PARAMETER AND STRUCTURAL RETROFIT OF PALM OIL FATTY ACID FRACTIONATION PROCESS FOR IMPROVED PRODUCTIVITY AND ENERGY EFFICIENCY

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ABSTRACT

The procedures for retrofit (improvement) of the process structure and the operating parameters of a palm oil fatty acid fractionation process have been developed and presented in this thesis. A local palm oil fatty acid fractionation process has been used as a case study. The incentives of this research is two-fold – namely to increase productivity and to reduce the operating cost (in this case, to reduce energy consumption) through optimal operation and improved process structure. The research offers two schemes for plant improvement. Each scheme can only be implemented exclusive of the other. The first scheme involves the improvement of process parameters without any investment. The second scheme, which offers a long term solution and calls for some investment, involves modifications of the process structure to maximise energy efficiency. The first scheme was conducted in four stages: (1) Development of a reliable property database for fatty acid fractionation process in a commercial simulator, Aspen Plus®, (2) Steady state process modeling using Aspen Plus ® simulator, (3) Development of correlations between the individual operating parameters and the production rate, and, (4) Optimisation of the multiple operating parameters. The economic benefit predicted from the alteration of operating parameters through the first scheme is an annual profit of about RM 52,500 in terms of net productivity and increase. The steady state (base case) model developed in the first scheme is used for structural modifications in the second scheme, with the aim of maximising energy efficiency. Here, a pinch analysis technique has been used. Retrofit using this scheme is estimated to save 956 KW of utilities. These savings comprised of up to 20.6 % of the fatty acid fractionation process utility consumption (excluded reboiler duties). The payback period for investment in this second scheme is predicted to be 13.8 months. As far as it can be found, a thorough search in the open literature shows there has been very less published work covering the process modeling and

simulation, structural retrofitting using pinch technology in *palm-oil fatty acid fractionation* process. It is hoped that this work will brings us a step closer to our goal of establishing a comprehensive guideline for process improvement and debottlenecking for the oleochemical industry in Malaysia.

ABSTRAK

Prosedur memperbaiki struktur loji dan parameter proses bagi proses pemecahan asid lemak sawit telah dikembangkan dan dibincangkan dalam tesis ini. Sebuah loji pemecahan asid lemak tempatan telah dijadikan sebagai kes kajian ini dan bertujuan untuk mempertingkatkan produktiviti serta mengurangkan kos operasi yang melibatkan penggunaan tenaga. Hasil kerja ini dilakukan menerusi pengoptimuman parameter serta pengubahan stuktur proses dengan menawarkan dua skima peningkatan prestasi loji. Setiap skima perlu dilaksanakan secara berasingan antara satu sama lain. Skima pertama melibatkan peningkatan parameter proses tanpa sebarang perlaburan kapital, manakala skima kedua telah menawarkan penyelesaian jangka panjang melalui modifikasi ke atas struktur demi memaksimumkan keberkesanan penggunaan tenaga. Skima pertama dilaksanakan dalam empat peringkat: (1) Pembangunan pangkalan data untuk proses pemecahan asid lemak dengan penggunaan simulator komersial, Aspen Plus ®, (2) Menggunakan Aspen Plus ® dalam pembinaan model proses pemecahan asid lemak, (3) Kolerasi yang menghubungkaitkan parameter individu dengan parameter operasi dan produktiviti, (4) Pengoptimuman multi-parameter operasi berbilang. Dari segi ekonomi, manfaat yang diperoleh ekoran daripada pengoptimuman berbilang parameter operasi bagi skima pertama telah meramalkan perjimatan tahunan sekurang-kurangnya RM52,500 daripada pulangan produktiviti dan penjimatan tenaga. Dalam skima yang sama, model proses aliran mantap yang dibangunkan akan digunakan untuk tujuan modifikasi struktur, bagi mencapai objektif yang serupa – memaksimumkan keberkesanan penggunaan tenaga. Penggunaan Teknologi Sepit pada peringkat ini telah berjaya menghasilkan penjimatan tenaga atau utiliti sebanyak 956 kW. Kadar ini merangkumi 20.6% daripada jumlah utiliti yang digunakan dalam proses pemecahan asid lemak . Dengan pulangan yang diperolehi hasil dari integrasi tenaga, tempoh bayar balik ialah 13.8 bulan. Pada akhir penyelidikan, adalah diharapkan

supaya teknik pengoptimuman proses oleokimia dapat maju selangkah lebih hampir ke arah mencapai objektif membangunakan satu garis panduan untuk pembaikan proses yang komprehensif dalam industri oleokimia di Malaysia.

