FEASIBILITY STUDY
ON
THE ESTABLISHMENT OF A CITRIC ACID PLANT
IN
THE REPUBLIC OF ZIMBABWE

(SUMMARY)

MARCH 1992

JAPAN INTERNATIONAL COOPERATION AGENCY

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Chapter 1 Outline of the Study

1-1 Preface

Citric acid has a clean and refreshing acid taste which makes it one of the most popular of the acidulants used for food and pharmaceuticals, and it is completely nontoxic and quite safe for humans. Citric acid is used in a wide variety of applications, such as beverages, food, pharmaceutical and other industrial uses. The largest usage of citric acid is as an acidulant for beverages, accounting for about 75 percent of total acidulants.

Also, in Zimbabwe, citric acid is widely used, mainly in the field of beverages, food stuffs and pharmaceuticals. The rate of growth of demand for the beverage sector in Zimbabwe has exceeded the rates of increase in the population and GDP. With the increase of the beverage demand, the demand for citric acid will increase steadily. The total amount of citric acid required for domestic consumption, about 620 tons per year, is imported. Since the transportation cost of imported goods is high because of the inland location, the price of citric acid is relatively expensive, compared with the international market prices. Under these circumstances, domestic users of citric acid have great expectations for the domestic production and supply of citric acid.

Citric acid is produced by a fermentation process using carbohydrate raw materials, such as molasses, glucose solution from starch, cornstarch, and sweet potato starch extraction residues. Agriculture is prosperous in Zimbabwe and large amounts of maize and sugarcane, which can be sources of raw materials for citric acid, are produced; some of these products are even exported to foreign countries. Furthermore, Zimbabwe is the second most industrialized country, after the Republic of South Africa, among Sub-Sahara African countries. The electric power supply which is one of the principle factors for establishing a citric acid industry, is extremely good and stable in Zimbabwe.

Currently, world citric acid demand is about 500,000 tons per year and more than 80 percent of citric acid is produced in Europe and North America. In Africa and the Middle East, citric acid is produced in Israel and Turkey but their total production is only 3 to 4 percent of the world production. Production by five major producers in Europe and the U.S.A. accounts for approximately 75 percent of the world production of citric acid. Under an oligopolistic market structure, the fundamental strategy of the citric acid majors is to stress the sales of the product and usually they do not intend to sell or supply their production technology. In Japan, citric acid producers have developed their own process technologies.

The quality of citric acid produced in Japan is as high as any in the world.

Under these circumstances, the government of Zimbabwe requested the government of Japan to conduct an investigation into the viability of establishing a citric acid plant using agricultural products harvested in Zimbabwe as the raw material. This study meets the objectives of the industrial development plan promoted by the government of Zimbabwe in terms of the utilization of domestic resources, reducing foreign currency outflow and increasing the inflow as well as relatively low capital investment. The above is the background of this feasibility study.

1–2 Objective of the Study

The objective of this study is to investigate and evaluate the viability of citric acid production using the raw materials locally available at present, or in the future, from the technical, financial and economical viewpoints and formulate all of the findings in the form of a study report. This study has been conducted in accordance with the "Scope of Work" agreed and signed between the preliminary survey team of JICA (Japan International Cooperation Agency) and the Zimbabwean counterpart, IDC (Industrial Development Corporation of Zimbabwe Limited) and MIC (Ministry of Industry and Commerce).

JICA dispatched a study team to carry out a field survey in the Republic of Zimbabwe from May 30 to June 25, 1991.

1–3 Method of the Study

Citric acid is produced by a fermentation process using carbohydrates as the raw material. Since the fermentation process utilizes microbial reactions, the fermentation performance is affected to a great extent by the combinations of raw materials, fungus and fermentation conditions. Therefore, in this study, appropriate combinations of fermentation processes and raw materials were studied through fermentation tests conducted in Japan, using the following raw materials which were collected during the field survey:

– Cornstarch (2 kinds)	:	10 kgs each
– Dry sweet potato chips	:	24 kgs
– Dry cassava chips	:	3 kgs
– Crude sugar	:	3 kgs

- Affination syrup : 3 kgs
- Condensed sugarcane juice : 5 kgs
- Process molasses : 3 kgs
- "B" molasses : 5 kgs
- Bagasse (used as a carrier) : 12 kgs
- White maize (for analysis of starch content) : 1 kg
- Yellow maize (for analysis of starch content) : 1 kg

Based on the results of the fermentation test and taking into consideration the raw material situation (prices and availability), the appropriate production size of the plant based on a market study, and the plant site, the most feasible project scheme was established.

A conceptual design of the plant, construction cost estimates, financial and economic analyses of the project were also carried out for the selected project scheme.

This feasibility study report was made based on the above procedure and this report is a summary of the study. The details are described separately in the main report.

