PRODUCTION, CHARACTERIZATION AND PRE-COMMERCIALIZATION OF LAUNDRY DETERGENT POWDERS INCORPORATED WITH PALM C16 METHYL ESTER SULPHONATES

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A dissertation submitted in partial fulfilment of the
requirements for the award of the degree of
Doctor of Engineering (Process Plant Management)

Faculty of Chemical Engineering
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FEBRUARY 2015

DEDICATION

I dedicate this humble effort to my parents,
my beloved wife and our lovely children for their
continuous prayers, love, support and understanding

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to my supervisors, Prof. Ramlan Aziz and Prof. Dr. Nooh Abu Bakar for their advice and guidance throughout the course of study. My sincere appreciation also extends to Assoc. Prof. Dr. Shreeshivadasan Cheliappan and Dr. Zainul Akmar Zakaria for their invaluable support and assistance.

This research was supported by the Ministry of Science, Technology and Innovation (MOSTI) and Ministry of Education (MOE) and I am very grateful for their financial contribution. I am also thankful to the staff members of the Institute of Bioproduct Development (IBD, UTM), my colleagues in Pentamoden Sdn. Bhd. and Ir. Dr. Hj. Hamdan Ya and Tn. Hj. Ropien Jokiman of SIRIM Berhad for their great help during the course of my research.

In the process of preparing this dissertation, I was in contact with many people, including researchers, engineers, academicians, industry experts and consultants. They have contributed extensively towards my understanding and thoughts. My heartfelt appreciation also extends to all of them. I will forever be thankful to Datuk Dr. Salmiah Ahmad for introducing me to the wonderful universe of oleochemicals.

I am deeply indebted to my parents. Without them, I would not be the person I am today. Finally, and most importantly, I would like to thank my wife, Subashini and children, Anupreetha, Rishanthan and Rhenupriosha for their continuous love, support and encouragement.

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ABSTRACT

Palm C16 methyl ester sulphonate (C16MES) is an anionic surfactant that has the potential as an active ingredient in the production of laundry detergent powders. Although C16MES has been successfully applied in the production of high-density laundry detergent powders (HDDP), it could not be employed during spray drying process in the production of market preferred low-density laundry detergent powders (LDDP) without compromising the detergency and other significant attributes. This dissertation encompasses experimental research on phosphate-free laundry detergent (PFD) powders incorporated with binary anionic surfactants of C16MES and linear alkyl benzene sulphonic acid (LABSA) at both laboratory and pilot scales and also include consumer studies towards laundry detergent products with special reference to palm C16MES incorporated laundry detergent powders. Initial laboratory experiments revealed that PFD powders resulted from C16MES/LABSA of 50:50 ratio and of pH 7 - 8 have good detergency stability upon one-week of continuous heating in an oven at 50 ^{o}C with 85% relative humidity. Subsequent experiments were carried out in a pilot spray dryer using PFD formulations of six different ratios of C16MES/LABSA under the same pH condition. Three PFD formulations were selected for further evaluation based on their suitability in the spray drying process. The cleaning properties and particle characteristics of the resulting spray dried detergent powders from these selected formulations were analyzed. Based on the overall evaluation, C16MES/LABSA in 40:60 ratio was selected as the ideal PFD formulation. Further tests confirmed that spray dried detergent powder (SDDP) from the ideal formulation has a high level of biodegradability (60% in 13 days), low eco-toxicity properties (LC_{50} of 11.3 mg/L) and moderate flowability characteristics (*Hausner* ratio of 1.27 and *Carr*'s index of 21.3). Other than experimental studies, a pilot survey was also carried out to study consumers' preferences (detergent format, brand and origin) and their purchasing behaviour (awareness, knowledge and perception) towards laundry detergent products, specifically with reference to palm C16MES incorporated detergent powders. The majority of the respondents (82%) reported that although they neither have the knowledge about palm MES incorporated detergent powders nor heard of its surfactants, their preferences to use this new eco-friendly product were generally positive (94%). The results imply the commercial potential of the MES incorporated laundry detergent powders and with effective commercialization strategies, the product can attain success in the marketplace.

