GREEN OIL FILTER CARTRIDGE DEVELOPED FROM KENAF FOR AUTOMOTIVE APPLICATION: A PROOF OF CONCEPT

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SULTAN IDRIS EDUCATION UNIVERSITY

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ABSTRACT

This study aimed to develop a proof of concept of green oil filter cartridge from kenaf for automotive application. The methodology involved paper making process which include soda pulping, fibre beating and pulp pressing. The physical, mechanical, chemical and thermal properties of the paper sheets produced at various beating degrees were testedaccording to standard guidelines. The results highlight that the kenaf paper sheet prepared at 4000 beating revolution exhibits the best tensile and burst indices comparable to selected commercial filter media. Thermal analysis showed that the paper sheet prepared at this parameter decomposed at a lower temperature (535°C) comparedto the selected commercial filter media (700°C). The kenaf paper prepared at 4000 beating revolution was selected to form proof of concept (POC) of oil filter cartridge. Certain technical aspects of the POC were validated by industrial experts. An international sustainable manufacturing guideline was adopted to evaluate green indicators of the developed POC. The biodegradability of used POC and selected commercial oil filter media was assessed at simulated landfill conditions. Many attributes for input and product achieved high scores for green indicator. The used POC showed faster biodegradability period compared to the selected commercial oil filter media. In conclusion, some properties of the POC are better or comparable to selected commercialoil filter media. This study implicates potential towards application of kenaf paper for green oil filter cartridge manufacturing in the automotive industry.

ABSTRAK

Kajian ini bertujuan membangunkan pembuktian konsep kartrij penapis minyak hijau dari kenaf untuk aplikasi automotif. Metodologi melibatkan proses pembuatan kertas termasuk penyediaan pulpa soda, pemukulan serat dan penekanan pulpa. Sifat fizikal, mekanikal, kimia dan termal kepingan kertas yang terhasil diuji mengikut garis panduan piawai. Hasil menunjukkan kepingan kertas kenaf diperbuat pada 4000 revolusi pemukulan mempunyai indeks tegangan dan koyakan terbaik setanding dengan media penapis komersial terpilih. Analisis termal menunjukkan kepingan kertas pada parameter ini terurai pada suhu lebih rendah (535°C) berbanding media penapis komersil terpilih (700°C). Kertas kenaf yang dihasilkan pada 4000 revolusi pemukulan dipilih untuk membentuk pembuktian konsep kartrij penapis minyak. Beberapa aspek teknikal dari pembuktian konsep ini telah disahkan oleh pakar dari industri. Garis panduan pembuatan mampan antarabangsa telah digunakan untuk menilai penunjuk hijau pembuktian konsep yang terhasil. Biodegradasi pembuktian konsep dan beberapa media penapis minyak terpakai telah dinilai pada keadaan simulasi tapak pembuangan sisa pepejal. Banyak ciri input dan produk mencapai skor yang tinggi bagi penunjuk hijau. Pembuktian konsep terpakai menunjukkan tempoh biodegradasi yang lebih singkat berbanding beberapa media penapis komersil. Kesimpulannya, sebahagian ciri pembuktian konsep adalah lebih baik atau setanding dengan beberapa media penapis minyak komersil. Implikasi kajian menunjukkan potensi kearah aplikasi kertas kenaf untuk pembuatan kartrij penapis minyak hijau dalam industri automotif.

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LIST OF ABBREVIATIONS

KBF	Kenaf Bast Fiber
POC	Proof of Concept
OEM	Original Equipment Manufacturers
TAPPI	Technical Association of the Pulp and Paper Industry
MS ISO	Written standard for quality management system based on the International Organisation for Standardization

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces a general overview of the dissertation. The chapter starts off by presenting a background that ignites the current research interest. It then proceeds to explain the problem statement and significance of research to justify the importance of current work for the scientific community and nation. Finally, the objectives of study and framework within which this research was conducted are outlined.