Chapter 2 Executive Summary

2–1 Project Scheme

– Product : Citric acid monohydrate (complying with BP standard)
– Capacity : 3,000 tons per year (by the submerged fermentation process)
– Plant site : Mukuvisi area in the suburbs of Harare city

2–2 Citric Acid Markets

(1) Market size in Southern Africa

Country	Demand (metric tons)			Average Annual Growth Rate (%)
	1990	1996	2000	1990–2000
– Zimbabwe	620	910	1,180	6.7
– Republic of South Africa/ S.A. Customs Union	3,500	4,700	5,750	5.1
– Other Countries	500	600	670	3.0
Total	4,620	6,210	7,600	5.1

(2) Potential sales

For the above market, the market share for the proposed Zimbabwean company in 1997 is estimated to be 83% in Zimbabwe, 36% in the Republic of South Africa and Southern Africa Customs Union, 52% in other surrounding countries, or 45% of the total region. The ratio of domestic to export sales on a weight basis will be 28:72 in 1996 and it will reach 50:50 in 2010, with the increase of domestic consumption and expansion of the domestic market share.

2–3 Raw Material and the Fermentation Process

(1) Raw Material .... Cornstarch made in Zimbabwe (consumption: 4,100 tons/y)

Candidate raw materials were collected and brought to Japan for fermentation tests.

As a result of the fermentation tests, it is recognized that cornstarch made in Zimbabwe can be used as the raw material for commercial production of citric acid. Current production of cornstarch in Zimbabwe is 12,000 ton a year and there is no surplus capacity to supply the citric acid industry. However, as the domestic demand for cornstarch is rapidly expanding and it is quite certain that an expansion of cornstarch production will be made by the public sector, the future supply of cornstarch to the citric acid industry will be possible and realistic. The required amount of maize, the raw material for the production of cornstarch, is about 6,000 tons a year. This is a tiny fraction of the annual production of maize, which is more than one million tons, in Zimbabwe. In this study, the price of cornstarch is set at 562 Z$/ton.

(2) Fermentation process .... Submerged culture fermentation
(Liquid culture solution is agitated with enough aeration of sterilized air in a fermentation vessel)

2–4 Outline of the Plant

The citric acid plant consists of a fermentation process and a separation process. After planting the fungus and culturing the solution sequentially in three different sizes of fermenters, citric acid is crystallized and separated as calcium citrate in the separation process. This calcium citrate is decomposed by sulfuric acid to obtain citric acid solution, which is concentrated to separate citric acid crystals. For environmental protection measures, the improved batch type lagoon process and cyclones are to be furnished for the treatment of waste water and waste gas.

2–5 Total Capital Requirement

– Plant construction costs	:	US$ 24.33 million
– Pre-operation costs	:	US$ 0.74 million
– Initial working capital	:	US$ 0.10 million

In addition to the above, the interest during construction for the long-term loan is to be included in the total capital.

2–6 Results of the Financial Analysis

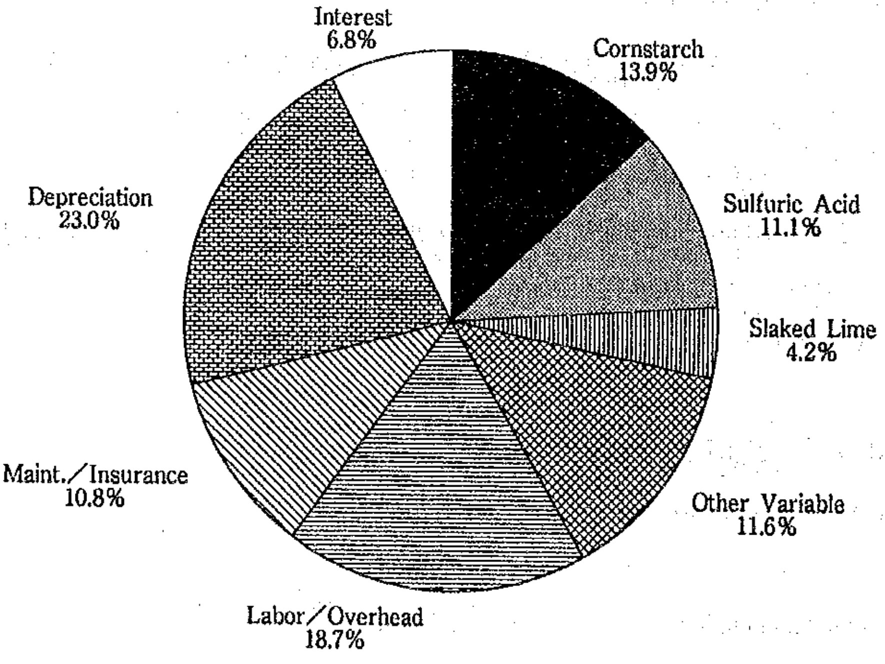
(1) The total capital costs will be supplied by the owner's own equity, a long term loan from foreign banks and a long term loan from domestic banks, in which the share of capital will be 32%, 38% and 30% respectively in the case of a long term foreign loan with an annual interest rate of 4.5%. Two cases of interest rate for the foreign long term loan are simulated; 10.75% for Case 1 and 4.5% for Case 2. The interest rate for the domestic long term loan is 20% on a Zimbabwe dollar basis, but in the study this rate was converted to 4.6% on a US dollar basis because the exchange rate of the Zimbabwe dollar to the US dollar is declining at the rate of 15.4% yearly for the last 10 years from 1980 to 1990.