ABSTRAK

C16 metil ester sulfonat berasaskan minyak sawit (C16MES) merupakan surfaktan anionik yang mempunyai potensi sebagai bahan aktif di dalam penghasilan serbuk detergen pakaian. Walaupun C16MES telah berjaya digunakan di dalam penghasilan serbuk detergen berketumpatan tinggi (HDDP), tetapi ianya tidak boleh digunakan semasa proses pengeringan semburan di dalam penghasilan serbuk detergen berketumpatan rendah (LDDP) seperti yang dikehendaki oleh pasaran tanpa menjejaskan ciri kebersihan detergen dan sifat-sifat lain yang penting. Disertasi ini merangkumi penyelidikan eksperimen mengenai serbuk detergen tanpa fosfat (PFD) gabungan surfaktan anionik binari C16MES dan asid alkil benzena sulfonik linear (LABSA) pada skala makmal dan loji pandu serta meliputi kajian pengguna terhadap produk detergen pakaian khasnya merujuk kepada serbuk detergen pakaian gabungan C16MES berasaskan sawit. Eksperimen makmal peringkat awal telah mendapati bahawa serbuk PFD detergen hasilan C16MES/LABSA pada nisbah 50:50 dan pH 7 – 8 mempunyai kestabilan ciri kebersihan yang baik apabila dipanaskan secara berterusan selama seminggu di dalam ketuhar pada suhu 50 ^{o}C dengan kelembapan relatif sebanyak 85%. Eksperimen berikutnya telah dijalankan di dalam loji pandu semburan kering menggunakan formulasi-formulasi PFD dari enam nisbah C16MES/LABSA yang berlainan dan pada keadaan pH yang sama. Tiga formulasi PFD telah dipilih untuk penilaian selanjutnya berdasarkan kesesuaian formulasi-formulasi tersebut di dalam proses pengeringan semburan. Ciri-ciri dari segi kebersihan dan sifat partikel serbuk detergen yang terhasil dari tiga formulasi terpilih ini telah dianalisa. Berdasarkan kepada penilaian keseluruhan, C16MES/LABSA pada nisbah 40:60 telah dipilih sebagai formulasi PFD yang ideal. Ujian seterusnya telah mengesahkan bahawa serbuk detergen semburan kering (SDDP) dari formulasi ideal mempunyai tahap biodegradasi yang tinggi (60% dalam masa 13 hari), ciri eko-ketoksikan yang rendah (LC_{50} sebanyak 11.3 mg/L) dan sifat kebolehaliran partikel yang sederhana (nisbah *Hausner* pada 1.27 dan indeks *Carr* pada 21.3). Selain dari kajian eksperimen, satu kajian rintis telah dijalankan untuk mengkaji pilihan (format, jenama dan asal detergen) dan tabiat pembelian (kesedaran, pengetahuan dan persepsi) pengguna terhadap produk detergen pakaian, khususnya serbuk detergen pakaian gabungan MES berasaskan sawit. Majoriti responden (82%) melaporkan bahawa walaupun mereka tidak mempunyai pengetahuan mengenai serbuk detergen yang digabungkan dengan MES dan juga tidak pernah mendengar mengenai surfaktan MES, tetapi pilihan mereka untuk menggunakan produk mesra alam yang baru ini secara amnya adalah positif (94%). Keputusan ini menunjukkan bahawa terdapat potensi komersil untuk serbuk detergen pakaian gabungan MES berasaskan sawit dan dengan strategi pengkomersilan yang efektif, produk ini boleh mencapai kejayaan di dalam pasaran.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	-	Reflectance after wash
AE	-	Alcohol ethoxylate
AES	-	Alcohol ether sulphate
APG	-	Alkylpolyglycoside
AOS	-	Alpha olefin sulphonate
AS	-	Alcohol sulphate
ASTM	-	American Standard Testing Method
B	-	Reflectance before wash
BOS	-	Blue Ocean Strategy
C16ME	-	Saturated C16 carbon chain methyl esters
C16MES	-	C16 carbon chain methyl ester sulphonate
cm	-	Centimeter
CI	-	Carr’s index
CMC	-	Carboxymethyl cellulose
C_o	-	Reflectance of the original unsoiled test fabric
CrMC	-	Critical micelle concentration
D_{10}	-	Particle diameters at cumulative volume percentage of 10%
D_{50}	-	Particle diameters at cumulative volume percentage of 50%
D_{90}	-	Particle diameters at cumulative volume percentage of 90%
DO	-	Dissolved oxygen
D_b	-	Bulk density
D_t	-	Tapped density
EPP	-	Entry point projects
FAS	-	Fatty alcohol sulphate