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CHAPTER 1

INTRODUCTION

Oleochemicals are chemical components derived from vegetable oil and fat. Oleochemicals include palm oil, rapeseed oil, sunflower oil, soybean oil, ground nut oil, coconut oil, corn oil etc. Out of these types of vegetable oils, the palm oil, *Elaeis guineensis*, is used as the feedstock for the oleochemical refinery process of this research project. The oleochemical components that are commonly produced in the oleochemical industries are the fatty acids, fatty alcohol and glycerine. These chemicals are the intermediates used mainly in food production (cooking oil, margarine, shortening, *etc*) and also for non-food applications (soap, detergent, cosmetics, *etc*) [Burhanuddin, et al., 1998]. The commercial value of the palm-based chemicals mainly comes from the palm oil which can be obtained from the mesocarp of the palm fruit and the palm kernel oil which is derived from the nut. These two sources of oil are the main precursor for the palm-based oleochemicals.

Malaysia records a tremendous productivity and export capacity of palm-based products in the region. Table 1.1 shows Malaysia has acted as one of the key exporters of palm oil from year 1994 to 2000. The success of the Malaysian palm oil industry is the result of the ideal climatic conditions, efficient milling and refining technologies and facilities, extensive research and development, and efficient and adequate management skills. A unique phenomenon in the development of the palm oil industry in Malaysia is that there has been no existing progressive palm oil industry elsewhere in the world to model upon [Sukaimi, 1998], or up to date advanced technologies or innovations that can be readily obtained or bought. The palm oil is native to Africa but there has been no large scale commercial planting of the palm there and hence no advanced technologies to adopt from. In the 1980s, Malaysia was the first nation to embark on large scale planting and processing of palm oil [United Nations, 2000]. These results in the lack of readily available custom-made technologies and relevant existing R&D findings or technologies that required to support the development of the industry [Walter, et. al., 2000]. There is also a relative lack of technical information on palm oil as compared to other oils such as rapeseed oil, sunflower oil and soybean oil which is more commonly used in the developed countries.

Table 1.1 : World major exporter of palm oil : 1994 - 2000 ('000 Tonnes) [MPOB, 2001c].

Country	1994	1995	1996	1997	1998	1999	2000
Malaysia	6,750	6,513	7,212	7,490	7,465	8,914	9,081
Indonesia	2,173	1,856	1,851	2,982	2,002	3,319	4,170
Papua New Guinea	231	220	267	275	235	254	294
Cote D'Ivoire	148	120	99	73	102	105	110
Colombia	20	21	29	61	86	90	86
Singapore	328	399	289	298	241	292	293
Hong Kong	234	275	305	173	103	94	158
Others	876	791	711	821	577	749	812
TOTAL	**10,760**	**10,195**	**10,763**	**12,173**	**10,811**	**13,817**	**15,004**

1.1 Scenario of Palm-Based Oleochemical Industry in Malaysia

Oleochemical industry is one of the most rapid growing industries in Malaysia and South East Asia region. Figure 1.1 shows that since the mid of 90s Malaysia has achieved a vast production capacity, and accounted for more than 1 million tonnes of oleochemical being produced in year 1997 [MPOB, 2001a]. Besides, Malaysia exported oleochemical products with volume that exceeds 1 million tonnes per annum in year 1999 and 2000 (Figure 1.2), and it is expecting an increment in the new millennium [MPOB, 2001b]. Malaysia currently has the capacity to produce about 20% of the world's production of basic oleochemicals [MPOB, 2001d] such as fatty acids, fatty methyl esters, other fatty alkyl esters, fatty alcohols and glycerol. These products are exported to more than 50 nations mainly from EU, America and some Asian countries (Figure 1.3), leading to the huge gain in the foreign currency.