(2) Product sales price (ex-works)

– Domestic price in Zimbabwe	:	2.26 US$/kg
– Neighboring countries	:	1.40 to 1.54 US$/kg
– Average unit price for 20 years	:	1.81 US$/kg

(3) Composition of the production cost (Case 2)

– Average unit production cost for 20 years : 1.75 US$/kg



(4) Results of the financial analysis

Indicators	Base Cases		Sensitivity Cases (based on Case 2)		
	Case 1	Case 2	Product Price 20% up	Operation Cost 20% down	Plant Cost 30% down
IRROI (a/tax)	1.5%	1.5%	4.9%	3.9%	4.5%
IRROE (a/tax)	–	–0.1%	7.0%	5.1%	6.2%
Production Cost (US$/kg)	1.87	1.75	1.75	1.50	1.54
Total Profit after/tax (MMUS$)	–6.5	2.0	14.8	10.8	9.5
Cum. Cash Surplus (MMUS$)	–0.3	8.3	21.1	17.2	14.0

2–7 Results of the Economic Analysis

(1) After evaluating the economic benefits and costs, economic internal rates of return from the operation of the project were calculated as follows:

	Base Case	Sensitivity Cases			
(Economic benefit)	(100%)	(100%)	(100%)	(120%)	(80%)
(Foreign currency premium)	(1.50)	(1.33)	(2.00)	(1.50)	(1.50)
Economic Internal Rate of Return:	5.3%	3.5%	8.9%	11.0%	–2.5%

(2) Foreign currency balance over 20 year's operation

– In the case of a commercial bank loan (Case 1) : plus US$ 56.83 million

– In the case of a soft loan (Case 2) : plus US$ 63.92 million

2–8 Conclusion

The results of the financial analysis do not show such a good profitability for the project. This reflects the fiercely competitive situation of the current citric acid industries in the world. Also this is attributed to the very limited market size in the region and the inherent features of the industry of Zimbabwe, such as expensive materials, high transportation and personnel costs. Thus it will not be very easy for a new Zimbabwean company to enter the citric acid industry, especially with a plant size of 3,000 tons/year. It is concluded that the project is not feasible.

Chapter 3 Present Socio-Economics of the Republic of Zimbabwe

The Republic of Zimbabwe is located in the southern part of the African continent with a land area of about 391,000 km^2. On April 18, 1980, the Republic of Zimbabwe declared its independence, headed by president Mugabe. The population of the country was estimated to be 9,370,000 in 1990, and the capital city is Harare. Zimbabwe has a sub-tropical climate, moderated by its altitude of over 1,000 meters. ZANU-PF is the dominant political party in Zimbabwe, with its policies based on Marx-Leninism, whereas other parties have minor influence.

Before independence in 1980, the country had been dominated by the European minority lead by Prime Minister Ian Smith who unilaterally declared the country an independent state (UDI) and proclaimed "the Republic of Rhodesia" against the intention of the United Kingdom. This resulted in protests from all over the world and the United Nations imposed mandatory economic and trade sanctions against Rhodesia in 1967. Prime Minister Ian Smith stayed in power for 15 years until the globally recognized independence of 1980 when a government by African people was established as a result of a general election carried out in accordance with the Lancaster House Agreement of 1979. Because of the sanctions, the former government of Rhodesia developed industries to make the country as self-sufficient as possible. Since independence, the Republic of Zimbabwe took over these industries. The nature of Zimbabwean industries is as follows:

(1) Infrastructure such as power systems, water resources, railways and roads is well integrated, in contrast to many sub-Saharan countries.

(2) Industries are very diversified and most of them have a monopoly or oligopoly structure.

(3) The industries are lagging far behind as regards corporate rationalization and facility modernization as a results of less competitive domestic markets.

(4) Zimbabwe's trade is wholly dependent on the sea ports of neighboring countries because of its inland location.

(5) In spite of the political situation in Zimbabwe, the economy of the state is largely dependent on the Republic of South Africa.

Since the 1980s, Zimbabwe has experienced severe droughts twice and an oil price hike brought about by the Gulf War that caused a downturn in the state economy. Thus, Zimbabwe could not help cutting back the import of raw materials and spare parts for industrial machinery due to the lack of foreign exchange. Consequently, capacity utilization at present is said to be from 40 to 70 percent. Under such circumstances, the average GNP growth was only 2.7 percent per annum in the 1980's which was rather less than the population growth. In the same period inflation averaged 15 percent and the unemployment rate reached 26% in 1989. In recognition of these facts, the government of Zimbabwe made structural adjustment programs for the economy and announced a trade liberalization program associated with an OGIL (Open General Import Licence) system, deregulation schemes, and decontrol of domestic prices.

As a first step, the government announced "The Promotion of Investment: Policy and Regulations" in April, 1989, so as to further develop the manufacturing industries. Intermediate and capital goods industries are to be given priority, and export-oriented industries are mostly welcomed. In order to simplify the government procedures for investments, "The Investment Center" has been recently organized as a single interface organization.

As a second step, the government decided to decontrol the prices of all commodities except ten items such as bread, maize, beef, matches, cooking oil and fats, cement, ZISCO steel, fertilizer, petroleum fuels, and bus and railway fares at the end of 1990. The government started implementing trade liberalization through the OGIL system from October, 1990, and items which can be imported will be increased each year.