1.2 Research background

In recent years the automotive industry has undergone a revolution in hardware and materials. Driving these changes are global requirements for reduced emissions and improvements in vehicle fuel economy. This section describes role of transportation and automotive industry in greenhouse gases emission, sustainability manufacturing practices as well as research and development (R&D) needed which have sparked interest in the present study.

1.2.1 Transportation industry and greenhouse gases emission

Almost all of the increase in global greenhouse gases emission over the last 150 years are responsibly caused by human related activities (Intergovernmental Panel on Climate Change, 2014). There are three primary sources of greenhouse gas emissions associated with human activities in the United States. Greenhouse gas (GHG) emissions from transportation have increased every year since 2014. In the year 2018, the transportation sector generated the largest share (28.2%) of greenhouse gas emissions and drastically exceeded 29% of the year 1990 level (European Environment Agency, 2019).The second largest greenhouse gas emissions contributor was electricity production (26.9 percent). Approximately 63% of the United States electricity is generated through combustion of fossil fuels, mostly coal and natural gas (U.S. Energy Information Administration, 2019). The industry sector that processes goods from raw materials was the third greenhouse gases emitter (22%) mostly through activities like burning fossil fuels for energy as well as manufacturing and chemical reactions (United States Environmental Protection Agency (EPA), 2020).

Obviously, the progressing of automotive industry in recent decades pose a significant threat to global warming. Within time span of lesser than 3 decades from the year 1990 to 2016, carbon dioxide (CO_2) emissions from road transport has increased by 71% (IEA, 2020). The United States, European Union, China, Japan, and South Korea cumulatively account for over 70% of the total global vehicle market. In 2018 alone, 12 major car manufacturers in these regions including Volkswagen, Renault Nissan, Toyota, General Motors, Hyundai-Kia and Ford with 86 million cars sold were estimated to be responsible for a combined carbon footprint of 4.8 gigatons (Gt) of CO_2 emissions. This trajectory was equal to 9% of total global greenhouse gases emissions. The combined footprint exceeded the total annual greenhouse gases emissions of the entire European Union alone (Stephan, Lee & Kim, 2019).

Thus, the awareness to curb this issue has been addressed in the Paris Agreement on climate change by the United Nations (United Nations, 2015). The Paris Agreement has set the limit of global warming must urgently keep below or close to 1.5°C to avoid disastrous impact on planet earth and mankind. Car manufacturers are strongly urge to drastically change their business model in order to achieve this target (Stephan et al., 2019). The prime goal is to phase-out internal combustion engine (ICE) cars that heavily rely on diesel and petrol. In the Paris Agreement 2015, leading climate change scientists have clear evidence that humankind have limited duration of only 12 years to act out to achieve the 1.5°C global warming target. To survive in the competitive market, automotive industry must inventively change their business operation towards a more sustainable model and production of ICE cars has to be finally stopped by 2028 (Stephan et al., 2019).

1.2.2 Sustainability in global automotive industry

Sustainability manufacturing practices provides a continuous framework in dynamic automotive industry. Among others, the adoption of sustainable manufacturing practice aimed to improve business risk, environmentally friendly products and services, waste generation and efficient use of material and energy (Habidin, Hashim, Zainol, Salmuni & Mustaffa, 2015). Across the globe, recent automotive technology development trends inclined towards Next Generation Vehicle (NxGV), Mobility as a Service (MaaS) and Industrial Revolution 4.0 (IR4.0). Intelligent and environmentally friendly vehicle technology such as Electrification, Autonomous Driving, Internet of Things (IoT), Cooperative-Intelligent Transportation System (C-ITS) and Artificial Intelligence (AI) are primary R&D focuses for today's global carmakers (Ministry of International Trade and Industry Malaysia, 2020). For example Renault, Nissan, Daimler, and BMW leading 'Green eMotion' initiatives in Europe with €42 million fund to support R&D of transportation solutions utilizing green technology (Ministry of International Trade and Industry Malaysia, 2020). The various technology improvements implemented since 2005 have resulted in significant industry-wide impacts.