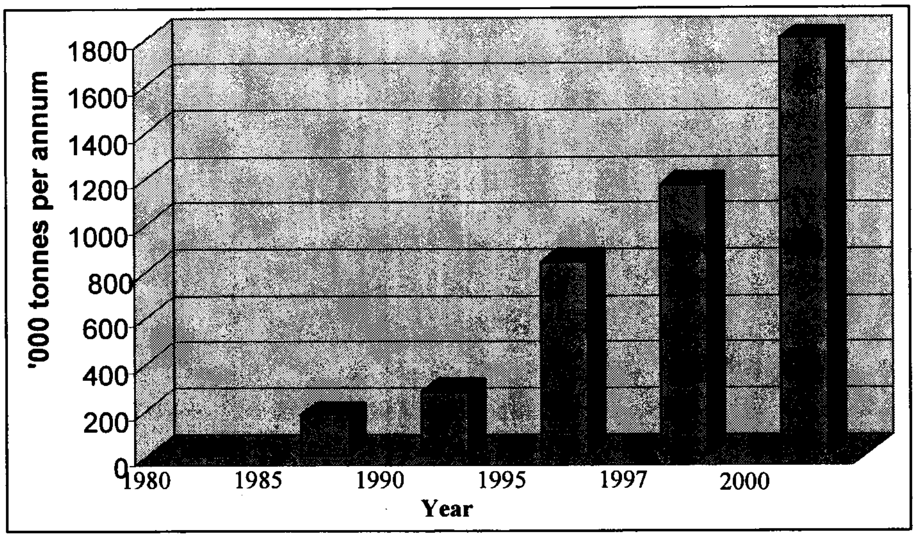

Figure 1.1 : Malaysia oleochemicals production capacity, 1980 – 2000 [MPOB, 2001c].

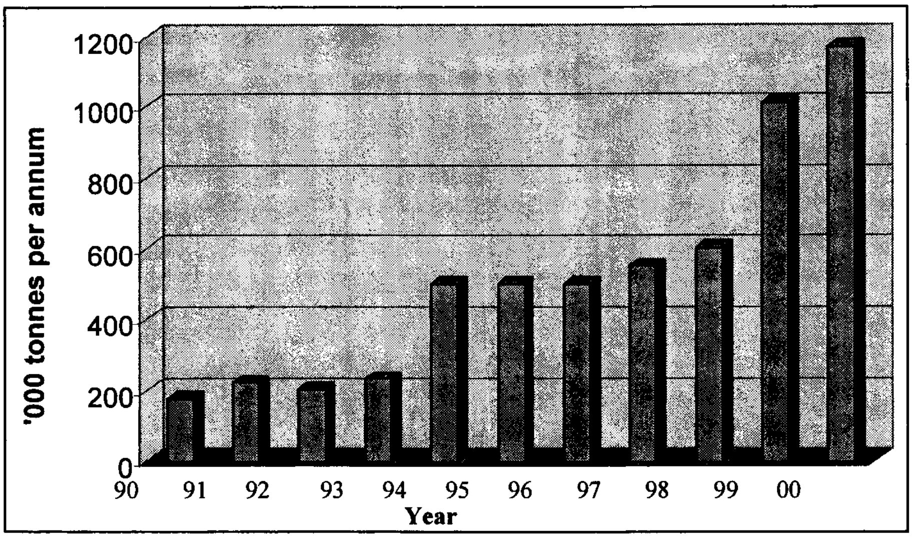

Figure 1.2 : Malaysia exports of oleochemicals, 1990 – 2000 [MPOB, 2001d].

