



**UNIVERSITI PUTRA MALAYSIA**

***OPTIMAL APPLICATION OF BIOSURFACTANT BY USING LINEAR  
PROGRAMMING (LP) MODEL***

**NAZIFA ATHIRAH BINTI MAT ZAKHI**

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**Optimal Application of Biosurfactant by using Linear Programming (LP)**

**Model**

**By**

**Nazifa Athirah binti Mat Zakhi**

**189661**

**Supervisor**

**Dr. Mohd Nazren Radzuan**

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## APPROVAL SHEET

This final year project report, entitled “Optimal Application of Biosurfactant by using Linear Programming (LP) Model” was prepared and submitted by Nazifa Athirah binti Mat Zakhi is partial to fulfilment of the requirement for the Bachelor of Agricultural and Biosystems Engineering.

..... Date:.....  


Dr. Mohd Nazren Radzuan

(Project Supervisor)

..... Date:.....

Assoc. Prof. Dr. Hasfalina Che Man

(Project Examiner I)

..... Date:.....

Dr. Mohamad Firdza Mohamad Shukery

(Project Examiner II)

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## LIST OF ABBREVIATIONS

**GAMS**

General Algebraic Modelling System

**LP**

Linear Programming



## LIST OF SYMBOLS

<b>I</b>	The type of biosurfactants
<b>(i, k)</b>	Price for biosurfactant
<b>K</b>	Application for biosurfactants in a product
<b>(b, k)</b>	Market price for biosurfactants application per liter
<b>C<sub>km</sub></b>	Market demand based on Malaysia population
<b>M</b>	Market for biosurfactants
<b>COST (i)</b>	Production cost for biosurfactants
<b>RCS (i)</b>	Resource of biosurfactants
<b>Con</b>	Constraints
<b>PROFIT</b>	Total profit for biosurfactant application

## LIST OF GREEKS

$\nabla$	All belong to
$\Sigma$	Summation



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**APPENDIX A**

The data coded into GAMS application

**APPENDIX B**

Results obtained from GAMS



## Abstract

In the generation of world industrialization, natural useful resource exploration has provided as a source of research and development for science and superior technology, leading to the manufacturing on the world market of products with high equity value, such as biosurfactants. Biosurfactants are amphiphilic microbial molecule that contains hydrophilic and hydrophobic that partition at liquid / liquid, liquid / gas or liquid / solid interfaces. Such characteristics of these biomolecules to play a key function in foam formation, detergence, emulsification, biopesticide and pharmaceutical which are acceptable aspect in a number of sectors. In addition to getting a strong advantageous effect on the major global issues, biosurfactant production performs a widespread function in establishing sustainable processes in the industry, such as the use of renewable resources and green products. Low toxicity and biodegradability have resulted in the escalation in scientific research on a broad range of industrial purposes for bioremediation biosurfactants as nicely as the oil, food processing, health, chemical, agricultural and cosmetic industries. This problem can be solved with the aid of developing a mathematical model that can determine the worthwhile products and biosurfactant-pathways that will give maximum profit to the biosurfactant application. There are eight stages of research methodology that will be employed in the improvement of the fine biosurfactant application. The model comprised of linear programming (LP) model that uses various equations to identify the most profitable application for biosurfactant.

## Abstrak

Dalam penajanaan industri perindustrian dunia, penerokaan sumber berguna yang semula jadi telah sebagai bekalan percubaan untuk sains dan teknologi unggul, yang membawa kepada pembuatan di pasaran dunia produk dengan nilai ekuiti yang tinggi, seperti biosurfaktan. Biosurfaktan adalah molekul mikrobiologi hidrofilik dan hidrofobik. Hidrofobik yang memisahkan cecair / cecair, cecair / gas atau cecair / pepejal antara dua lapisan. Ciri-ciri sedemikian membolehkan biomolekul ini memainkan fungsi utama dalam pengemulsi, pembentukan sabun, detergen, racun organik dan farmaseutikal yang boleh diterima dalam beberapa industri. Di samping mendapat kelebihan yang banyak ia turut memberi kesan kepada isu-isu global utama, pengeluaran biosurfaktan menjalankan fungsi yang meluas dalam mewujudkan proses perindustrian yang mampan, seperti penggunaan sumber yang boleh diperbaharui dan produk "hijau". Kadar toksik yang rendah telah menjadikan pengukuhan penyelidikan saintifik bagi pelbagai tujuan industri untuk biosurfaktan bioremediasi sebagai industri minyak, pemprosesan makanan, kesihatan, kimia, pertanian dan kosmetik. Masalah ini dapat diselesaikan dengan bantuan membangunkan model matematik yang dapat menentukan produk yang berfaedah dan laluan biosurfaktan yang akan memberikan keuntungan maksimum kepada aplikasi biosurfaktan. Terdapat lapan tahap metodologi penyelidikan yang akan digunakan dalam penambahbaikan aplikasi biosurfaktan yang baik. Model ini terdiri daripada model pengaturcaraan linear (LP) yang menggunakan pelbagai persamaan untuk mengenal pasti utiliti yang paling berfaedah untuk biosurfaktan.

# CHAPTER 1

## Introduction

### 1.1 Introduction

Biosurfactants are amphiphilic compounds produced by microorganisms such as bacteria, yeasts, and molds with indicating surface and emulsifying activities. The presence of hydrophobic and hydrophilic in biosurfactants confers these molecules the competency to accumulate between interfaces of multiple polarities like liquid/air, liquid/liquid, or liquid/solid interface and thereby has to lower interfacial and surface tension at the surface and interface regions, respectively (Karanth et.al., 1999). Surfactants that engender microbially are soluble in both natural (nonpolar) and aqueous (polar) solvents and relegated by their microbial inchoation and chemical composition. These biosurfactants include lipopeptides, glycolipids, fatty acids, phospholipids and neutral lipids (Saharan et al., 2012)

Kind of compound nature in biosurfactants are liable for its several properties and physiological functions which include growing the surface area and bioavailability of hydrophobic water-insoluble substrates, heavy metallic binding, bacterial pathogenesis, quorum sensing, and biofilm formation. these compounds may be synthesized thru the microorganisms developing on water-immiscible hydrocarbons as well as water-soluble compounds (Mukherjee et al., 2006). But optimization of the environmental situations and nutrient resources or use of

genetically altered microorganisms can also lead to elevated production of biosurfactants.

Numerous elements affect the producing of biosurfactants, which includes the character of the resources of carbon and nitrogen used as well as the presence of phosphorus, iron, manganese, and magnesium inside the middle of production. Further, different elements together with pH, temperature, agitation, and manner of carrying out the technique are fairly essential inside the volume and superb of biosurfactant produced (Ron and Rosenberg, 2001) .

Biosurfactants produced by way of microorganisms are turning into imperative biotechnology products for industrial and medical appliance because of their precise modes of motion, low toxicity, relative ease of preparation, and large applicability. They may be used as emulsifiers, de-emulsifiers, wetting and foaming advocates, functional food components, and as detergents in petroleum, petrochemical, environmental management, agrochemicals, foods and beverages, cosmetics and pharmaceuticals, and in mining and metallurgical industries. Surfactants moreover play an important function in more suitable oil healing with the resource of growing the apparent solubility of petroleum factors and effectively reducing the interfacial tensions of oil and water in situ. For clinical programs, biosurfactants are useful as antimicrobial retailers and immunomodulatory molecules (Roy, 2018) .

Mathematical modelling is a principal activity that has principles and methods behind it and can be used for a number of different reasons. For example, in sub- Saharan African, a complex mathematical model is derived to control the major threat to the food security. Simultaneously, this method can be performed to get the maximize profit in the most profitable biosurfactant application. There was

wide range application of biosurfactant. Mathematical optimization model was developed to help in determining the maximize profitability in biosurfactant application.

## **1.2 Problem Statement**

Biosurfactants have many advantages whilst as compared to their chemically synthesized, some of those are biodegradability, low toxicity, available of raw substances, physical factors that are biosurfactants are not stricken by environmental factors which include pH and power tolerance. Biosurfactants are produced by way of an expansion of a microorganism they may be secreted either extracellular or connected to elements of cells predominantly all through growth on water immiscible substrates. The composition and emulsifying action of the biosurfactant now not best relies upon at the producer strain but additionally on the lifestyle situations, for this reason, the nature of the carbon source, the nitrogen source in addition to the C: N ratio, dietary barriers, chemical and physical parameters which includes temperature, aeration, divalent cations, and pH have an effect on now not simplest the quantity of biosurfactant produced however also the kind of polymer produced. The capability application of biosurfactant is the role of biosurfactants in biodegradation strategies, biosurfactants and metals remediation, biosurfactants in the cosmetic industry, biosurfactants within the food industry, utility in medicine and application in agriculture. However, the excessive value of biosurfactant manufacturing and its low yields restriction its variety of commercial applications. This work consequently to identity method and the ability of biosurfactant applications that maximize profitability.

### **1.3 Research Question**

In order to design the sustainable biosurfactant application, research query must be addressed. The studies question of this study is as observe:

- 1) What is the potential of biosurfactant application in order to maximize profitability?

