intensity electron beam or UV light. Thus, development of new radiation curable materials from renewable materials which can offer lower cost and improved technical aspects has sparked more research interest.

The properties of radiation curable films from vegetable-based triglycerides depend on the nature of the fatty acids used, particularly on its structure, chemical arrangement, polarity, length of aliphatic chains, level of unsaturation, and interaction with the other components in the radiation curable formulations. Of particular interest is the number of unsaturated functional groups in triglycerides which varies depending on the composition of the fatty acids contained in the triglycerides itself which in turn may vary due to the source. The most common coating resin system that has been used for many decades employs alkyd resins which are based on the unsaturated triglycerides because of their potential for oxidative crosslinking (Paramarta *et al*., 2013). New functional polymers can be made by chemically modifying the unsaturation sites in the fatty acids. The internal double bond can be converted into epoxy functionality (Fertier *et al*., 2013). The oxirane ring functionality can be exploited further for applications in coating technologies by converting it into polyols for use in polyurethanes (Petrovic, 2008), and utilised in curing the melamine-formaldehyde system (Sharif *et al*., 2006), cationic polymerisation (Childers *et al*., 2014), epoxy-amine and epoxy-anhydride crosslinking (Ma *et al*., 2014), or acrylated for use in UV-cured systems (Cheong *et al*., 2008). One example is UV irradiation crosslinking of acrylated castor oil blended with a trifunctional thiol (Lligadas *et al*., 2013; Black and Rawlins, 2009).

Palm oil as one of the major commodity vegetable oils has low iodine value or unsaturated fatty acids content due to the presence of high levels of saturated fatty acids, especially palmitic acid and stearic acid, which limits its use as

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coatings (Nagaraj, 2009). A high iodine value indicates a high level of unsaturation which makes the fatty acids in the triglycerides viable for additional reactions. Hence, palm oil products and its oleochemical derivatives that have high iodine value, such as oleic acid, oleyl alcohol, polyols, and polyol esters like sucrose oleate, (Paramarta *et al*., 2013), can be further derivatised by acrylation to be used as coating materials. One of the promising applications is the use of acrylate esters of polyesters, polyethers, polyurethanes and epoxy resins for UV radiation curable materials. The petroleum-based chemicals can be blended with these vegetable-based derivatives to increase the bio-based content itself.

The radical or cationic curing mechanisms employ high intensity UV light in the speed curing process to create photochemical reactions which generate a crosslinked network of polymers that instantly cures inks, adhesives and coatings (Carroll *et al*., 2011). UV curing systems basically consist of oligomers or long-chain monomers sourced from petrochemicals, photoinitators and reactive diluents to alter the viscosity of the formulation and the properties of the cured films (Mashouf *et al*., 2014; Masson *et al.*, 2000). These systems were initially developed in an effort to reduce volatile organic compounds in coating formulations. Some of the key attributes of the UV curing process are low temperature, fast curing and solventless by polymerisation rather than by evaporation (Stowe, 1996). UV curable coating technology provides benefits such as being environmental friendly, sustainable, having decent performance and processing efficiency.

APPLICATIONS OF UV RADIATION FORMULATIONS

Newly developed radiation curable materials are suitable for application as plastics and wood coatings, pressure-sensitive adhesives (PSA) and printing inks, and in electronic industries and digital video disk printing (Paul, 1996). UV curing has also been used in curable acrylate systems such as dental and biomedical applications (Keskin and Usanmaz, 2010), polymer electrolytes for batteries (Ugur *et al.*, 2014; Santhosh *et al*., 2006), polymer films for electronic circuit protection (Oprea and Potolinca, 2013), ion-exchange membranes (Nagarale *et al*., 2004), coatings and adhesives (Degrandi-Contraires *et al.*, 2012; Dzunuzovic *et al*., 2012; Seo *et al*., 2010).