A recent survey (United Nation Environmental Protection Agency (EPA), 2020) in "The 2019 EPA Automotive Trends Report Greenhouse Gas Emissions, Fuel Economy and Technology Since 1975", concluded that automotive industry has made significant progress towards lower CO_2 emissions and improved fuel economy from model year 2013 to model year 2018. In automotive manufacturing industry, vehicles are redesigned within approximately five years cycle. Therefore, this five years survey depicts a more accurate manufacturer trends than focusing on a single year. Of all major car manufacturers in 2018, Tesla which produces only electric vehicles, had by far the highest fuel economy and the lowest tailpipe CO_2 emissions at zero. Honda is the second to achieve 5-year improvements through its low emissions hybrid and electric models (United States Environmental Protection Agency (EPA), 2020). In addition to these manufacturing advances, Honda claims its products are to be 99% recyclable at end-of-life making waste reduction even more significant for this brand (Honda Motor Co., 2020).

Apart from electrifications and hybrids, some manufacturer has taken a different path towards improving CO_2 emissions and fuel economy by incorporating renewable biomass based material in car parts. At present, soybean-based foam has been a key material used in the seat cushions, seat backs and headrests of all Ford vehicles build in North America. Other biomass materials such as wheat, rice, castor, kenaf, tree cellulose, jute and coconut are also commercially built in Ford vehicles with more biomass type still undergoing research. Since 2011, more than 18.5 millionFord vehicles entering market with this sustainable features and help to save more than 228 million pounds CO_2 emissions (Mielewski, 2018). In addition, sugar cane are used in the manufacturing materials of the instrument panel, sun visors, roof lining, seat upholstery, step garnish in Honda (Clarity Model) and the ultra-suede trim on the Honda's Touring Model (Honda Motor Co., 2020).

The approach towards sustainability manufacturing practices not only benefitting the environment but economic survival of the automotive industry itself. With the increasing sustainability awareness around the globe, consumer's perception and demand for sustainable vehicles are also increased. For example, in 2018 Tesla increased production to over 190,000 vehicles, or four times the production achieved in model year 2017 (United Nation Environmental Protection Agency(EPA), 2020).In the competitive automotive market, failure to adapt changes towards more sustainable vehicles apparently means a brand is unlikely to survive tillthe next decade.

1.3 Problem statement

Integration of environmental considerations into the design process represents a complex challenge to local automotive manufacturers and suppliers. The following section outlines various key problems currently faced by local industry players, underlying basis of interest to conduct the present study.

The world markets have recorded a positive growth of 7.7% in vehicles sold from year 2014 to 2018. From this value, green vehicles sales increased steadily from 2% in 2014 to 4% in 2018. In ASEAN region, the growing automobile industry offers vast investment opportunities for stakeholders. For similar duration of year 2014-2018, the automotive industries within ASEAN countries recorded increase of 12% growth in sales and 10% for vehicle production respectively (Ministry of International Trade and Industry Malaysia, 2020). The green vehicle sales in ASEAN,meanwhile, achieved 32% penetration in 2018. One of key challenges to local automakers is the ecosystem for the supply chain of vehicle components has been established in another country for decades. This situation apparently gives an economic advantage for a vehicle producing brand to export. Presently, Japan's Original Equipment Manufacturers (OEMs) in general have strong dominance over the manufacturing and market segments in ASEAN. The long dominancy has impacted the expansion plan of local components which currently only at the level of assembly and not at the level of product R&D and tooling.

To solve this problem, Malaysia Vehicle Project will be implemented in line with the future direction and strategies of the National Automotive Vision 2020 (Ministry of International Trade and Industry Malaysia, 2020). The Malaysian Vehicle Project will focus on the development of manufacturing capabilities in a holistic manner as it involves the entire value chain and the automotive industry ecosystem. This project outlines that significant R&D on vehicle parts such as top hat and upper body must be done locally. In addition, majority (75%) of supply chain development will involve local vendors to break dominancy of foreign vendors (Ministry of International Trade and Industry Malaysia, 2020). Therefore, local R&D institutions and technology centres must inventively work together with stakeholders in automotive industry to produce environment friendly auto parts and build a sustainable OEMs supply chain to reduce reliance on foreign OEMs.