In January, 1991, the government announced "A Framework for Economic Reform (1991–95)", which set the target economic growth rate at 5 percent by 1995. Also the prime objectives of this economic reform are to improve the living standards of the people and to banish poverty from Zimbabwe with an expansion of the social welfare budget. In this plan, the government plans to reduce the prevailing tax rates, and the total taxation income is expected to drop from 35 percent of GDP in FY1990/91 to 33 percent in FY1994/95. Budgets for medical fees, education fees and also for retraining people who have been made redundant will be expanded, while the deficit of the national account will be reduced from 10.4 percent of GDP in FY1990/91 to 5 percent in FY1994/95.

Trade liberalization and decontrol of domestic prices may cause high rates of inflation in the initial stages of this economic reform. Therefore, very sophisticated and cautious monetary policies are also required.

Along with Zimbabwe's policy on the liberalization of trade and investment, it is expected that investment and technology transfer from the Republic of South Africa will be accelerated.

Chapter 4 Citric Acid and Its Production Technology

4–1 Introduction

Citric acid is a hydroxy tribasic acid and is widely used in the fields of food, beverages and pharmaceuticals. Citric acid is found most abundantly in the citrus fruits, particularly in lemons and limes. In the past, citric acid was extracted from the juice of lemons and limes. Today, it is most commonly produced by the fermentation of carbohydrates. Currently world demand of citric acid amounts to 500,000 tons per year.

4–2 Citric Acid Uses

Citric acid is extensively used in the fields of beverages, food, pharmaceuticals and so forth for its safety (non toxicity), pleasant acid taste, high water solubility, chelating properties and price dominancy. Other applications have been developed for liquid detergents, metal cleaning, plasticizers, photography, etc.

In beverage applications, the dominant acidulant is citric acid. Citric acid is used in most soft drinks, except cola which uses phosphoric acid and grape-flavored drinks which use tartaric acid.

In the market sectors where acidulants in general and citric acid in particular play a role, the second major consumer of citric acid is confectionery, jams and preserves. In food citric acid is also used to stabilize color and to prevent changes of taste and smell.

In pharmaceuticals citric acid is employed in vitamin C tablets, antacid preparations and analgesics. Citric acid also adds a palatable flavor in medicinal preparations which would otherwise be rather bitter. Citric acid also increases product shelf life by complexing trace metals that might otherwise lead to product degradation. Sodium citrate is used as a buffer to maintain optimum pH. The anticoagulant property of sodium citrate is employed for plasma and blood fractionation. Ferric ammonium citrates are used as iron sources for treatment of anemia. Cupric citrates are used in ointment for trachoma and conjunctivitis.

In recent years citrates have been employed instead of sodium tripolyphosphate (STPP) in heavy duty laundry detergents as builder. Citrates are rather poor sequestrants but they have been accepted by the major detergent producers in U.S.A. and also Europe because citrates do not cause eutrophication in lakes and marshes. Citric acid is also used for water treatment, oil field applications, plasticizers for PVC and other plastics, flue gas desulphurisation, and industrial metal cleaning and finishing products.

4–3 Properties of Citric Acid

There are two types of citric acid formations, i.e. anhydrous citric acid and citric acid monohydrate which contains one molecule of water of crystallization. The anhydrous form is obtained through crystallization of a hot aqueous solution, whereas the monohydrate form is through crystallization of a cold aqueous solution. The transition temperature between the anhydrous and monohydrate forms is 36.6 degrees centigrade. Anhydrous citric acid has monoclinic crystals which have a melting point of 153 degrees centigrade. Citric acid monohydrate has prismatic crystals and is also deliquescent. Citric acid monohydrate loses water of crystallization in dry air or by heating at 40 to 50 degrees centigrade. Citric acid is highly soluble in water and alcohol, but insoluble in other organic solvents. The pH of a 0.1 mol solution of citric acid is about 2.1.

In biochemistry citric acid is an important substance in the citric acid cycle. Decomposition and synthetic reactions are made repeatedly by microorganisms like Aspergillus niger through enzymatic dissimilation.

4–4 Standards of Citric Acid

Standards for citric acid differ in each country depending on the applications. In the competitive world markets today, consumers require stringent quality control of the physical forms, as well as chemical properties, like particle size distribution. The specification adopted in UK is shown in Table 4–1.

Table 4-1 Specification for Citric Acid in United Kingdom (British Phermacopoeia)

Description	Anhydride	Monohydrate
Clarity & Color of Solution	within the limit	within the limit
Barium	within the limit	within the limit
Calcium	200 ppm or less	200 ppm or less
Heavy Metals (as Pb)	10 ppm or less	10 ppm or less
Iron	50 ppm or less	50 ppm or less
Chloride	50 ppm or less	50 ppm or less
Oxalate	350 ppm or less	350 ppm or less
Sulphate	150 ppm or less	150 ppm or less
Readily Carbonizable Substance	within the limit	within the limit
Sulphated Ash	0.1% or less	0.1% or less
Water	1.0% or less	7.5 ~ 9.0%
Content	99.5 ~ 101.0%	99.5 ~ 101.0%

4-5 Manufacturing Technologies for Citric Acid

Citric acid is manufactured in two ways; extraction of natural citric acid from the juice of certain citrus fruits and production of synthetic citric acid through fermentation from carbohydrate materials. Before commercial productions based on the fermentation technology were established, citric acid was extracted from citrus fruits. Today, production by fermentation substantially accounts for all citric acid consumed in the world. The fermentation technology is classified into the following three methods:

(1) Surface culture : Liquid culture solution is fermented in shallow pans.