FAES	-	Fatty alcohol ether sulphate
ft	-	Feet
FMCG	-	Fast moving consumer goods
g	-	Gram
gal/h	-	Gallon per hour
g/h	-	Gram per hour
HDDP	-	High-density detergent powder
HR	-	Hausner ratio
hPa	-	Hectopascal
I_2	-	Iodine
IV	-	Iodine value
JB01	-	Carbon soiled fabric
JB02	-	Protein soiled fabric
JB03	-	Sebum soiled fabric
kg	-	Kilogram
kg/L	-	Kilogram per liter
kV	-	Kilo volt
LABS	-	Linear alkyl benzene sulphonate
LABSA	-	Linear alkyl benzene sulphonic acid
LDDP	-	Low-density detergent powder
LC_{50}	-	Lowest concentration causing 100% mortality
m	-	Meter
M	-	Mean
ME	-	Methyl ester
MEE	-	Methyl ester ethoxylate
MES	-	Methyl ester sulphonate
MESA	-	Methyl ester sulphonic acid
mg/L	-	Miligram per liter
mL	-	Mililiter
min	-	Minute
MOSTI	-	Ministry of Science, Technology and Innovation, Malaysia
MPOB	-	Malaysian Palm Oil Board
n	-	Number of data points

N	-	Sample size
NKEA	-	National Key Economic Areas
nm	-	Nanometer
PFD	-	Phosphate-free detergent
PORIM	-	Palm Oil Research Institute of Malaysia
ppm	-	Parts per million
PS	-	Palm stearin
PSD	-	Particle size distribution
PS-Dryer	-	Pilot scale spray dryer
R'_{AW}	-	Average reflectance for standard detergent powder after washing
R_{AW}	-	Average reflectance for detergent sample after washing
R'_{BW}	-	Average reflectance for standard detergent powder before washing
R_{BW}	-	Average reflectance for detergent sample before washing
RM	-	Ringgit Malaysia
rpm	-	Revolution per minute
ROS	-	Red Ocean Strategy
P_u	-	Particle size uniformity
s	-	Seconds
SD	-	Standard deviation
SDDP	-	Spray dried base laundry detergent powder
SE	-	Standard error
S_{ed}	-	Spread of equivalent particle diameter
SEM	-	Scanning electron microscopy
SLES	-	Sodium lauryl ether sulphate
STPP	-	Sodium tripolyphosphate
SWOT	-	Strength, Weakness, Opportunities and Threats
THOD	-	Theoretical oxygen demand
USDA	-	United States Department of Agriculture
US$	-	US Dollar
X	-	Individual data point
Zeolite 4A	-	Sodium aluminosilicate

Σ	-	Sum of
µm	-	Micron

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Detergent industry is a highly competitive market and detergent powders have the largest market share worldwide compared to other detergent formats. The major players in the business of laundry detergent powders, which supplied almost 50% of the global volume, are Procter and Gamble (P & G), Unilever, Henkel, Lion Corporation and Kao Corporation (Boerefijn *et al.*, 2007). Laundry detergent powders are used in millions of households around the world and they typically contain surfactants, builders, bleaching agents, enzymes and fillers (Scott and Jones, 2000) in various proportions. Among these ingredients, surfactants or surface active agents exert a pivotal role where its cleaning chemistry has been the driving force in detergent innovation for years (Lafferty, 2010). In 2008, the annual global production of surfactants was 13 million metric tonnes and the turnover reached US$24.33 billion in the subsequent year, a 2% increase from the previous year. It is expected that the global surfactant market would generate revenues of more than US$41 billion in 2018 (Reznik *et al*., 2010).