A primary objective under NAP 2020 is to reduce carbon emission from vehicles by improving fuel economy level in Malaysia to 5.3 Lge/100km (litres of gasoline-equivalent per 100 kilometres) by 2025 in line with the ASEAN Fuel Economy Roadmap This target could be met by increasing use of biomass and biofuels in automotive application. The National Biomass Strategy 2020 (Agensi Innovasi Malaysia, 2020) was initiated in November 2011 to assess how Malaysia can gain more revenue from its palm oil industry through utilisation of the associated biomass as a start. Among others, the policy empower technical research activities and comprehensive validation system for biodiesel application in the transportation sector. As result, Malaysia introduced the B5 programme (5% blend of palm oil biodiesel with 95% petroleum diesel) in 2011. The programme was enhanced to B7 (7% blend of palm oil biodiesel with 93% petroleum diesel) in December 2014. Subsequently, the B10 (10% blend of palm oil biodiesel with 90% petroleum diesel) programme was implemented since February 2019 (Agensi Innovasi Malaysia, 2020). While the strategy initially focused on the palm oil industry since it was the largest producer of biomass in Malaysia, the scope of version 2.0 of the NBS 2020 released in 2013 is expanded to include biomass from Forestry sector and DedicatedCrops on Marginal Land as feedstock to higher value downstream second generationproducts. Together with biodiesel blends project, the accomplishment so far looks promising. However, there are plenty of opportunities for other developments from biomass.

In Malaysia, one of the most potentially recognized renewable forestry biomass for various industrial application is kenaf. Kenaf af (*Hibiscus cannabinus*, L. family Malvaceae) is an herbaceous annual plant that can be grown under an extensive range of weather conditions, for instance, it grows to more than 3 meter within 3 months even in moderate ambient surrounding. This plant has also been skilfully optimised by mankind in prehistoric era as a rope, canvas and sacking while in modern days, kenaf is used as a raw substance in replacing wood in pulp and paper industries to prevent forests destruction and also benefited as non-woven matsin the automotive industries, textiles, and fibre-board (Ayadi et al., 2016). At global stage, Ford has successfully commercialized vehicles that has kenaf biomass built in the brand's auto parts (Mielewski, 2018). Therefore, kenaf is noteworthy as a biomass of interest for R&D activities in Malaysian automotive industry.

Concurrently, kenaf is being researched by developed and developing countries as a promising raw material for pulp, paper and wood composites production (Nishino et al., 2003). Within Malaysia context, kenaf was identified as a potential alternative fibrous material for the production of panel products such as fibreboard and particle board and the government has also shown concern on extending the research in pulp and paper industry (Mossello, Harun, Md Tahir, et al., 2010). Specifically for automotive industry in Malaysia, the state of the art R&D activities on kenaf application in cars is currently focusing on composite material for friction tooling (Adole et al., 2019; Mustafa et al., 2015; Talib et al., 2018) and body parts (Loh et al., 2014; Mustafa et al., 2015; Yuhazri et al., 2017, 2018).

In view of the government promoting kenaf to produce pulp and paper, it is plausible for R&D activities to be conducted on application of kenaf to produce paper for the automotive industry. For this study, feedback from PROTON Berhad was garnered to provide indicative demand for paper in manufacturing of vehicle parts. It was suggested that significant application for paper in this industry is for oil filter and air filter media. At present, a foreign vendor (UMW Toyota) supplies almost all oil filters for various Malaysian car brands including models made by PERODUA and PROTON. It is estimated that around 6 million filters are produced annually at UMW Toyota Shah Alam factory to meet demands from local automotive industry.