(2) Submerged culture : Liquid culture solution is agitated to provide enough aeration by sterilized air in a fermentation vessel.

(3) Solid/semi-solid culture : Solid culture medium is filled into open trays for fermentation in fermentation rooms.

Currently the submerged culture process is the most used of the above fermentation technologies in the world. The solid/semi-solid culture process was developed in Japan and is employed in several Asian countries. The surface culture process has been used for a long time but only small scale production is carried out. A variety of carbohydrates (starch and sugar) may be employed as raw materials for the fermentation but in practice cheap and easily obtainable materials, including beet molasses, cane molasses, starch syrup, cornstarch and potato starch residues, are utilized for commercial processes.

In the fermentation process, the retention of the citric acid yield of the fungi is the prime concern. For that purpose, citric acid producers are inclined to develop methods of preserving the strain to avoid degeneration of the fungi and also methods of separating superior strains. The fermentation yield largely depends on the type of fungi which must be selected according to the process and raw materials to be used. Thus the research and development of strains are prerequisites for citric acid producers.

Table 4-2 summarizes the fermentation processes adopted in commercial plants.

Table 4–2 Fermentation Process and Raw Material

Raw Material	Surface Culture	Submerged Culture	Solid Culture	Remarks
<< Starch >>				
Sweet Potato/Cassava		○	○	
Sweet Potato/Cassava Residues			○	
Cornstarch		○		
<< Sugar >>				
Cane Molasses	△	○		
Beet Molasses	△	○		
Pineapple Juice			△	Pilot Plant Only
Sugar		○		

Note ○ : Used at large scale commercial plant.

△ : Used at small scale commercial plant and/or pilot plant.

Chapter 5 Markets for Citric Acid and By-Products

This feasibility study establishes a target territory for citric acid markets in Zimbabwe and Southern African countries. This inevitably is based on a number of uncertain factors concerned with marketing and the sales which may affect the introduction of a largely export oriented citric acid plant. These include:

(1) Very tough competition can be expected from major citric acid producers as the markets in the countries north of the Sahara are close to the major world source of citric acid, which is Europe, and the markets in the Middle East and further east are the territories of the South East Asian and Chinese producers.

(2) Currently, there is equilibrium in the world's supply and demand for citric acid.

This chapter describes world citric acid markets, the domestic market in Zimbabwe and markets in surrounding countries for the projection of potential sales and plant capacity and for the estimation of product sales prices.

5-1 World Citric Acid Market

5-1-1 World Supply and Demand for Citric Acid

World demand for citric acid in 1990 is estimated to be 500,000 tons and the demand has been steadily expanding at an average growth rate of 4 to 5 percent per annum. Major contributions to the demand growth were increased demands in the diet soft drink markets in U.S.A. and conversion from phosphates to sodium citrate for use as a builder in detergents in the American and European markets to cope with environmental issues of eutrophication. The world production capacity for citric acid is estimated to be some 550,000 to 600,000 tons. Five companies, including Haarmann & Reimer (Germany), Jungbunzlauer (Austria), Archer Daniels Midland (U.S.A.), Roche (Switzerland), Pfizer (U.S.A.), have over 75 percent of the world production capacity. World citric acid markets are said to be in an oligopoly structure. By region, Western Europe is a world supply source, accounting for 45 percent of world supply, and of this one half of the production is for export.

Supply and demand balance for citric acid is shown in Figure 5–1, which indicates a considerably tight period approximately every six years. In the long-term the worldwide demand for citric acid will maintain the past trend and principally will move in line with the growth of global GNP. World citric acid demand in 1996 is projected to be 597,000 tons after which it would increase at an average annual rate of 3 percent.