In general, surfactants can be defined as compounds that lower the surface tension of water and possess the wetting, emulsifying and dispersing properties that enable the removal of stain from fabrics (Mukherjee, 2007). Surfactants also can be broadly classified as being anionic, cationic, non-ionic, and amphoteric or zwitterionic by the charge on the surface active component (Gecol, 2006). In the production of laundry detergent powders, anionic surfactants are used in greater volume than others because of their ease of use and low cost (Yangxin *et al*., 2008). The conventional raw materials used for the production of anionic surfactants are primarily derived from two sources, petrochemicals and oleochemicals (Rust and Wildes, 2009). About 75% of anionic surfactants (excluding soaps) used globally are based on synthetic raw materials (Pletnev, 2001).

During the twentieth century, petrochemical based linear alkyl benzene sulphonate (LABS) has been the dominant workhorse of the detergent industry (Chemsystems, 2007) and Malaysia being one of the importers of this surfactant (Ahmad *et al.*, 2007). Since the beginning of this millennium, LABS has been under relentless pressure due to a dramatic surge in crude oil prices (Foster, 2006 and Scheibel, 2004). Moreover, green and eco-friendly became two big buzzwords in the marketing of detergents at the same time (Guala and Merlo, 2013). This development poses a great challenge to the formulators to find ways in increasing the green olechemical based surfactants (De Guzman, 2010) and reducing harmful detergent ingredients such as phosphates (Kohler, 2006) in the detergent formulations. In addition, this scenario also has heightened public concern on LABS over its environmental impact towards the aquatic ecosystem (Huber, 1989 and Okbah *et al.*, 2013). Under these circumstances, the attention of the detergent formulators gets shifted into detergent products that address the cost, environment and sustainability (Lafferty, 2010).

As oleochemistry provides the solution for sustainable future, extensive studies on detergent formulation have been carried out towards this direction. However, the challenge for today's detergent still lies in providing high performance with low cost of production (ICIS Chemical Business, 2010). This challenge has provided an enormous opportunity for methyl ester sulphonate (MES) to emerge into limelight after several decades of research. MES is an anionic surfactant, which produced via sulphonation of oleochemical feedstock such as methyl esters (ME). These ME can be derived from natural oils such as palm oil, coconut oil and soybean oil. MES is well known for its superior detergency, water hardness tolerance, rapid biodegradability and low production cost (Martinez *et al.*, 2010). It has the potential to substitute LABS and other oleochemical based anionic surfactants such as fatty alcohol sulphate (FAS) and fatty alcohol ether sulphate (FAES) (Ismail *et al.*, 2002).

MES was fundamentally studied in the 1950s by the United States Department of Agriculture (USDA) (Weil *et al.,* 1953; Weil and Stirton, 1956) but only known as a class of surfactant in the 1980s (Hibbs, 2006). In the initial stage of development, MES has been associated with several disadvantages mainly on its poor solubility, tendency to hydrolyze, longer processing time, irritancy, dark colour and also due to the presence of skin sensitized products. These negative properties of MES were back then created a fear factor for the detergent industry to scale-up the technology into large-scale production. However, with continuous research and good manufacturing practice, these technical issues were solved by several MES technology providers. As a result, the technology for producing excellent quality MES became commercially available in the early nineties (Satsuki, 1998). However, due to lack of producers for ME (Sun, 2006) and its subsequent MES, slow progress has been seen in the development of MES based laundry detergent powders.

The 2000s was the decade where MES became the main topic of interest to the detergent industry. The interest was driven by the development of palm oil based biodiesel in Southeast Asia, which offers possibilities for more abundant palm oil based saturated C16 carbon chain ME (C16ME) at competitive cost (Giese, 2006; Ahmad *et al.*, 2007; Mazzanti, 2008). Although C16ME is a by-product obtained from biodiesel production, it is the most suitable ME feed for the production of C16 methyl ester sulphonate (C16MES) (Foster, 2006). Besides the biodiesel process route, C16ME also can be produced in oleochemical processing plants through fatty acid esterification using methanol (Yaakob and Bhatia, 2004).

C16MES derived from C16ME was found to have the edge over LABS in the aspects of green, performance, production cost and sustainability. In addition, the C16MES is also known for its excellent detergency (ability to remove stain from fabric) against MES derived from ME of other carbon chain lengths such as C14 and C18 carbon chains (Satsuki, 1998). Therefore, C16MES has great potential not only as the sole surfactant but also as co-surfactant in the production of laundry detergent powders (Adami, 2008).