Engine oil filter is an important and essential component in the satisfactory operation of the lubrication system in vehicle engines. The primary function of an oil filter is to purify engine oil by filtering and removing contaminants from lubricants. This is to ensure engine compartments are free from pollutants, a main factor for abrasion which consequently leads to melting of metallic compartments and damage the automobile engines (Whitford et al., 2002). Thus an oil filter in the engine system plays its vital role in filtering out these contaminants and ensures the longevity of the lubricants. Ensuring the engine supplied with clean oil prevents excessive engine wear and protects the vehicle engine system (Nissan, 2006). Modern oil filters are characterized by their strength and capability of withstanding high-temperatures during longer service intervals. They also have to be capable of maintaining continuous mechanical stability and resistance to dangerous contaminants in the oil during engine operation (Whitford et al., 2002).

There are various types of vehicle's oil filters available in the current market. However, the most common and well-known oil filters are the canister or spin-on and cartridge types. A spin-on filter is physically made up of metal casing that incorporates various types of filter media from different materials. Cartridge type oil filter is comprised of inners of a spin-on oil filter (the filter media with end caps and centre tube) without the outside metal casing. As the key function of oil filters is to retain and remove contaminants such as debris and dirt from the lubricants as the oil flows through the engine, one of the most important components in oil filter is the filter media (Fitch, 2013). These filter elements are responsible in capturing the organic and inorganic contaminants as the oil flows through the engine parts. Filter media is the actual and major component of the oil filter which is made up of microscopic cellulose fibres and synthetic fibres that act as a sieve to capture contaminants before the oil flows to the engine. The filter media is either pleated or folded for great efficacy (McAfee, 2015).

Preparation of these filter papers involved various technologies and papermaking method is one of it. Among the commercial automobile engine oil filtration material, wood pulp paper is one of the most common ones found in the market (Jianyong & Jianchun, 2013). However, the demand of cellulosic fibres from wood crops had outgrown its number, and became a big challenge in meeting the supply sustainably. Of all global wood harvest, 42% is estimated to be used by paper industry. Thus, non-wood plants are seen as the alternative cellulosic fibres that can be potentially used in applications that requires alike materials provided by the wood fibres (Mechi Nawabia, Khiari Ramzi, Elaloui Elimame, 2016). This was also supported by the view of (Ashori, Harun, Raverty & Yusoff, 2006), that increasing population and industrialization in developing countries are expected to rise the need for paper and paperboards by 4.3% per annum as compared to 1.2% in developed countries. Thus, non-woods have become one of the essential sources of fibrous material for the 21st century. Their study also stated that, non-woods such as bagasse, wheat and rice straws, bamboo, and kenaf are being utilised in the production of pulp and paper around the globe.

As green as it seems though, in reality paper production industry has long being recognized as a major source of pollution to the environment. Paper production normally involve pulping and bleaching process that rely on toxic chemicals like chlorine and chlorine compounds. In addition, potential by products from this industry including mercury, water effluents such as absorbable organic halides and total suspended solids, and solid waste such as boiler ash and effluent sludge. Other chemicals used in paper manufacture such as dyes, inks and bleach can also be harmful when they are released into the environment (Suraj & Khan, 2015). In view of this harmful practice, it is a challenge for R&D stakeholders to invent sustainable paper material for automotive industry from renewable cellulosic biomass such as kenaf, with desirable quality and has lower impact on the environment.