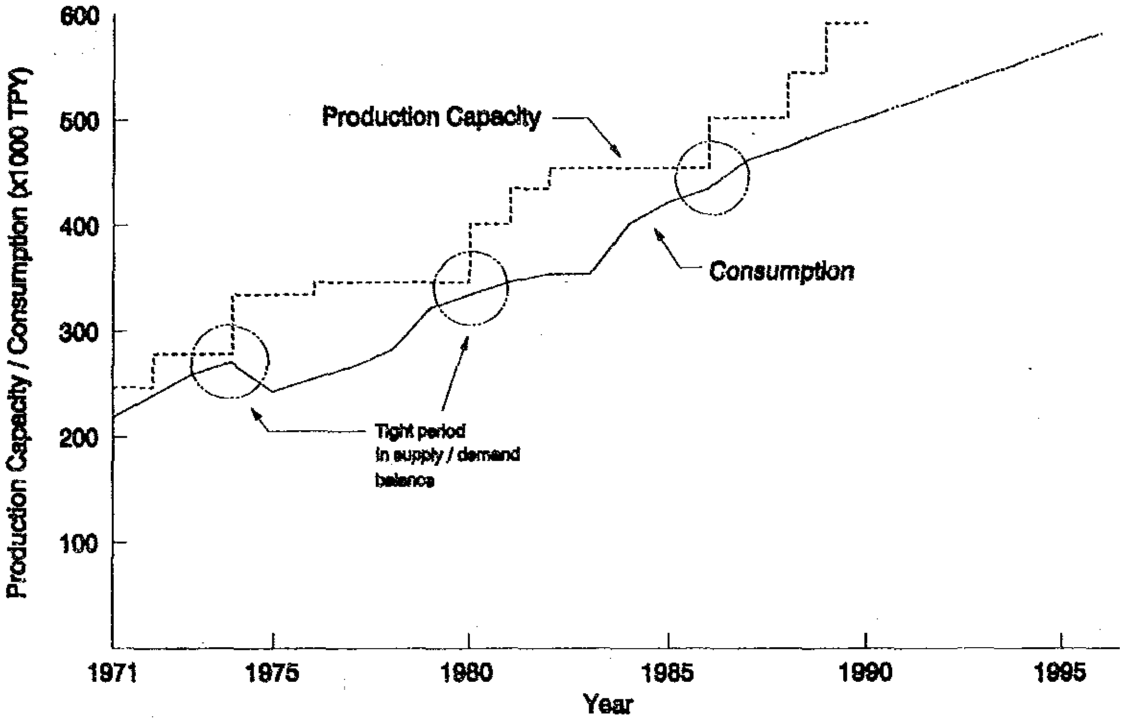


Figure 5–1 Worldwide Production Capacity and Consumption of Citric Acid

5-1-2 Prices of Citric Acid

Changes in citric acid export prices (fob basis) are indicated in Figure 5-2. The prices for Ireland, Italy and the world average vary in the range of 1.0 to 1.6 US$/kg, while the price for China 0.9 to 1.1 US$/kg. From the figure it can be understood that the prices go down when supply/demand balance is in over supply and go upwards when the market is bullish. Current international export prices (fob basis) are expected to be 1.3 to 1.5 US$/kg.

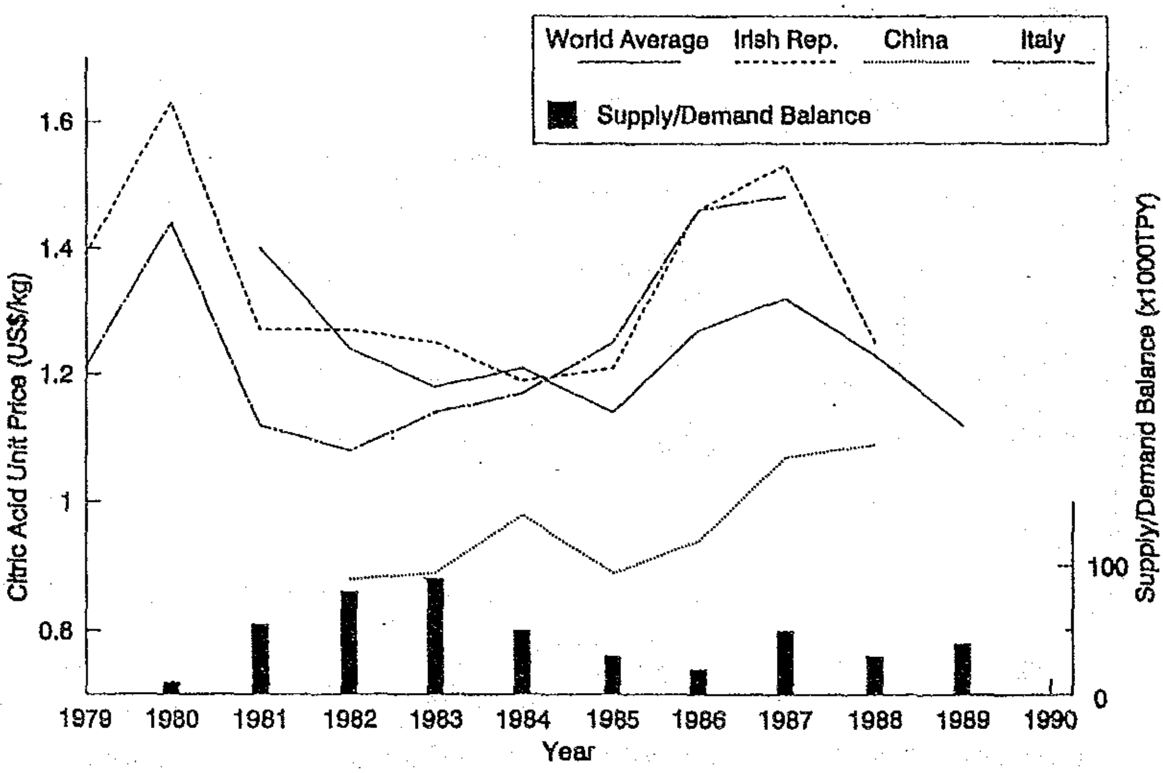
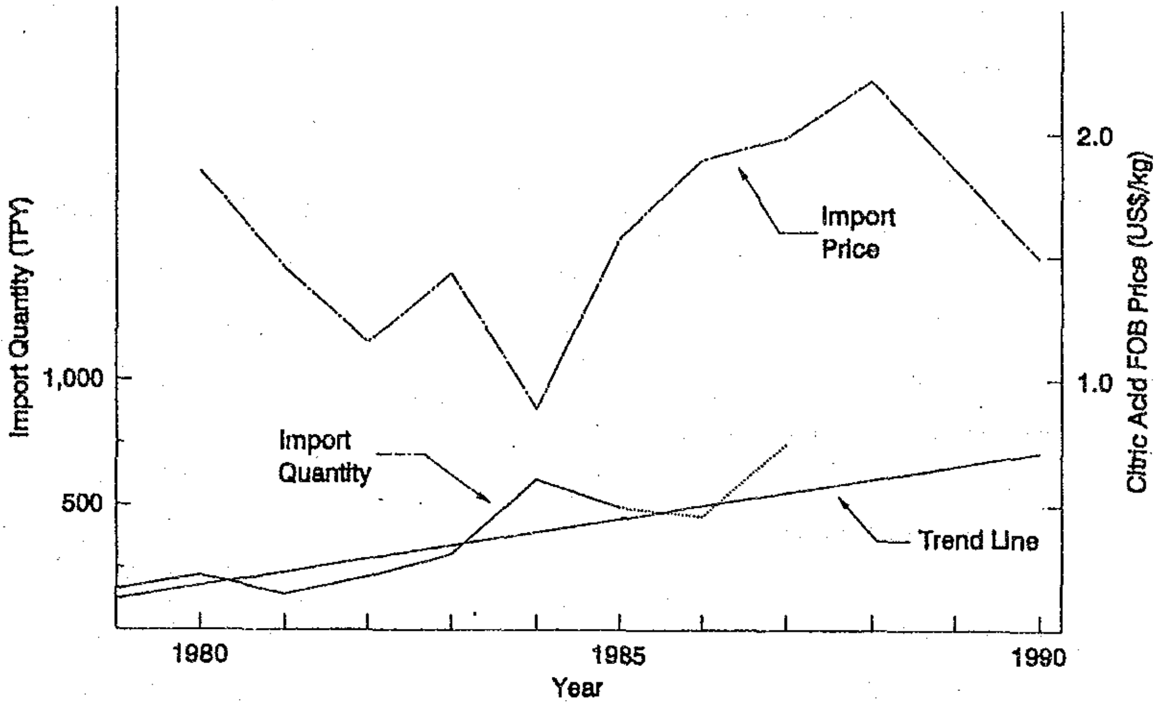