1.2 Problem Statements

In terms of performance, MES derived from natural oils has all the effective properties to outperform LABS. However, the primary challenge concerning C16MES still lies in the formulation and production process of low-density detergent powders (LDDP). In contrast to LABS, MES could not be applied directly into the spray drying process for the production of LDDP without sacrificing the detergency and other significant properties (Trivedi, 2006). MES in general has been reported as suitable for non-tower agglomeration process (Roberts *et al.*, 2008), which yields high-density detergent powders (HDDP) with bulk densities ranging between 0.55 to 0.75 kg/L and higher. The spray tower process, which normally used to produce LDDP with bulk densities ranging from 0.25 to 0.45 kg/L (Jacobs *et al.*, 1992), on the contrary was found to be unsuitable for MES. In the developing world, LDDP are highly preferred by consumers (Zoller and Sosis, 2010) due to its low cost and high volume over weight ratio.

Earlier studies have indicated that MES will undergo partial hydrolysis (decomposition of ester group) under spray drying conditions and degrades into a less active by-product – disalt (Yamane and Miyawaki, 1989). Disalt possesses inferior detergency properties and will result in deterioration of the detergency performance (Huish *et al.*, 2004a). This hydrolysis process normally occurs when MES is exposed for a long time at a pH of below 3 or above 10 (Stein and Baumann, 1975; MacArthur *et al.*, 1999) and also at high spray drying temperature (Satsuki, 1992). It has been reported that binary anionic surfactants containing MES and LABS could provide a solution to the MES hydrolysis problem in the spray drying process (Satsuki, 1998). Binary MES and LABS also may provide synergistic effect in the laundry detergents where their combined detergency could be higher than their respective individual surfactant. However, due to insufficient scientific data on this subject matter, extensive studies on detergent formulations using binary anionic surfactants of MES and LABS are necessary to evaluate its suitableness in the spray drying process.

1.3 Research Aim and Objectives

The primary aim of this research is to overcome the technical disadvantage of MES in the spray drying process and thus to maximize its use in the common LDDP formulation without compromising the detergency and other useful properties. Therefore, the objectives of this research are as follows:

i. To scale-up the detergent powder production from laboratory into pilot production using selected phosphate-free detergent formulation incorporated with palm C16MES
ii. To optimize the pilot spray drying process and gain the know-how for the production of palm C16MES incorporated laundry detergent powders
iii. To produce phosphate-free, detergency-stable and cost effective palm C16MES incorporated laundry detergent powders using ideal detergent formulation
iv. To ascertain Malaysian household consumers preferences and purchasing behaviour towards commercial laundry detergents with special focus on palm C16MES incorporated laundry detergent powders
v. To develop a commercialization strategy using Blue Ocean Strategy tools (Four Action Framework and Strategy Canvas) with the intention to visualize competitive differentiation and innovation opportunities for palm C16MES incorporated laundry detergent powders (OleoKleen)

1.4 Research Design

As research design is a key part in the dissertation process, a number of research questions were prepared prior to the development of the research methodologies. Based on the problem statements, the research questions for two categories (experimentation and pre-commercialization) were developed in order to guide the research process.

The research questions developed for the experimentation (laboratory and pilot scale studies) are as follows:

i. What would be the effects of detergent formulations comprising different ratios of C16MES:LABSA (at controlled pH between 7 – 8) on:

  a) detergent slurry concentration?
  b) detergency (initial and after prolonged storage period), foaming ability and wetting power of the resulting spray dried detergent powders?
  c) density, particle size distribution, surface morphology of the resulting spray dried detergent powders?
  d) detergent formulation cost?

ii. What would be the optimal ratio between C16MES and LABSA in the phosphate-free detergent formulation that can be used advantageously to produce detergency-stable and cost effective spray dried detergent powders?

The research questions developed for the pre-commercialization (pilot survey) are as follows:

i. What would be the preferences and purchasing behavior among Malaysian household consumers towards laundry detergents?
ii. What would be the acceptance level among Malaysian household consumers towards new palm C16MES incorporated laundry detergent products?

Based on the above research questions, a framework for the research program was designed. Figure 1.1 illustrates the flowchart of the research activities, which covered under this dissertation. The outcomes of these research activities were then integrated to develop the commercialization strategy for palm C16MES incorporated laundry detergent powders with respect to Blue Ocean Strategy (BOS).