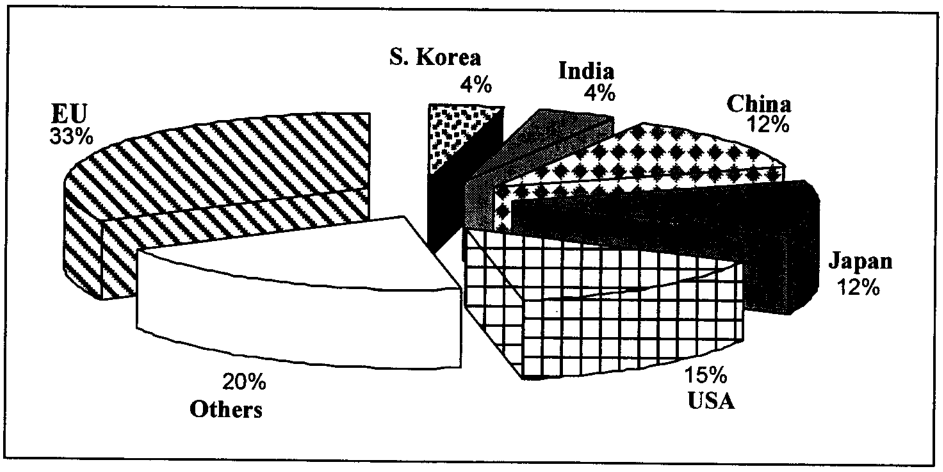

Figure 1.3 : Malaysia export of oleochemicals by destination, 2000 [MPOB, 2001d]

The world demand for palm oil-based oleochemical products is increasing and these products are expected to become more popular in the future due to the fact that they are not only biodegradable but also environmentally-friendly and sustainable compared to petrochemical-based products [MPOB., 2001b]. For the 10 years period beginning in 1995, world annual production of oleochemicals is forecasted to grow by 50% from the 5 millions tonnes in year 1995 to about 8 millions tones [Basiron and Ahmad, 1997]. A large scale of growth is forecasted to be in Asia. By that time, Asia will contribute up to half of the world production of oleochemicals. Currently, Malaysia ranks as one of the biggest producer of basic oleochemicals in the world, contributing about 20% of the total world supply of oleochemical products [MPOB, 2001d]. To remain the position of one of the key oleochemicals producers in the region, at present, Malaysia has a total 16 oleochemical plants nationwide. Table 1.2 shows number of oleochemical plant and its capacities in year 2000.

Table 1.2 : Number of oleochemical plants and capacities for year 2000 [MPOB, 2001c]

State	No.	Capacity (tonnes / year)
Johore	5	296,790
Penang	3	519,925
Selangor	6	505,760
Other states	2	477,490
Malaysia	16	1,799,965

Table 1.3 : Export volume and value of oleochemical products : 1999 & 2000 [MPOB, 2001c]

Oleochemical Products	1999		2000	
	(Tonnes)	(RM Million)	(Tonnes)	(RM Million)
Stearic Acid	*196,818*	*389.0*	*207,392*	*346.4*
Palmitic Acid	*51,143*	*94.8*	*41,714*	*65.8*
Lauric Acid	*48,618*	*155.0*	*52,272*	*154.8*
Myristic Acid	*18,644*	*65.3*	*15,546*	*65.9*
Lauric - Myristic Acid	*6,739*	*17.0*	*17,303*	*43.8*
Oleic Acid	*13,584*	*42.5*	*13,961*	*45.4*
Caprylic - Capric Acid	*9,392*	*46.1*	*8,132*	*40.6*
Split Undistilled Fatty Acid	73,709	166.5	42,072	86.2
Distilled Fatty Acid	31,478	73.0	58,186	109.5
Other Fatty Acids	29,052	83.8	36,420	103.5
Fatty Alcohol	220,410	861.1	189,246	769.8
Methyl ester	129,875	351.7	190,778	423.1
Glycerine	118,670	358.1	143,458	562.6
Soap Noodles	62,690	128.7	120,717	212.8
Others	0	0.0	559	1.8
Total	**1,010,823**	**2,832.6**	**1,137,871**	**3,032.3**

Table 1.3 presented Malaysia's export volume and value of oleochemical products in year 1999 and 2000, the fatty acids that being studied in this project (*italic font*) counted more than 30% of the total amount exported in both years. These valued fatty acids produced by the company play an important role in contributing export volume and profit to the country.