PALM OIL-BASED ACRYLATED RESIN

Much research has focused on the synthesis of epoxidised palm oil acrylate for different applications (Tajau *et al.*, 2013; Cheong *et al*., 2008; Azam *et al.*, 2001). Most palm oil-based products for UV-curable coating are prepared from epoxidised palm oil (EPO), *e.g*. cationic photoinitiator-induced UV curing of EPO and cycloaliphatic diepoxide (Rosli *et al*., 2003). Radiation curable acrylates can be derived from epoxidised palm oil or epoxidised palm olein by reacting them with acrylic acid (Kosheela *et al*., 2015; Ooi and Hazimah, 2001). Epoxidised palm olein acrylate (EPOLA) has been prepared by reacting EPO with acrylic acid and catalysed using triethylamine. The gelling inhibitor used was 4-methoxyphenol (Hussin *et al*., 1992). EPOLA has possible application as radiation curable pressure-sensitive adhesives (Mohd Hilmi *et al*., 2001). Acrylated polyester resins, made from crude or refined, bleached and deodorised palm oil, were incorporated with trimethylolpropane triacrylate or hexanediol diacrylate monomers. These resins were found to be most suitable when applied on wood as a coating (Azam *et al*., 2001).

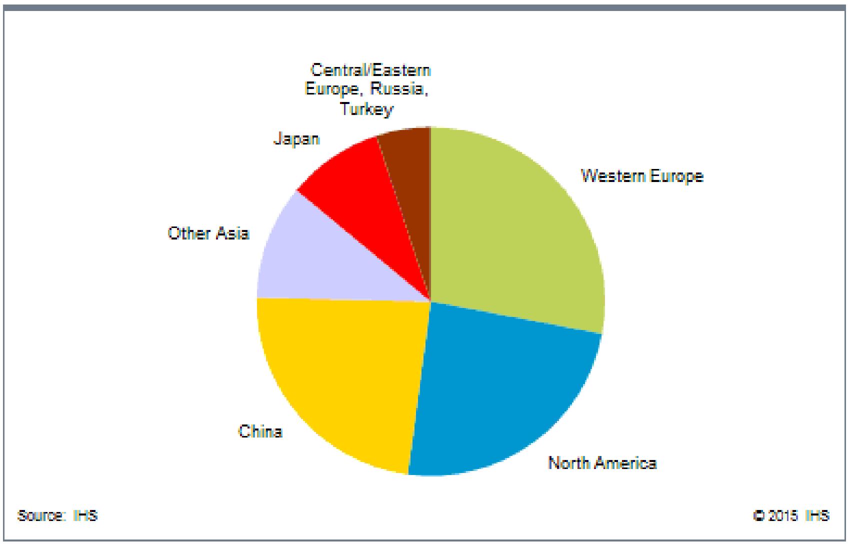
PROSPECTS AS A RADIATION CURABLE PALM-BASED COATING

The liberal use of solvents poses environmental concerns and this is reflected in the market prospects of future coating technologies, particularly in the industrial paint sector. The 1999 EU Council Directive outlined VOC regulations against harmful emissions from the use of organic solvents to protect public health and the environment from their harmful consequences as well as to guarantee citizens the right to a clean and healthy environment (Schwalm, 2007).

Over the last ten years, until 2015, the radiation curable market enjoyed healthy growth, and it has been postulated that it will remain at an average growth of 8%-9% annually in Europe and the North American Free Trade Agreement region, and at 12%-13% in Asia (Radtech Europe, 2005). Of the total global market for industrial coatings, radiation curable coatings account for 2% although radiation curable products are used for a wide variety of applications. In Europe, wood coatings and graphic arts (which include overprint inks and varnishes) markets account for about 80% of demand. The graphic arts sector predominates in North America while the adhesives, coatings and other industries have less importance. In Asia, except for China, radiation curable semiconductor resists, color filter resists and film resists are used extensively for printing plates, printed circuit boards, semiconductors, and other components which account for 30%-40% of the total market for radiation curable products (*Figure 1)*. Meanwhile in China, about 60% of the total market is based on radiation curable coatings for plastics, bamboo, paper and wood (IHS Markit, 2015).

CONCLUSION

In the United States of America and Europe, regulations were promulgated to address the issues of air pollution and concerns about human health; hence, they will be the driving force behind the adoption of radiation curable coatings and other low-pollution coating technologies. Moreover, radiation curable coatings have other desirable advantages such as high productivity,



Source: IHS Markit (2015).

Figure 1. World consumption of radiation curable coatings.

ambient temperature curing, non-flammability, chemically resistant finishes, instant curing, hardness, and small application equipment footprint. However, due to the high costs of equipment and materials, the radiation curable products account for only a small portion of the total coatings market (IHS Markit, 2015). Nevertheless, palm products and its oleochemical derivatives have great potential as cheaper feedstocks for synthesising radiation curable materials for the coating industry, and to increase the bio-based content of their synthetic coatings as well as their global market share.

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