Figure 5-2 Citric Acid Export Price (FOB)

5–2 Citric Acid Market in Zimbabwe and By-Products

5–2–1 Citric Acid Market in Zimbabwe

Figure 5–3 indicates movements in citric acid import volume and its unit prices in Zimbabwe.



Note : Figures from 1985 to 1989 for only reference

Figure 5–3 Citric Acid Imports in Zimbabwe

Import volume increased when the price went down; it is expected that price elasticity to demand is relatively high. Major exporting countries, including Belgium, (West) Germany, UK, U.S.A. and China, account for over 50 percent of the total volume.

Major citric acid consumers in Zimbabwe and their consumption are shown in Table 5–1.

Table 5–1 Citric Acid Consumption in Zimbabwe (June, 1991)

Major End Users	Citric Acid Demand (ton/year)
(1) Soft Drink/Beverage Industry	
– Schweppes Ltd.	360–400
– Bush Boake Allen Zimbabwe Ltd.	20–30
– United Bottlers	22–30
– Lyons & Brooke Bond	24
– Coldrac Products Ltd.	24
– Coca Cola Export	65
	(515–573)
(2) Food Industry	
– Lever Brothers Ltd. Zimbabwe	5–7
– Cairns Holdings	5–6
– Lyons & Brooke Bond	6
– Arenel	20–30
– Olivine Industries	5 (*1)
– Crystal Candy	10 (*1)
	(51–64)
(3) Pharmaceutical	
– CAPS (Central African Pharmaceutical Society)	1–2
– Sterling Products International, Ltd.	5 (*1)
	(6–7)
(4) Others	10–20 (*1)
Total (approximately)	582–664

Note: (*1) Estimated Figures

The current estimated demand figure is 620 metric tons per annum. The soft drink sector accounts for 87 percent of the demand and the food industry for 9 percent. The overall production volume of soft drinks is estimated to be 230 million liters per year. Over 90 percent of the production is for carbonated drinks and the remaining 10 percent for non-carbonated drinks (crush and quench juices). Nearly 80 percent of the citric acid in the soft drink sector is used in non-carbonated drinks. Production of soft drinks showed a high growth, an average of 13 percent a year, in recent years as indicated in Table 5–2 although the level of actual personal incomes has been decreasing.

Table 5–2 Annual Production of Aerated Beverages

Year	Annual Production (Million liters)	Growth Rate (%)
1986	129.7	
1987	146.7	13.1
1988	158.0	7.8
1989	173.3	9.7
1990	211.3	21.9

Source : Central Statistical Office

It is estimated that the potential demand for soft drinks is very considerable and citric acid consumption will increase with the growth of soft drink consumption. The results of the citric acid demand forecast for Zimbabwe are summarized in Table 5–3.