A technology must evolved through several phases before it finally matured and commercialized. Technological maturity could be characterised using Technology Readiness Levels (TRLs) guideline method (MOSTI, 2017; NASA, 2017). The TRLs measure technological maturity in 9 levels from the most basic research (TRL 1) through to full-scale-real world operation (TRL 9) (Figure 1.1.). When a technology is at TRL 1, scientific research is at very beginning. The results are being translated into next level of R&D. TRL 2 occurs once the basic principles have been studied and practical applications can be applied to those initial findings inTRL 1. TRL 2 is rather speculative and there is little to no experimental proof of concept for the technology. A technology is elevated to TRL 3 when active research and design begin that requires both analytical and laboratory studies. Often during TRL 3, a proof-of-concept model is constructed to assess viability of a technology to proceed further to TRL 4. TRL 4 involves laboratory validation of multiple component pieces are tested with one another. TRL 5 is a continuation of TRL 4. However, a technology that is at TRL 5 must undergo more rigorous testing than technology that is only at TRL 4. During TRL 5, simulations should be run in realistic environments. Once the testing of TRL 5 is complete, a technology may advance to TRL 6 with functional prototype or representational model. TRL 7 requires that the working model or prototype be demonstrated in an operational environment before it proceeds to TRL8. At TRL 8, the technology has been completed, qualified and ready for implementation into an already existing technology environment. A technology that has complete its operational evaluation reaches TRL 9 and ready for commercialization.

TRL	Description	Characterisation
1	Basic Principle	• Technology research • Pure science begins translation to R&D
2	Formulation of Concept	• Early studies for application formulation. • Invention & Practical Application Begins.
3	Experimental Proof of Concept	• Analytical validation & proof of concept • Start active research & development
4	Lab validation	• Validation in laboratory environment • Ready to begin bridge for technology transition
5	Validation in real environment	• Validation in relevant environment • Ready to enter technology development
6	Demonstration in real environment	• Demonstrated in relevant environment • Ready to enter system development
7	Demonstration of prototype	• Demonstrated in operational environment • Ready for limited production decision
8	System complete and qualified	• Compliant, qualified & test/demo complete • Ready for operational evaluation
9	System proven	• Completed operational evaluation • Ready for full-rate

Figure 1.1. Technology Readiness Level (MOSTI, 2017)

From Figure 1.1., obviously TRL3 and TRL4 (highlighted in blue lines) are two critical levels in technology maturity pipeline to bridging early studies at TRL 1 and TRL2 with TRL5 and above. At TRL3, it is important for a proof of concept to be produced with critical analysis and further validated in laboratory environment at TRL4. For research and development of green technology, it is therefore important to taking into consideration the element of sustainability at these two stages.

1.4 Significance of research

Moving forward to the next decade, there are various critical issues and challenges faced by the Malaysia's automotive industry. From the above problem statements, several research significance could be drawn as follows:

i. *Automotive industry need to reduce reliance on foreign OEMs* – At present, Malaysia's automotive industry business model is at the level of assembly rather than at the level of product R&D and tooling. The reliance to foreign technology and OEMs supply chain expose Malaysia's automotive industry to significant risk of vulnerability to market dominancy and manipulation by foreign brands. To achieve primary National Automotive Policy 2020 goal of making Malaysia as leader in Asean automotive market, it is significant to conduct vigorous R&D on local technology at par with competitive foreign brands. This is crucial to ensure the industry grows with conducive supply chain environment that utilizing internal resource as well as benefitting local vendors.

ii. *R&D needed on biomass and biofuels application* – Global consumerism pattern indicates strong demand on sustainable vehicles. Transportation industry also need to shift conventional business model towards lowering emission to meet the Paris Agreement target on climate change by 2028. For Malaysia's automotive industry, there are multiple strategies could be employed to achieve this target. Apart from palm oil biomass, it is plausible to research on other renewable biomass such as kenaf which could be the next gold crop for making vehicle body parts, brake pads, interior finishes and filters to improve carbon footprint in car manufacturing.

iii. Need on sustainable paper production from kenaf for automotive application – Most of oil filter cartridge used on local car brands are supplied by international vendor. R&D on locally manufactured green oil filter media is still limited and acts as a barrier for Malaysia's automotive industry to progress. From sustainability point of view, there is demand to develop filter paper media from renewable kenaf biomass with limited chemical usage during manufacturing process. The paper product should not compromisedto have desired quality with its OEM peers if not better. Thus, developing a proof of concept of oil filter cartridge from kenaf and evaluate its characteristics in accordance to selective OEM specifications are significantly novel.