### **1.4 Research Objective**

The general objective of this research is to develop a new systematic framework to synthesize a maximize profitability application of biosurfactant by using structural-based optimization. The sub-objective is as follow:

- 1) To develop and optimize a mathematical model that can determine the profitable biosurfactant and application that will give maximum profit.

### **1.5 Scope of Research**

In order to achieve the intended research objectives, several scopes of the study have been identified as follows:

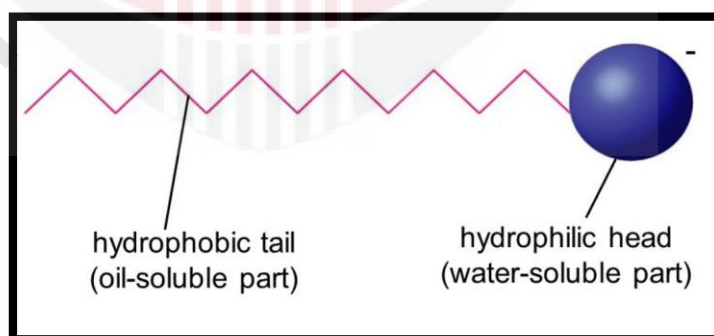
- 1) Literature review on the current and the state-of-the-art scenario on the biosurfactant application and potential enhancement were from worldwide journals.
- 2) The data input was extracted from previous study, which means that no direct data collection from the site.

## CHAPTER 2

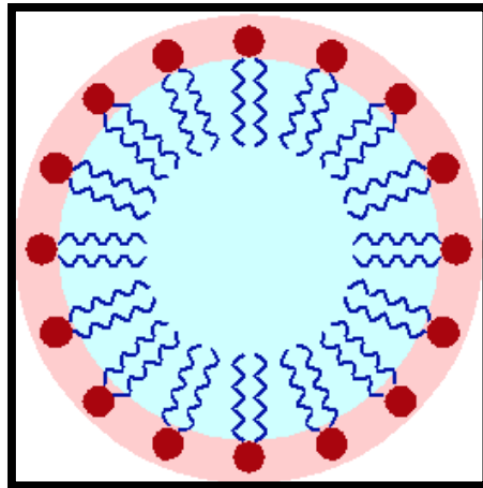
### Literature Review

#### 2.1 Surfactant

Surfactants are an amphipathic molecule with both hydrophilic and hydrophobic molecules, subdivision especially on the interface between fluid phases with various tiers of polarity and hydrogen bonding, along with oil and water, or air and water interfaces. The hydrophobic range is generally a hydrocarbon place while the hydrophilic space may be non-ionic, emphatic or counter-charged or amphoteric (Desai JD et al., 1997). growing the requested sub-atomic film on the interface reduces interfacial power (interfacial tension, IFT) and surface tension and is chargeable for one of the surfactant molecules type. Ethoxylates, ethylene, and propylene oxide copolymers and sorbitan esters are the maximum broadly identified non-ionic surfactants. Several natural particles are amphiphilic and parcel specifically at interphases. (Banat IM et al., 2000).



*Figure 2.1 Surfactant*



*Figure 2.2 Surfactant molecules*

## **2.2 Biosurfactant**

The biosurfactants a time period derived from the biological surface-active properties is a molecule of the destiny due to the several benefits over their chemical synthesized counterparts because of biodegradable and less toxicity and are high attribute at several temperatures or pH values and can be comprised of several less expensive waste substrates, thereby decreasing their production fee. Even though, no particular surfactant is suitable for all of the manageable applications. This makes very important to broaden even greater multifunctional biosurfactants to broaden the spectrum of properties available. The dropping economics of the biosurfactants production makes it greater vital for better and environment-friendly bioprocesses to lead them to competitive are unable to compete economically with the chemically synthesized compounds inside the marketplace, because of excessive production costs. This is due to inefficient bioprocessing methodology to be had, terrible strain productiveness and use expansive substrates (Singh p, 2004).

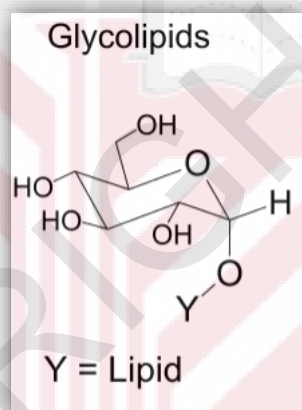
## 2.3 Types of Biosurfactant

### 2.3.1 Glycolipids

Most of the biosurfactants which can be well-known produce glycolipids. They are created from sugars with long-chain of acyclic acids or hydroxyaliphatic acids. The affiliation is by means of strategies for both ether or natural compound congregation.

The simplest famous glycolipids are rhamnolipids, sophorolipids, and trehalolipids.

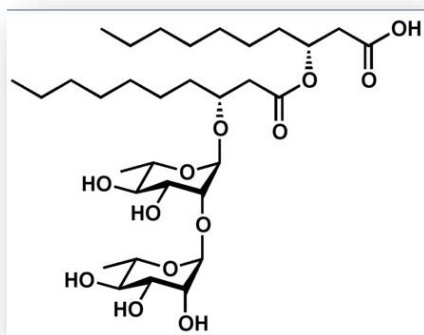
Figure 2.3 shows the chemical structure of glycolipids.



*Figure 2.3: Chemical structure of glycolipids*

### 2.3.2 Rhamnolipids

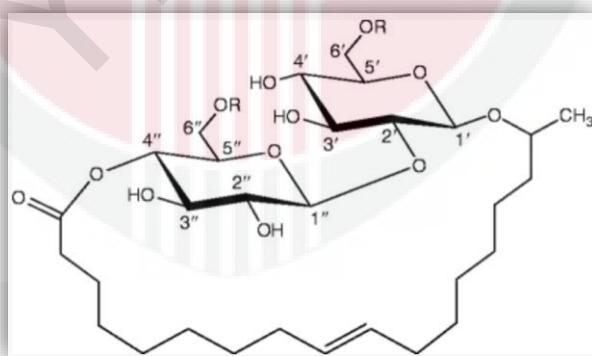
Rhamnolipids are the glycolipids inside which one or two molecules of rhamnose are coupled to 1 or more molecules of hydroxydecanoic acid. Figure 2.4 shows the chemical structure of rhamnolipids. It is miles the huge studied biosurfactant which might be the predominant glycolipids produced via *P. aeruginosa*.



*Figure 2.4: Chemical structure of rhamnolipids*

### 2.3.3 Sophorolipids

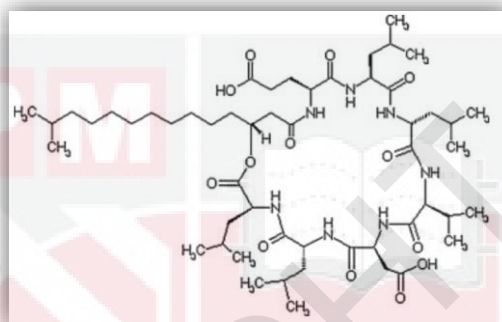
Those are glycolipids that are made by using yeasts and carries a dimeric saccharide sophorose joined to an extended-chain chemical institution fatty acid by glycosidic linkage. Sophorolipids, usually a mixture of at least six to nine totally special hydrophobic sophorolipids and lactone kind of the sophorolipid is desired for several applications. The discern shows the chemical structure of sophorolipids. Figure 2.5 suggests the chemical structure of sophorolipids.



*Figure 2.5: Chemical structure of Sophorolipids*

### 2.3.4 Surfactin

That is a standout among the most ability of biosurfactant is integrated by using *Bacillus subtilis*. It is miles constituted of a seven amino corrosive ring structure joined to associate unsaturated fat chain via strategies for lactone linkage. Figure 2.6 shows a structural of the surfactin molecule.



*Figure 2.6: Structural of the surfactin molecule*

### 2.4 Biosurfactant Production

Biosurfactants are typically produced extracellularly or as the segment of the cellular membrane by means of yeast, bacteria or filamentous fungi. Maximum of such microorganism used are isolated from infected normally containing petroleum hydrocarbon with the aid of products and/or commercial wastes (Rahman et al., 2006). Table 2.4 shows the biosurfactant magnificence and microorganisms to produce this form of biosurfactants.

Table 2.4: Biosurfactants class and microorganisms to produce biosurfactants

Biosurfactant class	Microorganism
Rhamnolipids	<i>P. aeruginosa</i> and <i>P. putida</i>
	<i>P. chlororaphis</i>
	<i>Bacillus subtilis</i>
	<i>Renibacterium salmoninarum</i>
Sophorolipids	<i>Candida bombicola</i> and <i>C.apicola</i>
Surfactin	<i>Bacillus subtilis</i>

#### 2.4.1 Factors affecting biosurfactant production

A selection of factors has an impact on the manufacturing of biosurfactants. These factors consist of environmental elements in addition to a source of carbon substrate among others.

##### 2.4.1.2 Environmental factors

Biosurfactant production like any exceptional chemical reaction is affected with the resource of some of factors that both enlarge its productivity or inhibit it. For this reason, environmental factors along with pH, salinity, and temperature have an effect on biosurfactant manufacturing (Rahman et al., 2002b). Desai and Banat (1997) moreover verify the truth that environmental factors and growth situations which include pH, temperature, agitation and oxygen availability additionally affect biosurfactant production via their results on cellular increase or activity.