<table>
<tr><th>EXPERIMENTATION – LABORATORY & PILOT SCALE</th><th>PRE-COMMERCIALIZATION (PILOT SURVEY)</th></tr>
<tr><td>- Raw Materials and Chemicals
- Laboratory & Pilot Scale Detergent Formulations
- Laboratory & Pilot Scale Preparation of Detergent Slurries
- Laboratory & Pilot Scale Preparation of Detergent Powders
- Detergent Slurry & Powder : Analysis and Characterization</td><td>- Survey Location
- Questionnaire Development</td></tr>
<tr><th>EXPERIMENTAL DATA ANALYSIS</th><th>PILOT SURVEY DATA ANALYSIS</th></tr>
<tr><td>LABORATORY SCALE
- Identification of a Suitable Phosphate-Free Base Detergent Formulation under different pH conditions
- Evaluation on Detergency: Before & After Accelerated Ageing Test

PILOT SCALE
- Selection of Appropriate Phosphate-Free Detergent Formulations
- Preparation of Detergent Slurries and Powders
- Evaluation on Detergent Slurry Concentrations
- Evaluation on Resulting Detergent Powders: Detergency, Foaming Ability & Wetting Power
- Comparison Among Detergent Powder Properties and Selection of the most suitable formulations
- Evaluation on Detergency Stability, Bulk Density, Particle Size & Surface Morphology
- Selection of Ideal Formulation
- Evaluation of Biodegradation, Eco-toxicity, Particle Flowability and Formulation Cost</td><td>- Respondents Demographic Characteristics
  - Gender, Age Group, Race, Education Level, Monthly Income
- Respondents Preferred Detergent Brand/Format/Origin
- Respondents Awareness/Knowledge on Use of Synthetic & Natural Based Actives in Laundry Detergent Products
- Respondents Awareness/Knowledge on Existence of Palm Based Methyl Ester Surfactants (MES)
- Respondents Perception on Palm MES Based Detergent Powders</td></tr>
<tr><th colspan="2">COMMERCIALIZATION STRATEGY FOR PALM C16MES INCORPORATED
LAUNDRY DETERGENT POWDERS (OLEOKLEEN)</th></tr>
<tr><td colspan="2">- Competitive Analysis of Leading Laundry Detergent Powder Manufacturers in Malaysia
- Value Innovation for OleoKleen (Four Action Framework - Eliminate, Reduce, Raise & Create Grid)
- Strategy Canvas for OleoKleen</td></tr>
</table>

Figure 1.1: Flowchart of the research activities

1.5 Research Significance and Benefits

In today's marketplace, the laundry detergent manufacturers are competing on features such as cost, green, eco-friendly and performance. In view of this, the research attempts to produce phosphate-free, detergency stable and cost effective LDDP by maximizing the green and eco-friendly palm based C16MES in the detergent formulation without deteriorating its cleaning performance and other significant properties. The findings of this research are expected to provide benefits not only to Pentamoden Sdn. Bhd. but also to the nation in general.

1.5.1 Pentamoden Sdn. Bhd.

Pentamoden Sdn. Bhd. is a subsidiary of Sun Jiang Trading Sdn. Bhd. Sun Jiang Sdn. Bhd. is a trading company located in Sg. Buloh, Selangor, Malaysia and specialized in the supply of household chemical products. This company, through a competitive analysis, had realized that research and development is a way forward for the company to excel in the household chemical business. The outcome of the competitive analysis has led Sun Jiang to setup Pentamoden Sdn. Bhd. where specific focus will be given on research activities leading to commercialization of green oleochemical based household chemicals. The company was setup in 2008 and the first research project undertaken by the new company is the development of palm C16MES incorporated laundry detergent powders. More details about the company and its commercialization strategies are given in Chapter 6.

1.5.2 Industry and Country

i. The palm oil industry is a significant contributor to the Malaysian economy and under the Palm Oil National Key Economic Areas (NKEA), eight entry point projects (EPP) has been identified. One of the EPP, EPP No. 6 was strategized to focus on high value palm oleo-derivatives.