1.2 Motivation

The motivation for this research project came from a tremendous industrial concern for R&D in the oleochemical industry. Palm oil competes with many other oils and fats in the world market. Therefore, research and development is critical to sustain the growth and competitiveness of the other oils and fats as illustrated in Table 1.4. This table shows the major imported oil and fat products in the world. Notice that soybean oil, sunflower oil, rapeseed oil and coconut oil are the main competitors of the palm-based oil. Besides, to expand the market for palm oil, more information on its operation, productivity, uses, characteristics and other qualities will need to be researched and disseminated.

Table 1.4 : World import of 17 oils & fats : 1994 - 2000 ('000 Tonnes) [MPOB, 2001c]

Oils/Fats	1994	1995	1996	1997	1998	1999	2000
Palm Oil	10,614	10,457	10,770	12,269	11,047	13,845	15,374
Palm Kernel Oil	896	801	931	1,053	1,059	1,257	1,262
Soybean Oil	4,693	5,392	5,098	6,977	7,745	7,566	6,568
Cottonseed Oil	232	272	236	235	214	194	193
Groundnut Oil	269	261	246	258	253	240	253
Sunflower Oil	2,006	2,903	2,609	3,445	2,797	2,908	2,700
Rapeseed Oil	1,778	1,888	1,839	1,881	2,211	1,811	1,905
Corn Oil	484	622	610	644	804	680	748
Coconut Oil	1,571	1,635	1,385	1,772	1,949	1,156	1,862
Olive Oil	443	404	323	509	472	560	530
Castor Oil	196	296	261	242	243	231	272
Sesame Oil	23	22	22	23	22	23	26
Linseed Oil	132	191	127	133	116	131	160
Total	**23,337**	**25,144**	**24,457**	**29,441**	**28,932**	**30,602**	**31,853**

Besides R&D encouragement from the industries mentioned, the research is also motivated by the importance of energy conservation and inefficient energy consumption in the industry [Barlow, 2000]. Oleochemical industries in Malaysia, in general, does not show a sound awareness of this issue as mush as its remarkable productivity [Basiron, 1992]. This is important for the industry and environment point of view, as some oleochemical processes operate under close-to-vacuum pressure and high temperature. For instance, the distillation system has been known as a key operation in chemical, oleochemical and petrochemical processes; but also counted as one of the most extensive energy consumers. There is a possibility that a huge amount of high quality energy may be released and wasted to the surroundings due to process and equipment inefficiencies. Therefore, this project is strongly motivated by the importance of the energy utilisation efficiency because it has been widely recognised that it has a big impact in manufacturing profitability and greenhouse effect.

To minimise its extensive usage of energy and thus increase its efficiency, many research and improvement works have been carried out actively in both chemical and petrochemical processes. To support this improvement works, computerised process modeling that assisted by the modeling software packages has been established successfully. The success of process modeling and improvement in the chemical and petrochemical industries is also one of the motivations of this work, since these practices have yet to be extended significantly in oleochemical.

With the rapid growth in the world demand (refer Figure 1.2) for palm-based oleochemicals, the increase in fuel and water prices as well as the environmental issues that are becoming more critical, for that reasons, research to improve process productivity and efficiency aimed at increasing the profitability of oleochemical processes must be emphasised.

1.3 Problem Statement

The parameters and structural retrofit of palm oil-based oleochemical processes to enhance productivity and energy efficiency are key issues that have yet to be addressed. The process of fractionating fatty acid from palm oil, as considered for this study, consists of a series of energy-intensive distillation column operation. Given the existing process structure and product quality, it is desirable to find the optimum combination of operating parameters to achieve the highest productivity. On the other hand, for the given product quality and productivity, it is looked-forward to find an optimum process structure to achieve maximum energy efficiency, thereby reducing the operating cost and enhance the profitability of the plant.