iv. *Systematic technology development in accordance to technology maturity pipeline*- Previously, the research group in UPSI has developed paper, adsorbent and a proof of concept of filter cartridge from kenaf mainly for application in wastewater treatment (Shamsudin, Abdullah & Kamari, 2016;Kamari et al., 2019) With reference to Technology Readiness Level guideline in Figure 1.1., the data from work done previously on wastewater treatment application form fundamental framework for conducting the present study. This research is focus to garner significance knowledge pool in the area of green oil filter cartridge developed from kenaf fiber for automotive application at TRL3. Since TRL3 (and TRL4) are the stage for bridging the technology transition to higher level, it is important to include validation of initial proof of concept model by the automotive industry expert. Sustainability evaluation at this early stage is also significant to provide indicative data for future direction and what technology improvement neededon the next level.

The research outcomes are expected to contribute significant baseline data for local automotive stakeholders to move on to higher TRL levels of green oil filter parts until commercialization status is achieved finally. The data also could open opportunities for development of other filter material type such as air filter. Together with other R&D projects carried out on kenaf biomass application in car manufacturing, data from this work would be beneficial for Malaysia Vehicle Project. Furthermore, this research will surely align with the goals of National Automotive Policy, National Biomass Strategy and National Key Priority Area in development of green technologyand reduction of carbon emission.

1.5 Research objective

This study embarks on the following objectives:

i. To develop a proof of concept (POC) of green oil filter cartridge from kenaf bast fiber (KBF).

ii. To validate the properties of green oil filter cartridge POC in accordance to local car manufacturer’s selective criteria.

iii. To assess sustainability indicators of oil filter cartridge POC based on present laboratory scale manufacturing process and its biodegradability in simulated landfill conditions.

1.6 Research framework

In this study, a research framework (Figure 1.2) is built to resolve three objectives outlined in section 1.4. The study was conducted in three stages:

i. Stage 1 – At this stage, a proof of concept of green oil filter cartridge was developed from kenaf bast biomass. The work involved preparation of paper from kenaf with minimal chemical use and characterisation study benchmarked against commercial OEMs filter media.

ii. Stage 2 - The POC produced in stage 1 then underwent validation by an industry expert. The validation criteria was limited to assembly of POC in accordance to criteria used for assembly of commercial OEMs.

iii. Stage 3 – The sustainability aspect of oil filter POC was evaluated using two indicators. The first indicator was adopted from an international reference to score sustainability criteria of POC and POC inputs. The second indicator was assessing the biodegradability of used oil filter cartridges by simulating municipal solid waste dumping conditions. The second indicator is important since Malaysia currently not practicing recycling of used oil filter. Therefore, biodegradability of discarded used oil filter cartridge from kenaf was studied to foresee its impact in worst case scenario.