### **2.4.1.3 Carbon substrates for biosurfactant production**

Some of the carbon substrates were used in lots of kinds of research all through biosurfactant manufacturing. Certainly, the kind, exceptional, and quantity of biosurfactant manufacturing are affected and inspired by the character of the carbon substrate (Singer, 1985; Raza et al., 2007). Diesel and crude oil have been recognized to be applicable resources of carbon for biosurfactant production by using organisms. Other water-soluble compounds such as glucose, sucrose, and glycerol have additionally been said to be a supply of carbon substrate for biosurfactant manufacturing (Desai and Banat, 1997; Rahman et al., 2002a).

### **2.4.1.4 Estimation of biosurfactant activity**

This includes measuring the adjustments in surface and interfacial tensions, stabilization/destabilization of emulsions and hydrophilic-lipophilic stability (HLB). The surface tension of distilled water is stated to be  $72 \text{ mN}\cdot\text{m}^{-1}$  and addition of biosurfactant lowers it to as low as  $28 \text{ mN}\cdot\text{m}^{-1}$  (Rahman et al., 2006). Hence, together with a biosurfactant to water reduces its surface tension to an essential degree above which amphiphilic molecules simply shape supramolecular structures like micelles, bilayers, and vesicles seemed as Critical Micelle Concentration (CMC). CMC is consequently described as the ability of a biosurfactant internal an aqueous phase and is commonly used to measure the efficiency of a biosurfactant (Desai and Banat, 1997).

## **2.5 Biosurfactant Classification and Characteristics**

Many micro-organisms are capable of generating surface molecules. Microorganisms produce foremost varieties of surface-active compounds: biosurfactants and bio emulsifiers. Biosurfactants appreciably reduce the surface tension of air-water at the same time as for bio emulsifiers not decrease the surface anxiety however stabilize the emulsions of oil in water. Over the previous many years, there was a growing interest in keeping apart microorganisms that produce surface-active molecules with specific surfactant traits along with low CMC and excessive emulsification interest, with low toxicity and suitable biodegradability at the equal time (Rosenbergh E, 2007). Biosurfactants are basically categorized consistent with their microbial starting place and chemical composition. Lipopeptides are one of the major classes of biosurfactants, at the whole, centered on the latest engineering procedures because of the fact of their unique properties in surface activity and the ability for antibiotics. (The Dekel S, 2001)

### **2.5.1 Biosurfactant Properties**

The precise characteristics of biosurfactants in evaluation with their chemically synthesized surfactants and their huge availability of substrates made them appropriate for commercial use. The exceptional traits of microbial surfactants are related to their surface activity, pH tolerance, temperature, and ionic energy, biodegradability, low toxicity, emulsifying and antimicrobial (Sarubbo, 2014). The important thing characteristics of every biosurfactant assets are referred below.

### **2.5.1.1 Surface and interface activity**

Surfactant facilitates in reducing surface tension and interfacial tension. Surfactin produced by using *B. subtilis* can lower the surface tension of water to twenty-five  $\text{mN m}^{-1}$  and interfacial tension water/hexadecane to a whole lot much less than 1  $\text{mN m}^{-1}$ . The rhamnolipids produced by *P. aeruginosa* reduced the surface tension of water to 26  $\text{mN m}^{-1}$  and interfacial tension of water/hexadecane to a lower value which is less than 1  $\text{mN m}^{-1}$  (Cooper et., al 1981). In general, biosurfactants are more effective and environment-friendly and their Critical Micelle Concentration (CMC) is ready numerous times lower than chemical surfactants, i.e., for maximal lower on surface tension, much less surfactant is requisite (Desai and Banat, 1997).

### **2.5.1.2 Temperature and pH tolerance**

McInerney et al. (1990) stated that lichenysin from *Bacillus licheniformis* used to be located to be proof against temperature up to  $50^{\circ}\text{C}$ , pH between 4.5 and 9.0 and NaCl and Ca concentrations up to 50 and 25  $\text{g L}^{-1}$ , respectively. On account that, commercial approaches contain publicity to extremes of temperature, pH and pressure, its miles vital to isolate novel microbial products that able to function below those prerequisites (Cameotra and Makkar, 2004).

### **2.5.1.3 Biodegradability**

Microbial-derived compounds may be effortlessly degraded whilst compared to chemically synthesized surfactants and are appropriate for an environmental appliance such as bioremediation/biosorption (Mulligan et al., 2001). The growing environmental concern forces to search for alternative products together with

biosurfactants (Cameotra and Makkar, 2004). Chemically synthesized surfactants impose to environmental problems and hence, biodegradable biosurfactants from marine microorganisms were concerned for the biosorption of poorly soluble polycyclic aromatic hydrocarbon, phenanthrene contaminated in aquatic surfaces (Olivera et al., 2003). Lee et al. (2008) controlled the blooms of marine algae, *Cochlodinium* the use of the biodegradable biosurfactant sophorolipid with the elimination efficiency of 90% in 30 min treatment.

#### **2.5.1.4 Low toxicity**

Biosurfactants, they are commonly regarded low or non-poisonous products and are suitable for pharmaceutical, beauty and meals use. Flasz et al. (1998) in comparison the toxicity and mutagenicity profile of biosurfactant from *Pseudomonas aeruginosa* and chemically derived surfactants and indicated the biosurfactant as non-toxic and non-mutagenic. The low toxicity profile of biosurfactant, sophorolipids from *Candida bombicola* made them beneficial in food industries.

#### **2.5.1.5 Emulsion forming and emulsion breaking**

Biosurfactants may additionally act as emulsifiers or de-emulsifiers. An emulsion may be described as a heterogeneous system, consisting of one immiscible liquid dispersed in some other in the structure of droplets, whose diameter, in trendy, exceeds 0.1 mm. Emulsions are generally two types which are oil-in-water (o/w) or water-in-oil (w/o) emulsions. They possess minimum stability which may additionally be stabilized through additives inclusive of biosurfactants and may be maintained as consistent emulsions for months to years. Liposan is a water-soluble

emulsifier synthesized through *Candida lipolytica* which have been used to emulsify consumption oils with the useful resource of coating droplets of oil, therefore forming relaxed emulsions and were often utilized in cosmetics and meals industries for making oil/water emulsions for making steady emulsions (Velikonja and Kosaric, 1993).

#### **2.5.1.6 Antiadhesive agents**

A biofilm can be defined as a group of microorganism/another natural count that has colonized/amassed on any surface (Hood and Zottola, 1995). Step one on biofilm establishment is bacterial adherence over the surface was affected through a quite more than a few of things which encompass the sort of microorganism, hydrophobicity and electrical expenses of a surface, environmental conditions and potential of microorganisms to provide extracellular polymers that assist cells to anchor to surfaces (Zottola, 1994).

## 2.6 Application of Biosurfactant

### 2.6.1 Biosurfactant Application in Cleaning product

Almost all surfactants are chemically produced and exert resistance to freshwater residing organisms, an enormous detail used in cutting-edge industrial washing detergents. Furthermore, those elements regularly generate unwanted effects. therefore, there may be growing government difficulty about the economic hazards and dangers connected with chemical surfactants in washing detergents. A recent have a look shows that cyclic lipopeptide (CLP) biosurfactants produced by *B. subtilis* traces had been stable over a pH variety of 7.0-12.0 and heating them at 80°C for 60 min did no longer result in any loss of their surface-active equity (Shaligram and Singhal, 2010) Crude CLP biosurfactants confirmed prosperity emulsion formation functionality with vegetable oils and verified accomplished compatibility and balance with industrial laundry detergents favoring their inclusion in laundry detergents formulations (Shaligram and Singhal, 2010)



*Figure 2.7: Cleaning product in industry*

## 2.6.2 Biosurfactant Application in Food Industry

Chemically synthesized surfactants had been used in food formulations, but chemically synthetic surfactants have problems inclusive of allegations of toxicity, their chemical nature, and are nonbiodegradable. Biosurfactants have most excellent traits for incorporation in food and cosmetic formulations, inclusive of reduction of surface tension and their emulsification capability in particular, especially suitable for edible oil emulsification. Biosurfactants as biocompatible, biodegradable, and/or nontoxic compounds have the compounding of a particular function that well-known shows a selection of the beneficial area for the food manufacturer, especially as emulsifiers, foaming, wetting, solubilizers (Banat et al. 2000), antiadhesive, and antimicrobial (Singh and Cameotra 2004).