1.4 Research Objectives

The main aim of this research is to enhance the profitability of an existing local palm oil fatty acid fractionation process by improving the energy efficiency and process productivity through retrofit and optimisation of the fatty acid fractionation process operating conditions and structure. Towards this end, this research also focuses on the goal of developing a computerised steady state process model that is crucial for the retrofit procedures mentioned.

1.5 Scope of Work

This research mainly covers the fatty acid fractionation process of an oleochemical plant, which is designed to separate the hydrogenated fatty acid mixture into high purity individual acids. To effectively and rapidly achieve the goal of this research, a reliable computer-based model of the fractionation process is first developed.

This research comprises two main retrofit schemes:

1. Process operational parameters' improvement

This scheme is conducted in four stages:

- Enhancement of the property database for fatty acid fractionation process in a commercial simulator, Aspen Plus®.
- Steady state process modeling using Aspen Plus® simulator
- Development of correlations between the individual operating parameters and the production rate.
- Optimisation of the multiple operating parameters.

2. Structural retrofit

Besides parameter alteration, this research offers an alternative for improvement through the structural modification of the fatty acid fractionation plant. This is aimed at maximising better energy recovery. The steady state (base case) model developed in the first scheme is used for structural modifications in the second scheme, with the aim of maximising energy efficiency.

Pinch technology is applied to improve the heat recovery network. The retrofitting proposal will be complimented by the economic and profitability studies since it involved structural modification within the system. However, a minimal investment is proposed during the pinch design. It should be realised that all the necessary efforts have been made to minimise investments and to keep the payback period (PBP) will keep to the minimum acceptable by The Company.

1.6 Contributions of This Research

Unlike in the case of petrochemical industries, in the past 20 years, oleochemical industries have seen very little progress being made on the improvement and optimisation of the operation and structure of the local palm oil based oleochemical processes [Aly and Ashour, 1993]. As the process equipment efficiency deteriorates over the years, there is a need to review the operating strategies and process structure to improve profitability. The results of this research is expected to generally contribute a great deal towards a better design, operation as well as understanding of the palm-based oleochemical process to achieve higher production efficiency and hence, higher profitability.

The key specific contributions that have emerged from this work include:

- the enhancement of the computersied property database for palm oil fatty acid fractionation operation that is crucial for use for fatty acid fractionation process modeling and optimisation.
- the development of a base case process model for palm-oil fractionation operation.
- the establishment of a set of correlations between the quality as well as productivity and process operating variables for each fatty acid fraction.
- the establishment of an optimum model for palm-oil fractionation
- the development of an alternative structure for improved energy efficiency and enhanced energy recovery for palm-oil fractionation.

1.7 Thesis Outline

This thesis is organised in eight chapters which are presented in the same chronological order as the different research stages of the project. This thesis begins with an introduction of the central theme and discussion of the project scope, objectives and contributions of the work.

Chapter 2 covers the literature review of the previous works done in chemical process modeling and retrofitting, provides a general overview of R&D scenario in the palm oil industries and the research activities that have been carried in the oleochemical industries. Besides, this chapter also discusses the critical features of Properties Constant Estimation System (PCES) in estimating missing fatty acid parameters in the simulator databank.

Chapter 3 provides detailed procedure for the development of a physical property database as well as the computerised steady state process model using Aspen Plus simulator. This chapter will then focus on three areas that include the methodologies for process modeling, parametric analysis and structural retrofit.

The results are presented and discussed in chapter 4 and 5. Chapter 4 covers the discussion of the estimated fatty acid components physical properties and the process flowsheet model. Chapter 5 presents the results and discussion of the first retrofit scheme which involving the parameter sensitivity analysis and optimisation.

The second scheme, which involves retrofit of the process structure, is presented in chapter 6. Note that these schemes for structural retrofit can only be implemented independent from the scheme for parameter retrofit discussed previously. The results of this study are produced from the application of the thermodynamics tool – Pinch technology. These results consist of a proposed heat recovery network.