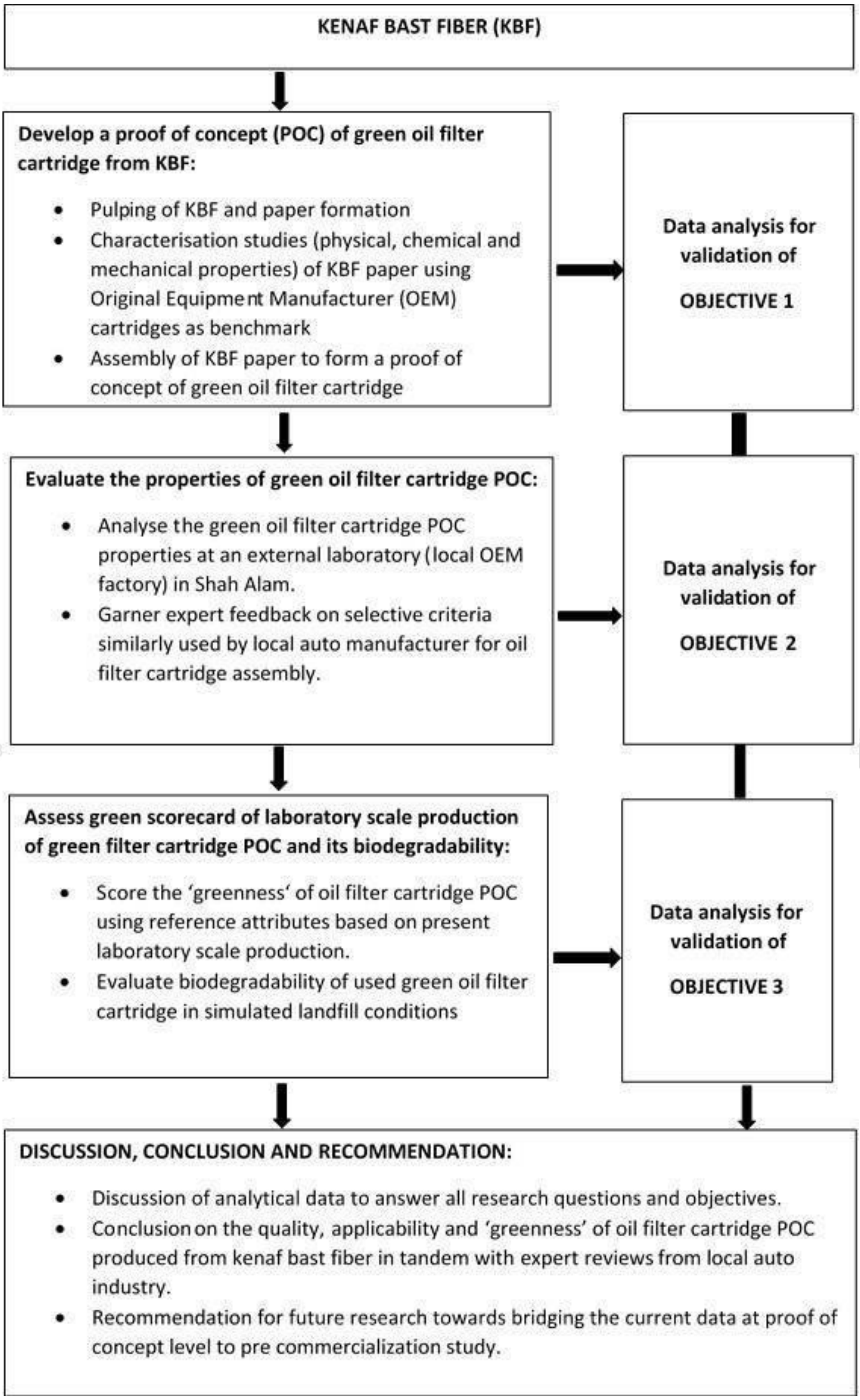

Figure 1.2. Research framework

1.7 Thesis organization

There are five chapters in this thesis. This introductory chapter describes the research background, problem statements, research objectives, research framework and significance of research. The rest of thesis chapters are arranged as follows:

The next chapter (Chapter 2) reviews literature on oil filter types and filter media categories, automobile filtration processes and kenaf bast fibre (KBF) as the raw material for production of oil filter material. This chapter also surveys technique for paper production. Research gaps that have been identified from the literature surveys were also presented.

Chapter 3 presents the methodology in two parts. The first part is on development of Proof of Concept (POC) of oil filter cartridge from KBF. The second part presents method for the evaluation of sustainability indicator of the oil filter POC as well as the biodegradability of the KBF papers and OEM oil filter papers.

Chapter 4 discusses the data on properties of kenaf paper benchmarked against commercial OEMs filter media. This chapter also presents and discusses feedback of the properties of KBF oil filter cartridge POC by the automotive industrial experts as well as sustainability indicators score and the biodegradability analysis of the KBF paper and OEM oil filter media.

Chapter 5 provides conclusions of the study, implications and recommendations for future work.