*Figure 2.8: Food emulsifiers*

### 2.6.2.1 Food emulsifiers

Biosurfactants display numerous equities in conjunction with emulsion-primarily based on formulations that have tremendous potential appliance in many fields of the food industry. An emulsion is a heterogeneous device, along with at least one immiscible liquid in detail dispersed in some other inside the shape of droplets,

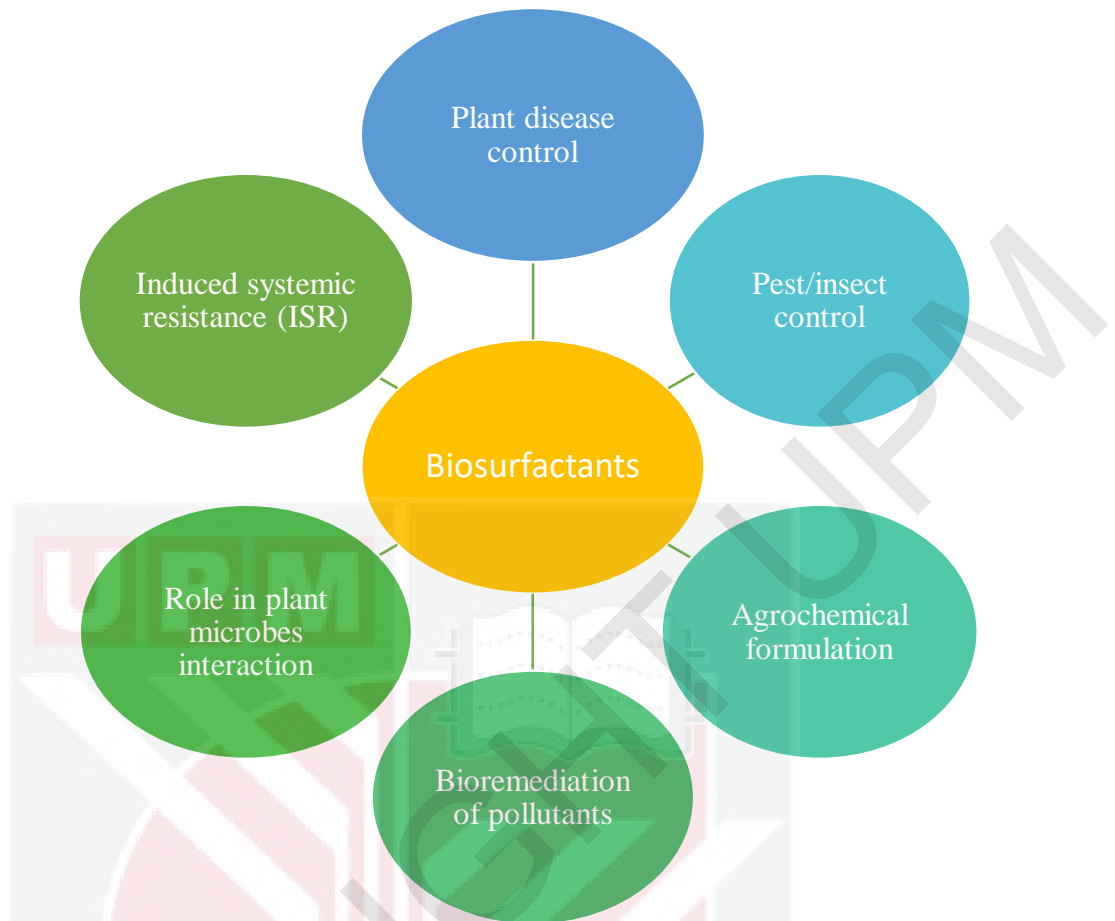
having dispersed and continuous segment. The addition of emulsifiers is of low cost for low-fats production (Rosenberg and Ron 1999) as it improves the feel and creaminess of dairy products. However, polymeric surfactants coat the droplets of oil and form very stable emulsions that nevermore coalesce. This property is, especially, useful for making oil/water emulsions for cosmetics and food.

### **2.6.2.2 Food Stabilizer**

Biosurfactants act as controlling consistency in bakery products and ice cream formulations. They are also have been applied as a fat stabilizer and anti-spattering agent at some stage in cooking of oil and fat. In meals processing, the addition of rhamnolipid surfactants improves the texture and self-existence of starch-containing products, modifies rheological properties and stability of wheat dough. Surfactants can also be used to govern the agglomeration of fats globules, stabilize aerated structures, and texture of fat-based definitely products). L-Rhamnose, which already has an industrial appliance as a precursor of incredible taste components like Furaneol (trademark of Firmenich SA, Geneva), is received by way of manner of hydrolyzing rhamnolipid surfactants produced thru *P. aeruginosa* (Banat et al., 2000)

### **2.6.3 Biosurfactant Application in Agriculture**

A number of the many thrilling properties of biosurfactants, some are of specific interest and use in agriculture together with emulsification, foaming, dispersion, wetting, penetration, thickening, microbial growth enhancement and sequestration properties. Figure 2.9 shows the potential application of biosurfactants in agricultural fields.



*Figure 2.9: Areas of potential applications of biosurfactants in agriculture*

Surfactants are must as adjuvant with fungicides, insecticides, and herbicides. The synthetic surfactant nowadays utilized in insecticides industries act as emulsifying, dispersing, spreading and wetting agent and enhance the efficiency of pesticides. Similarly, those surfactants are used in insecticides in current agriculture as those have defensive properties. Specific varieties of surfactants which include anionic, cationic, amphoteric, and non- ionic are currently being used at numerous pesticide manufacturing industries (Sachdev and Cameotra, 2013).

Accordingly, surfactants are widely used within the formulation of insecticides.

However, it is necessary to be aware that the surfactant found in insecticides formulations in getting entry to becomes gathered in soil and affects the texture,

shade, and growth of the plant. Those dangerous insecticides additionally grow to be leached from soil to the groundwater. Pesticide residues are known to persist for years in soil and unfold in air and water. These even continue to be at the surface of fruit and vegetables. Similarly, the chemically synthesized surfactants are considered as robust organic pollution in soil (Roy, 2018). Considering the adverse effect of pesticides and surfactants related to the insecticides, there may need to be applied the environmentally safe biosurfactants to replace these dangerous surfactants inside the million-dollar pesticide industries hence preventing the pollutions (Makkar et al., 2011).

Research related to the exploration of soil bacteria that may utilize the chemical surfactant in agriculture soil as a carbon supply can be another alternative to this environmental problem. There is an issue on bacteria belonging to *Pseudomonas* sp. and *Burkholderia* sp. from the paddy field to degrade surfactants (Shaligram and Singhal, 2010).

Agriculture crucial products like pesticides shaped with the assistance of biosurfactant can be widely used in agricultural fields. The need for agrochemical industries is to develop a powerful method and to attain this aim; many corporations can rent an aggregate of biosurfactants in one of a kind combination with the polymers to make great formulations for agricultural applications.

#### **2.6.3.1 Biosurfactant as a pesticide control**

In agriculture manufacturing, numerous insecticides were used for protection in opposition to plant diseases and insect pests with the result, those chemicals persist for an extended duration in culmination and veggies which inflicting harm to humans. The situation over the pesticide residues in fruits and vegetables have

brought about the improvement of many easy up and evaluation techniques. Biosurfactants are amphiphilic compounds produced through microorganisms, which incorporate every hydrophobic and hydrophilic moiety that confer the capability to accumulate amongst fluid degrees, hence lowering surface and interfacial tension on the surface and interfacial respectively. In evaluation to their chemically synthesized surfactants, biosurfactants have many advantages, environmentally friendly, biodegradable, a great deal much less poisonous and non-dangerous. They have got higher foaming properties and better selectivity, energetic at high temperature, pH and salinity as properly and can be made from agro-industrial by-products (Cunha et al., 2004)



Figure 2.10: Pesticides control product

## 2.7 Market for Biosurfactant

The worldwide demand for biosurfactants is estimated at USD 4.20 trillion in 2017 and is expected to achieve USD 5.52 trillion by 2022, at a CAGR of 5.6 percent over the forecast era. The growing demand for green alternatives mainly in private care and home care sectors is anticipated to fuel the development of the worldwide industry for biosurfactants. The worldwide biosurfactants industry was segmented into glycolipids and lipopeptides based on type. Due to greater purity

concentrations and improved functionality, the sophorolipids, rhamnolipids, lipopeptides and surfactin is expected to develop at a greater CAGR. These type of biosurfactants are widely used in application for industrial chemicals, pharmaceutical, and private care. Based on implementation, the worldwide market for biosurfactants has been segmented into detergents, private care, food processing, industrial chemicals, and others. The implementation of detergents represents a major requirement for biosurfactants as home care is the biggest sector using surfactants.

## **2.8 General Algebraic Modeling System (GAMS)**

General Algebraic Modelling System (GAMS) is used as the research tool in this research. This research mainly deals with optimization problems and thus, GAMS is high suitable as GAMS has incorporated ideas drawn from relational database theory and mathematical programming and has attempted to merge these ideas to suit the needs of strategic modelers. It is specifically designed for modeling linear, nonlinear and mixed integer optimization problems which is especially useful with large, and complex problems. Over the years, GAMS had been widely used to solve optimization problem throughout the world and thus, is proven useful for handling large and complex problems which may require many revisions to establish an accurate model. As the software is also incorporate with many types of solver, it is also convenient for the user to change between solvers (General Algebraic Modeling System, 2011).