C16MES is a palm based oleochemical derivative and its downstream products (such as detergents) are classified within this category. By 2020, the EPP initiative for value-added oleochemical derivatives is expected to generate an additional RM5.8 billion in gross national income and create 5,900 local jobs.

ii. The development of LDDP containing palm C16MES will make the local detergent industry less dependent on the petrochemical based anionic surfactant hence will reduce import and therefore more saving in foreign exchange.

iii. The locally produced palm C16MES can be used as surfactant in laundry detergent powder production.

iv. Phosphates, which have adverse environmental effects, can be totally eliminated from the laundry detergent formulation.

v. Marketing and exporting of LDDP containing palm C16MES to overseas would increase export trade of Malaysia.

vi. High quality human capital in the areas of research, development and production of surfactant and detergents can be produced.

1.6 Scope of Research and Limitations

The scope of this research is described below:

i. To perform laboratory scale studies using palm C16MES and linear alkyl benzene sulphonic acid (LABSA) in order to select appropriate phosphate-free detergent formulations for subsequent scale-up studies

ii. To setup pilot scale spray dryer and optimize the process conditions for the production of phosphate-free LDDP comprising palm C16MES and LABSA

iii. To identify suitable detergent formulations for pilot scale production and to evaluate the characteristics, cleaning performance and formulation cost of the resulting phosphate-free LDDP incorporated with palm C16MES

iv. To select an ideal pilot scale detergent formulation and followed by the evaluation on its environmental and powder properties
v. To analyze the preferences and purchasing behaviour among Malaysian consumers towards laundry detergents in general and particularly on palm C16MES incorporated laundry detergent powders
vi. To utilize Blue Ocean Strategy for commercialization of palm C16MES incorporated laundry detergent powders (OleoKleen)

The limitations of this research are as follows:

i. The experimental studies will be performed to determine the properties and characteristics of base laundry detergent powder, which formulated without the post mix ingredients
ii. Typical detergent formulation, which commonly used in the Asian region, will be utilized for LDDP production at both laboratory and pilot scales
iii. Consumer sampling for the pilot survey will be carried out in a particular shopping complex located in Kuala Lumpur city area

1.7 Structure of Dissertation

This dissertation is divided into seven chapters. Chapter 1 is the introductory chapter, which describes the research background, problem statements, objectives to be achieved, research significance and benefits, scope of research and the structure of the dissertation. Literature review in Chapter 2 presents mainly on the topics related to the development of laundry detergents. This chapter encompasses the history of detergents, detergent types and formats, unit operation for the production of laundry detergent powders, functions of detergent components, class of surfactants and more specifically on the history and development of oleochemical based MES. The chemistry, production process, processing plants, technologies, properties, economics, production capacity, application, environmental issues and consumer studies related to MES are also discussed.

Chapter 3 presents the research design methodology employed; quantitative experimentation and quantitative pilot survey. The quantitative experimentation, which performed at both laboratory and pilot scales, provides description on the materials, formulations, unit operations and test methods applied for analysis and characterization. The quantitative pilot survey, on the other hand, discusses on pre-commercialization studies. These include the sample preparation of MES incorporated laundry detergent powders, survey location and questionnaire development.

In Chapter 4, the laboratory and pilot scales experimental data are analyzed and discussed with respect to the effects of detergent formulations comprising different C16MES:LABSA ratios on cleaning performance and particle characteristics. This chapter also explains the criteria used in selecting the ideal phosphate-free detergent formulation and also analyzed the environmental test result and formulation cost calculation of the selected ideal formulation. Chapter 5 presents the analysis and discussion on the pilot survey, which mainly based on the information provided by the Malaysian household consumers through closed-end survey questionnaires.

Chapter 6 describes the commercialization strategy of Pentamoden Sdn. Bhd. with respect to Blue Ocean Strategy. This chapter also covers the competitive analysis of the company and the leading laundry detergent powder manufacturers in Malaysia. The new strategy goal and value innovation (ERRC - eliminate, reduce, raise and create; and strategy canvas) for commercialization of palm C16MES incorporated laundry detergent powders are also included in this chapter. The Chapter 7 concludes and summarizes the results and findings obtained from the previous chapters. This chapter also highlights contributions to the knowledge and industry besides giving recommendations for further study.

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