Both retrofit scheme discussed in chapters 5 and 6 will be analysed further in terms of their economics in chapter 7. This chapter mainly focuses on the profitability of the retrofit scheme. Finally, the Pay Back Period (PBP) for the improvement is calculated. In chapter 8, this research project will end with the conclusions and future work outlined for the project. Figure 1.4 will present the linkage and chronology of this work.

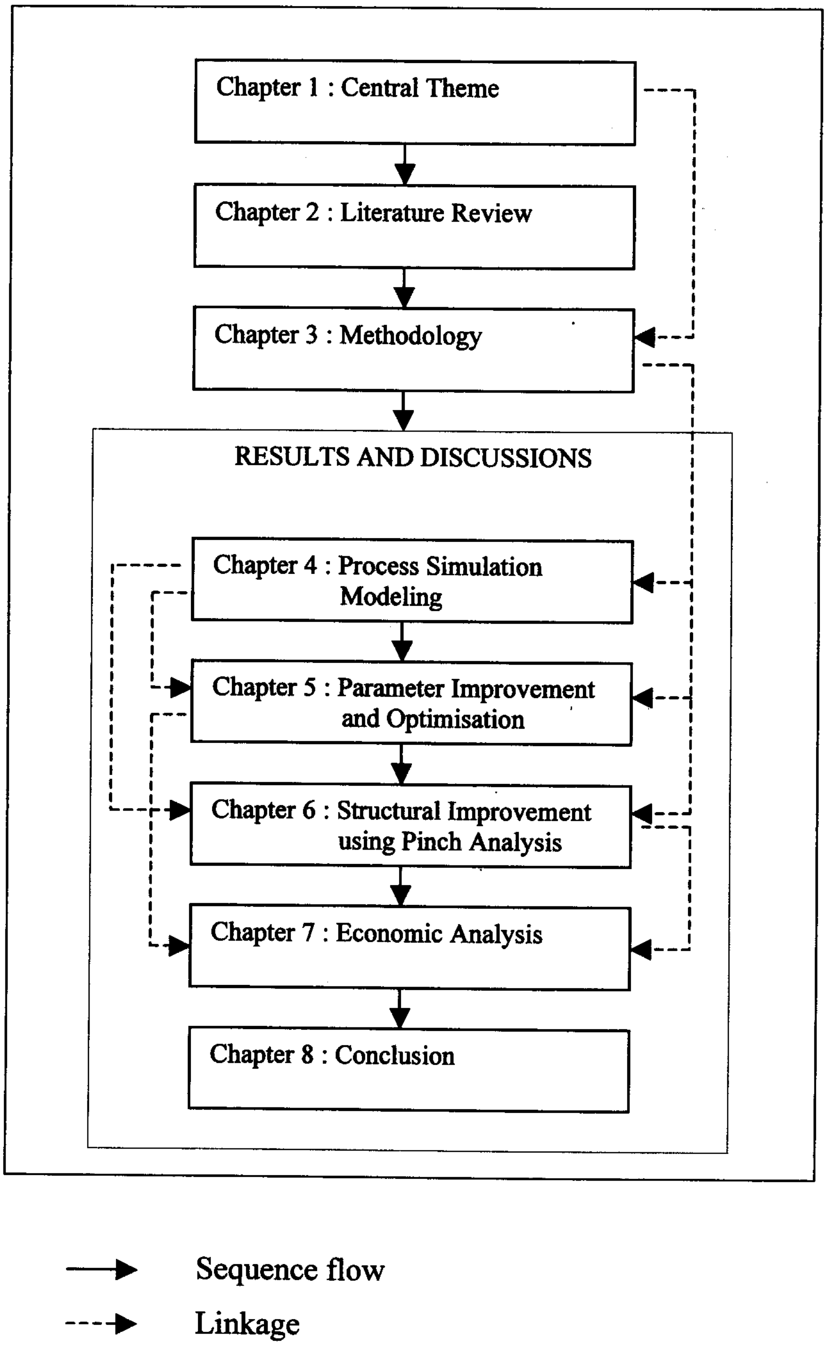

Figure 1.4 : Schematic of the linkages and the chronology of this research project.