## CHAPTER 3

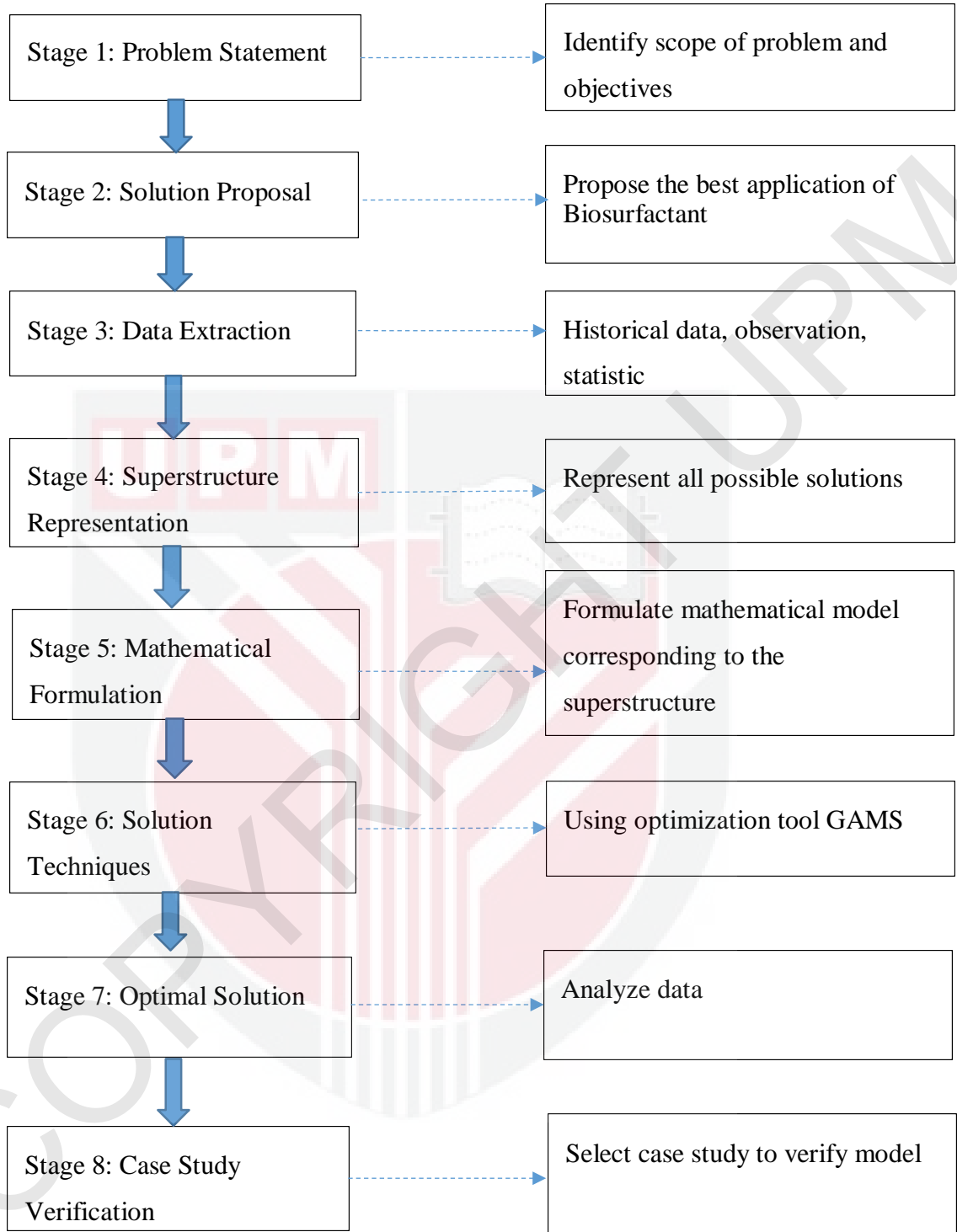
### METHODOLOGY

#### 3.1 Concept of Optimization Model of Biosurfactant

Surfactants are one of the most versatile group of chemicals used in different processes of industry. Surfactants are widely used for industrial, agricultural, food pharmaceutical application but most of these compounds are synthesized chemically and potential to cause environmental problem and toxicity to the environment. Their market is competitive, and producers will need to expand their production of surfactants in an environmentally friendly and cost-effective manner. Increasing interest in biosurfactants has led to intense research to produce biosurfactant environmentally friendly and cost-effectively. Biosurfactants structural diversity and functional properties make them an attractive group of compounds for potential use in a wide range of industrial, environmental and biotechnological applications. There are lot applications of biosurfactant in industry. But these mathematical model is developing to know the best selection of biosurfactant. Methods of screening make it easier to obtain potential microorganism-producing biosurfactant and this mathematical model was used to obtain the most profitable biosurfactant such as sophorolipids, rhamnolipids, lipopeptides and surfactin for industrial application in a cleaning, emulsifiers and biopesticides product.

### 3.2 Research Methodology

There are eight stages of research methodology that was employed in the development of biosurfactant application model. In Stage 1, the problem is identified as stated in Chapter 2 through literature review, articles, current issues and other sources. For the next step, Stage 2, this model is proposed as a solution for problems that have been identified in the earlier stage. Stage 3, data related to the solution was acquired via reported data, historical data and statistic. Thereafter, superstructure diagram was presented to view all possible options for solution in Stage 4. Mathematical model corresponding to the superstructure functions to formulate the equations and GAMS 27.2.0 version is used as the optimization tool to apply the solutions techniques in Stage 5 and Stage 6 respectively. Once the optimal solution is achieved in Stage 7, data analysis was performed to draw a conclusion. In Stage 8, a case study. Figure 3.2 shows the flowchart of the research methodology used in this research.

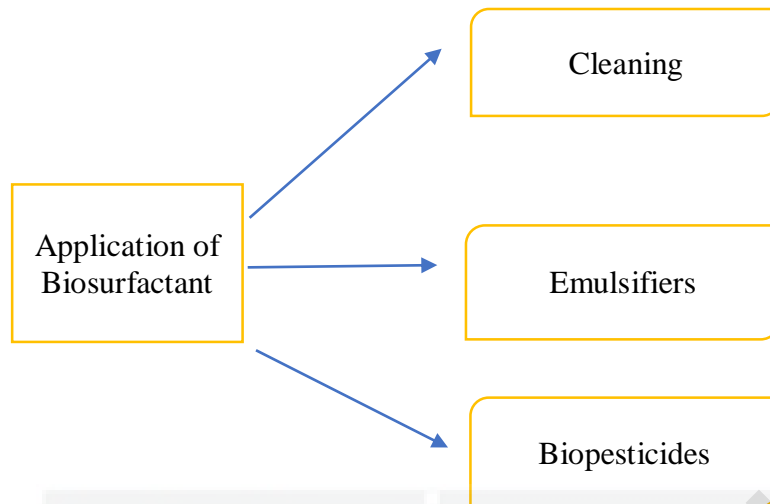


### 3.3 Mathematical Model Generation

Mathematical model is formulated based on simplified superstructure diagram generated. In this study, the mathematical model developed aims to know the best application of biosurfactant as discussed in Chapter 4. The developed linear programming model (LP) is able to identify the most profitable routes for biosurfactant applications. Table 3.1 shows the phase of Optimization model of biosurfactant while Figure 3.3 indicates the structure diagram to show the biosurfactant application in industry.

*Table 3.1: Development phase of Biosurfactant Optimization model*

<b>Phase</b>	Selection of biosurfactant
<b>Objective Function</b>	To know the most profitable biosurfactant and the best application of biosurfactant
<b>Decision variable</b>	Type of biosurfactants, market price and application
<b>Constraint</b>	Biosurfactant application in industry
<b>Model</b>	LP model



*Figure 3.2: Structure diagram that shows the Application of Biosurfactant*

### **3.4 Case Study and Input Data**

The case study of this research is selected by the numerous uses of the biosurfactant types, price of biosurfactant per liter, application of biosurfactant in a product and market demand for biosurfactant. The data is from below:

There are various biosurfactant classes with different microorganisms' production. This study chooses four different types of biosurfactant. Price/Liter for the selected biosurfactants was taken from the current market price. Price for biosurfactants per liter was shows in table 3.2.

In the global surfactant market, the most uses application for surfactant in a product is in a cleaning product, emulsifiers in food industry and biopesticides in pesticides industry. The product is usually using in daily product such as shampoo, detergents, bakery products and for agricultural used. The data for application of biosurfactants

was coded into GAMS application to meet the best profitable application for biosurfactants. The data for biosurfactant application is was obtain as the table 3.3.

Table 3.4 below shows the market demand for biosurfactant based on Malaysia population. The total global market for cleaning, emulsifiers and biopesticides for global population time Malaysian population to meet the amount of biosurfactants that have been used in Malaysia. The data for market demand for Malaysia population is obtained from data below:

<b>Biosurfactant</b>	<b>Price/Liter</b>	<b>References</b>
Sophorolipids	RM 83	Qingdao Fraken International Trading Co., Ltd.
Rhamnolipids	RM 4150	Qingdao Ocean Import and Export Co., Ltd.
Surfactin	RM 18	Pangoos Biotech Haboi Co., Ltd.
Lipopeptides	RM 40	Shandong Zhishang Chemical Co., Ltd.

*Table 3.2: Price for biosurfactants per /liter*

<b>Application</b>	<b>References</b>
Cleaning	On surfactants and formulation (face wash, shampoo and shower gels)
Emulsifiers	Surfactants: Basics and versatility in food industries
Biopesticides	Pesticides in the industry

*Table 3.3: Application for biosurfactant in a product*

<b>Application</b>	<b>Market Demand (RM)</b>	<b>References</b>
Cleaning	6.3 B	Global household cleaning products market 2018-2022
Emulsifiers	2.52 B	Global Market Study on Emulsifiers: Food & Beverage Application to witness significant growth during 2017-2024
Biopesticides	2.68 B	Biopesticides market by type (Bio insecticides, Bio fungicides, and Bio nematicides), source (Microbials, Plant Extracts, and Benefial insects), Mode of Application, Formulation, crop application and region-global forecast to 2023

*Table 3.4: Market demand for biosurfactant based on Malaysia population*

### 3.4 Coded into General Algebraic Modelling System

Process optimization is a decision-making tool to identify the solution that achieves the best value of performance criterion in a problem. In this stage, the developed mathematical formula is coded into Generalized Algebraic Modelling System (GAMS) as an optimization tool. GAMS is a commercial software for modelling linear, nonlinear and mixed integer optimization software. The incorporated model is then solved by the GAMS solver to obtain optimal network flow. GAMS is used based on several functions included:

- 1) Use algebraically based high-level language for representing large and complex models.
- 2) Simple and understandable coding that allows user to formulate and change specifications easily.
- 3) Provide a scalable modelling environment where verified small data set can be expanded to a large data set, due to subscript based expandability.
- 4) An open system that allows user to select the solver to solve the problem and incorporate newly available solvers to the system.

The coded GAMS input files for the developed models are presented in the Appendix Section.

## CHAPTER 4

### RESULT AND DISCUSSION

#### 4.1 Introduction

This chapter focused on the model development to maximize profitability of biosurfactant application in the industry. The biosurfactant information include their price, amount biosurfactant required in the product, application and market demand is formulated to maximize profit by identifying the most profitable biosurfactant application. The model also expenses profit generation for every type of biosurfactant. The developed model is coded into Generalize Algebraic Modelling System (GAMS) as optimization tool. The coding is formulated to identified the best biosurfactant and application methods that will maximize the profit to the biosurfactant industry. In Malaysia, the biosurfactant industry is still not commercialized due to high production rates and no awareness of the importance of the neutral use of materials to the environment. This mathematical model formulation can help to know the highest profit with low cost of production for different types of biosurfactant.

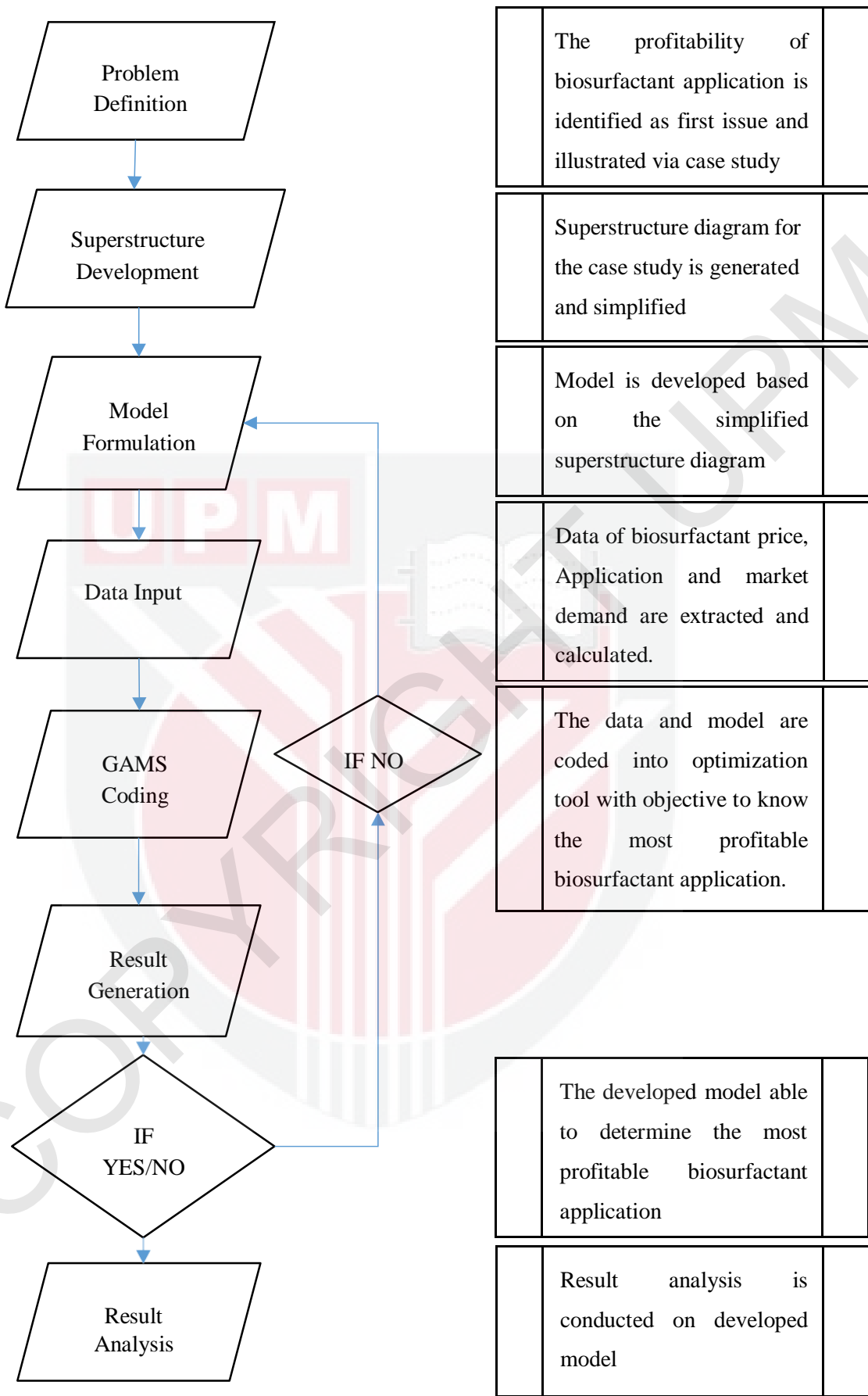


Figure 4.1: Methodology flowcharts for most profitable biosurfactant application

## 4.2 Problem Definition and Assumption

There are many types of biosurfactant nowadays. The types of biosurfactant include sophorolipids, Rhamnolipids, Lipopeptides and surfactin. However, the various generation of biosurfactant will not sustain for different type applications for biosurfactant. A most profitable biosurfactant application that can maximize profit need to be determine.

## 4.3 Superstructure development

The superstructure diagram comprises of three sets, which are a set a type for type of biosurfactant, set b-types for biosurfactant application and set-c types is market demand for biosurfactant. The superstructure of the biosurfactant types, applications and market demand as follow:

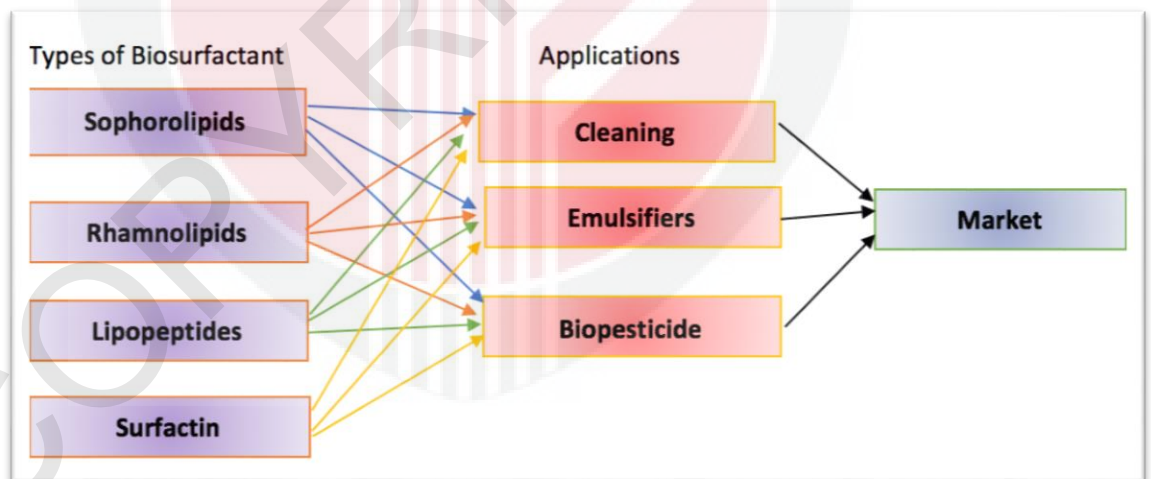


Figure 4.2: Superstructure diagram of the Biosurfactant

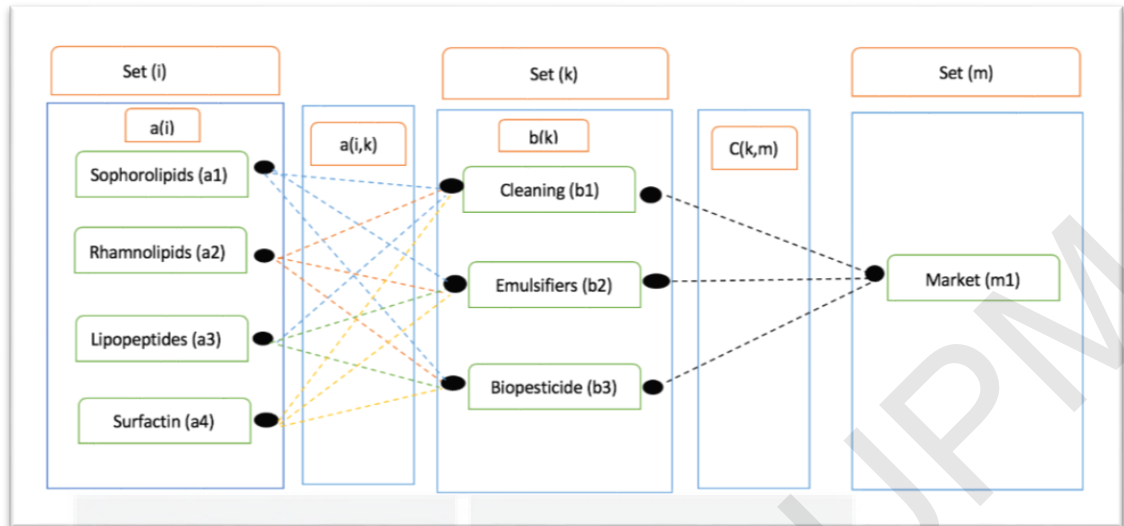


Figure 4.3: Simplified structure of Biosurfactant

#### 4.4 Model Formulation

Based on the simplified superstructure, the optimization problem is identified as follow:

##### 4.41 Objective Function

This objective function is describing the model that developed for this case study. The objective function for this study is to maximize the overall profit of biosurfactant application, represented by variable MAIN PROFIT as shown in equation 4.1. The variable  $k_m$  is the market price for application and  $C_{km}$  is the market demand for the product. The variable  $COST(i)$  is the price for biosurfactants. The variables are calculated when the summation of the product obtained multiplied by the price per liter for biosurfactants.

$$\text{MAIN PROFIT} = (\sum_{km} C_{km} \times \text{PRICE}(m)) - (\sum_{ik} a_{ik} \times \text{COST}(i)) \quad (4.1)$$

#### 4.4.2 Material Balance Constraints

In this model, the material balance constraints mainly consist of price for biosurfactants, application of biosurfactants in a product and market demand for biosurfactants which is only focus on the most profitable biosurfactants application. Equation 4.2 is developed to limit the type of biosurfactants which is only focus on the most valuable biosurfactant used in the industry. Equation 4.3 shows the type of application where the biosurfactant is used in the product. Equation 4.4 is when the application of biosurfactant in a product is met by the market demand for each type of application and product. Equation 4.5 is considered to calculate the total profit which consist of biosurfactants market price, application and market demand.

$$RCS(i) \geq \sum_k a(i, k) \times \nabla i \quad (4.2)$$

$$b_k = \sum_i a_{ik} \nabla k \quad (4.3)$$

$$b_k \times Con_{km} = C_{km} \quad (4.4)$$

$$C_{km} \geq demand(k, m) \quad \nabla k \quad \nabla m \quad (4.5)$$

#### 4.5 Overall profitable biosurfactant application

The maximum profit that can be achieved by biosurfactant application in the industries is RM 1M MYR. The type of biosurfactant that will give maximum profit for the the industries is *Lipopeptides* biosurfactant which is the profit that will gain from cleaning and emulsifiers application. Cleaning products shows high value which is 0.74 M compare to emulsifiers. Based on this mathematical model, it shows that market demand for cleaning product is higher as home care is the largest

industry that use surfactants in a cleaning product. Biosurfactants demonstrate improved characteristics in terms of removing hydrophilic stains, optimum efficiency under neutral conditions and easy degradability relative to chemical surfactants. Based on the figure 4.4 the model mainly selected Sophorolipids, Lipopeptides and Surfactin biosurfactants because the price for this type of biosurfactants is cheaper than Rhamnolipids biosurfactants. All types of biosurfactants can be applied for cleaning, Emulsifiers and Biopesticides product but the model will only select the most valuable cost production for biosurfactants to meet the objective function. Based on the figure, the sophorolipids biosurfactant only suitable to use for emulsifiers because the high demand for emulsifiers, Lipopeptides biosurfactant choose cleaning and biopesticides in term of price for biosurfactant and market demand and surfactin also choose cleaning and biopesticides because this type of biosurfactant meet what the model need.

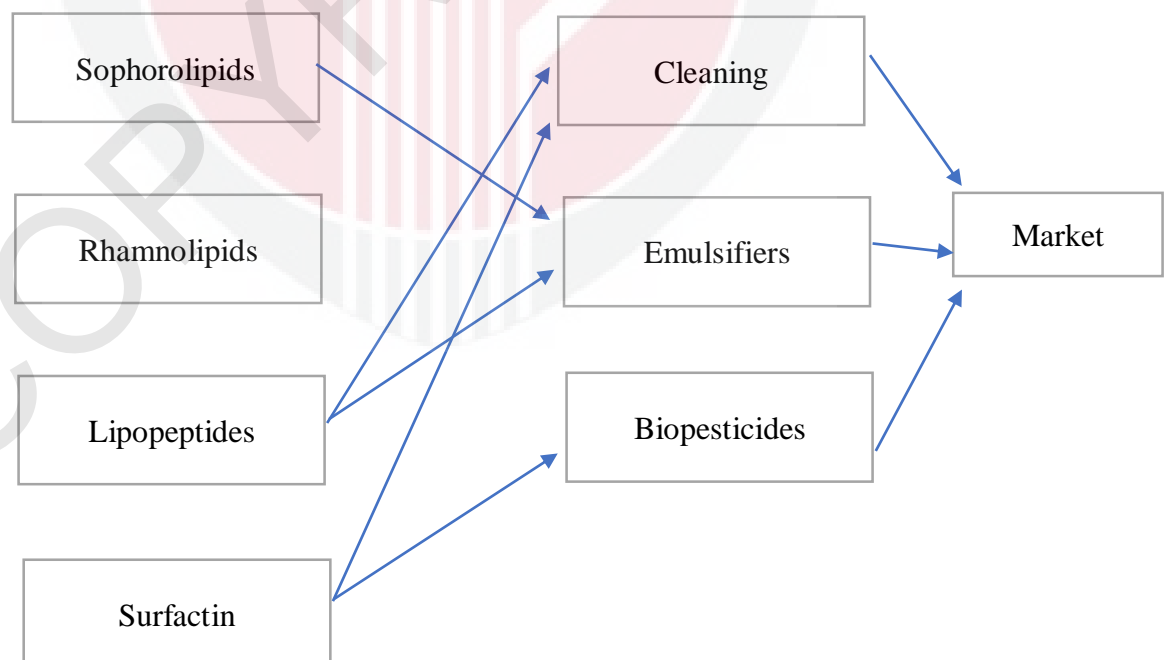


Figure 4.4: Results obtained from most profitable biosurfactant model

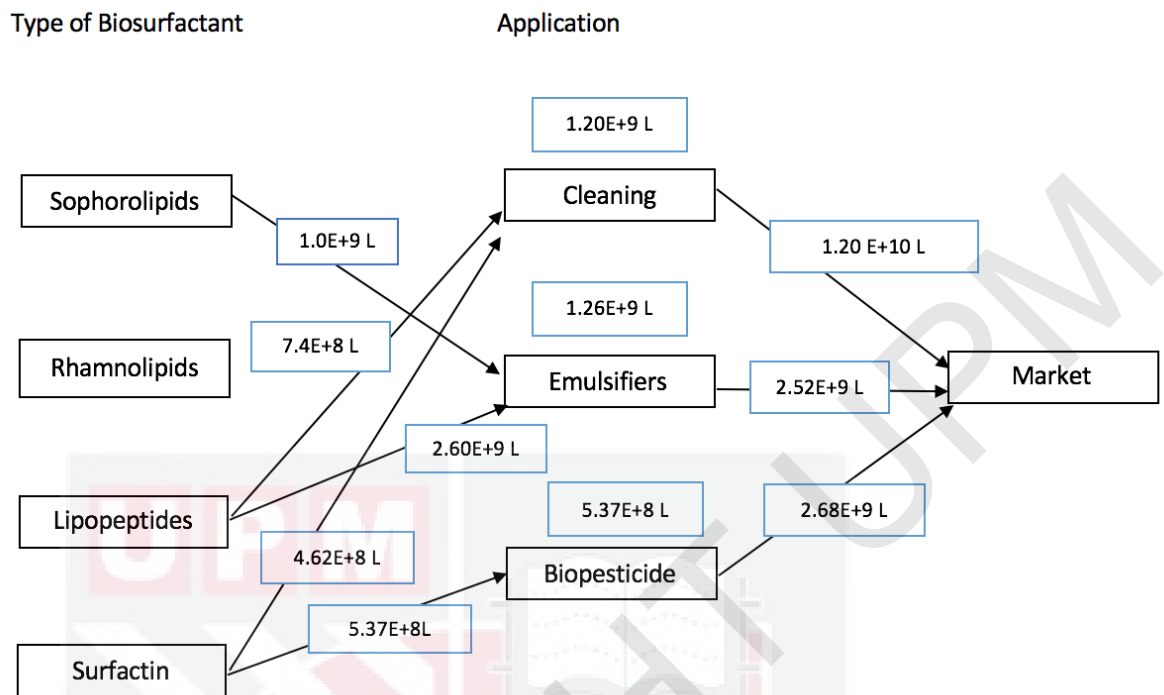


Figure 4.5: Result obtained from GAMS software

Figure 4.5 shows the result that was obtained for GAMS optimization model. Based on the figure above, Lipopeptides biosurfactants is the most valuable biosurfactant and the most uses application for biosurfactant in industrial product. This result shows that the value for cleaning that choose Lipopeptides type of biosurfactant is  $7.4E+8$  L and emulsifiers is  $2.60E+9$  L. So, the lipopeptides biosurfactant can be choose for the biosurfactant application in a product in term of low cost of production and the most profitable biosurfactant application. Price for lipopeptides biosurfactant is about RM 40 per liter and the market demand for this type of biosurfactants is high because of the availability of lipopeptides to be applied in many types of application. The most profitable application for biosurfactant in industrial product is as a cleaning product because of the high demand and this product was applied every day for household uses.

VAR A: Variance A is the profitable biosurfactants that will be use in an industry product. Based on the result, the profitable biosurfactants that will be used in industry is Sophorolipids, Lipopeptides and Surfactin due to the low cost of production. Price for sophorolipids is about RM 83 per liter, lipopeptides is RM 40 per liter and Surfactin is about RM 18 per liter.

VAR B: Variance B is the amount of product that will be produce based on the selected biosurfactants from Variance A. Resources parameter was coded into GAMS application which is the initial value is about 1 Million Liter for every types of biosurfactant.

VAR C: Variance C is the biosurfactants that have been choose to be applied in a product meet market demand of the product. The input parameters such as selling price for every product, cost for biosurfactants and market demand is coded into GAMS application. The selling price for cleaning product based on the market price is about RM 20/liter, emulsifiers is about RM 4.50/liter and biopesticide is about RM 4.50/liter. Market demand for cleaning application is about 6.3 B, emulsifiers is about 2.52 B and biopesticides is about 2.68 B. Result for Variance B was multiplied by market need which is cleaning is about 10, emulsifiers is 2 and biopesticide is 5. The result for variance C is obtain as below.

Variance A:

Optimal Result		
Biosurfactant	Application	Profit (Million Liter)
Sophorolipids	Emulsifiers	1
Lipopeptides	Cleaning	0.74
Lipopeptides	Emulsifiers	0.26
Surfactin	Cleaning	0.46
Surfactin	Biopesticide	0.53

*Table 4.1: The profitable biosurfactants that will be use in industrial product*

Variance B:

Application	Profit (Million Liter)
Cleaning	1.2
Emulsifiers	1.26
Biopesticides	0.537

*Table 4.2: Biosurfactants application that have been choose to be applied in industrial product.*

Variance C:

Market	Profit (Million Liter)
Cleaning Market	12
Emulsifiers Market	2.52
Biopesticides Market	2.68

*Table 4.3: Biosurfactants that have been choose to be applied in a product meet market demand of the product.*



## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

In conclusion, it has been estimated that lipopeptides biosurfactant is the most profitable biosurfactant compare to others biosurfactant in terms of price, application and market demand in the industries. Lipopeptides biosurfactant need to be selected as a biosurfactant type for product production as the price of this biosurfactant is cheap and more economical. As we know that surfactants are harmful to the earth, and the best way to replace surfactants is by using biosurfactants because biosurfactant is less toxic, environmentally friendly and a renewable resource. This finding reported in this study have provided useful guidance and government that require more attention in order to know the best selection of biosurfactant.

#### 5.2 Recommendation

For recommendation is to replace some estimated data used with the real data from the industries. Some of the data that have been used in this biosurfactant model is estimated because the limitations of the study. By replacing the estimated data with the real data from the industries it will gain more accuracy results for biosurfactant model.

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## APPENDICES

### APPENDIX 1: CODING

sets

i /Sophorolipids, Rhamnolipids, Lipopeptides, Surfactin /

k /Cleaning, emulsifiers, pesticide/

m /market /

;

parameters

res (i) /Sophorolipids 1000000000, Rhamnolipids 1000000000, Lipopeptides  
1000000000,

Surfactin 1000000000 /

price(k) / cleaning 20, emulsifiers 4.50, pesticide 4.50/

cost(i) / Sophorolipids 83, Rhamnolipids 4150, Lipopeptides 40,

Surfactin 18 /

;

Table con(k,m)

market

Cleaning 10

Emulsifiers 2

Pesticide 5

;

Table demand (k,m)

market

Cleaning	6300000000
Emulsifiers	2520000000
Pesticide	2688000000

variable

profit

;

positive variable

a (i,k)

b (k)

c (k,m)

;

equations

eq1

eq2

eq3

eq4

eq5

;

eq1..

Profit=e= sum ((k,m) , c(k,m) \* price (k)) - sum ((i,k) , a(i,k) \* cost (i) );

eq2(i)..

res(i)=g= sum (k, a(i,k)) ;

eq3(k)..

b(k) =e= sum (i ,a(i,k)) ;

eq4(k,m)..

b(k)\*con(k,m) =e= c(k,m) ;

eq5(k,m)..

c(k,m)=g=demand(k,m) ;

model biosurfactant /all/;

solve biosurfactant using LP maximise profit;

## APPENDIX 2: RESULTS OBTAIN FROM GAMS

### PROFIT

LOWER LEVEL UPPER MARGINAL

Cleaning. market	6.3000E+9	1.202E+10	+INF	
emulsifiers. market	2.5200E+9	2.5200E+9	+INF	-95.500
biopesticide. market	2.6880E+9	2.6880E+9	+INF	-35.500

LOWER LEVEL UPPER MARGINAL

---- VAR profit -INF 1.229E+11 +INF .

---- VAR a

LOWER LEVEL UPPER MARGINAL

Sophorolipids. Cleaning			+INF	EPS
Sophorolipids. emulsifiers			1.0000E+9	+INF .
Sophorolipids. biopesticide			+INF	EPS
Rhamnolipids .Cleaning			+INF	-3950.000
Rhamnolipids . emulsifiers			+INF	-3950.000
Rhamnolipids . biopesticide			+INF	-3950.000
Lipopeptides .Cleaning			7.4000E+8	+INF .
Lipopeptides . emulsifiers			2.6000E+8	+INF .
Lipopeptides . biopesticide			+INF	EPS

Surfactin .Cleaning . 4.6240E+8 +INF .

Surfactin .emulsifiers . +INF EPS

Surfactin .biopesticide . 5.3760E+8 +INF .

---- VAR b

LOWER LEVEL UPPER MARGINAL

Cleaning . 1.2024E+9 +INF .

Emulsifiers . 1.2600E+9 +INF .

Biopesticide . 5.3760E+8 +INF .

---- VAR c

LOWER LEVEL UPPER MARGINAL

Cleaning .market . 1.202E+10 +INF .

Emulsifiers .market . 2.5200E+9 +INF .

Biopesticide .market . 2.6880E+9 +INF .

**VAR a**

---- VAR a

	LOWER	LEVEL	UPPER	MARGINAL
Sophorolipids. Cleaning	.		+INF	EPS
Sophorolipids. emulsifiers	.		1.0000E+9	+INF
Sophorolipids. biopesticide	.		+INF	EPS
Rhamnolipids . Cleaning	.		+INF	-3950.000
Rhamnolipids . emulsifiers	.		+INF	-3950.000
Rhamnolipids . biopesticide	.		+INF	-3950.000
Lipopeptides . Cleaning	.		7.4000E+8	+INF
Lipopeptides . emulsifiers	.		2.6000E+8	+INF
Lipopeptides . biopesticide	.		+INF	EPS
Surfactin . Cleaning	.		4.6240E+8	+INF
Surfactin. emulsifiers	.		+INF	EPS
Surfactin . biopesticide	.		5.3760E+8	+INF

**VAR b**

---- VAR b

LOWER LEVEL UPPER MARGINAL

Cleaning	.	1.2024E+9	+INF
emulsifiers	.	1.2600E+9	+INF
biopesticide	.	5.3760E+8	+INF

**VAR c**

---- VAR c

LOWER LEVEL UPPER MARGINAL

Cleaning . market	.	1.202E+10	+INF
emulsifiers. market	.	2.5200E+9	+INF
biopesticide. market	.	2.6880E+9	+INF