Table 5–3 Forecast Demand for Citric Acid in Zimbabwe

Items	Demand (metric tons)			Averge Annual Growth Rate (%)
	1990	1996	2000	1990–2000
Beverages				
– Carbonated	110	196	285	10.0
– Crush/Quench	430	610	770	6.0
Food Processing	58	78	95	5.0
Pharmaceutical	7	8	10	3.0
Others	15	18	20	3.0
Total	620	910	1,180	6.7

5–2–2 Citric Acid Prices in Zimbabwe and Distribution

The current price configuration is shown in Table 5–4. Mode figures, obtained through the site survey, are in the range of 7.0 to 9.0 Z$/kg.

Table 5–4 Citric Acid Prices in Zimbabwe

Description	Price
(1) FOB price	1.3–1.6 US$/kg
(2) Freight & insurance (*1)	
(Israel-Durban)	0.08 US$/kg
(Brazil-Durban)	0.11 US$/kg
(3) Inland transportation (*1)	
(Durban-Harare)	0.12–0.18 Z$/kg
(4) Surtax	CIF × 20%
(5) Sales commission for suppliers	Landing price × (15–25)%
(6) Delivery price or wholesale price	6.0–10.0 Z$/kg

Note: (*1) Transportation by 20 tons container. Inland transportation by truckload.

Large scale consumers often import citric acid directly for most of their own consumption, whilst medium/small scale consumers purchase citric acid through chemical suppliers or agents in Zimbabwe. The number of major suppliers amounts to about ten. In general citric acid sales have high sensitivity with price and the purchase is made on a spot agreement basis.

5–2–3 Competitiveness with Other Organic Acids

Among other organic acids, malic acid can, to a small extent, be a substitute for citric acid. But it will not be in a competitive situation because of its flavor, price disadvantages and specification control at the global level by major consumers. Lactic acid and tartaric acid will not be competitive with citric acid.

5–2–4 Markets for By-Products

(1) Sweet Potato Starch

Sweet potato starch extraction residues are generated when the starch is produced from sweet potato, and are used for production of citric acid by the solid fermentation process. Sweet potato starch is not used in the starch market of Zimbabwe; instead, cornstarch dominates the market. About 47,000 metric tons of sweet potato starch is necessary, when 3,000 metric tons of citric acid is produced from the residue. In both supply and demand terms, the establishment of a sweet potato starch industry will not be justifiable at present.

(2) Gypsum

About 5,600 metric tons of gypsum will be produced annually in the process of refining 3,000 metric tons of citric acid. There is an oversupply situation for gypsum in the domestic market and it will be critical to find markets for all the amount of gypsum.

5–3 Citric Acid Markets in Southern Africa

Southern Africa for this study includes the following countries:

Republic of South Africa, Southern Africa Customs Union (Botswana, Lesotho, Namibia and Swaziland), Angola, Kenya, Madagascar, Malawi, Mozambique, Tanzania, Zaire, Zambia and Zimbabwe.

5–3–1 Citric Acid Demand in Southern Africa

The 1990 consumption of citric acid in Southern Africa is estimated to have been 4,620 metric tons of which the Republic of South Africa accounted for 60 percent, Swaziland 16 percent, Zimbabwe 13 percent and the remaining countries 11 percent.

Use in soft drinks accounted for 70 percent of the total regional use: 64 percent in the Republic of South Africa, close to 100 percent in Swaziland and over 88 percent in Zimbabwe. Most of the remainder is used in food applications with some pharmaceutical and industrial use occurring in the Republic of South Africa.

Growth of citric acid demand in the region is forecast to average 5.1 percent per year upto 2000. This would lead to an estimated 1996 consumption of 6,210 metric tons and in the year 2000, 7,600 metric tons. A breakdown of forecast demand is shown in Table 5–5.

Table 5–5 Forecast Development in Citric Acid Demand in Southern Africa, 1990 to 2000

Country	Demand (metric tons)			Averge Annual Growth Rate (%)
	1990	1996	2000	1990–2000
RSA/SACU	3,500	4,700	5,750	5.1
Zimbabwe	620	910	1,180	6.7
Kenya	150	180	210	3.4
Madagascar	100	120	130	2.6
Zambia	100	120	130	2.6
Others	150	180	200	2.9
Total	4,620	6,210	7,600	5.1

The market will continue to be dominated by South Africa which will amount for three quarters of regional demand. Beverages will continue to account for the majority of use and will grow in importance as growth rates are higher than expected for other applications.

5–3–2 Citric Acid Supply in Southern Africa

All consumption in the region is currently supplied by imports with the major sources being Belgium (La Citrique Belge - Hoffmann La Roche) and Ireland (ADM, previously Pfizer). Movement of citric acid imports in the region is illustrated in Figure 5–4.

Several companies in the Republic of South Africa have evaluated setting up citric acid production but in most cases these have been abandoned owing to the small size of the local market, adequate global capacity and the lack of appropriate raw materials. But C.G. Smith Sugar Ltd. of Durban is still seriously evaluating a citric acid project of 10,000 metric tons per year capacity.

A small citric acid plant was built in the early 1980s in Kenya but it was never started up. Owing to its derelict condition it is unlikely that it could be used.

Prices (duty paid, delivered) in the main market of the Republic of South Africa were in the range of 4.3 to 4.6 R/kg, or 1.54 to 1.65 US$/kg in June 1991. Both current fob prices and delivery prices are much cheaper than world average since the major suppliers are well entrenched.

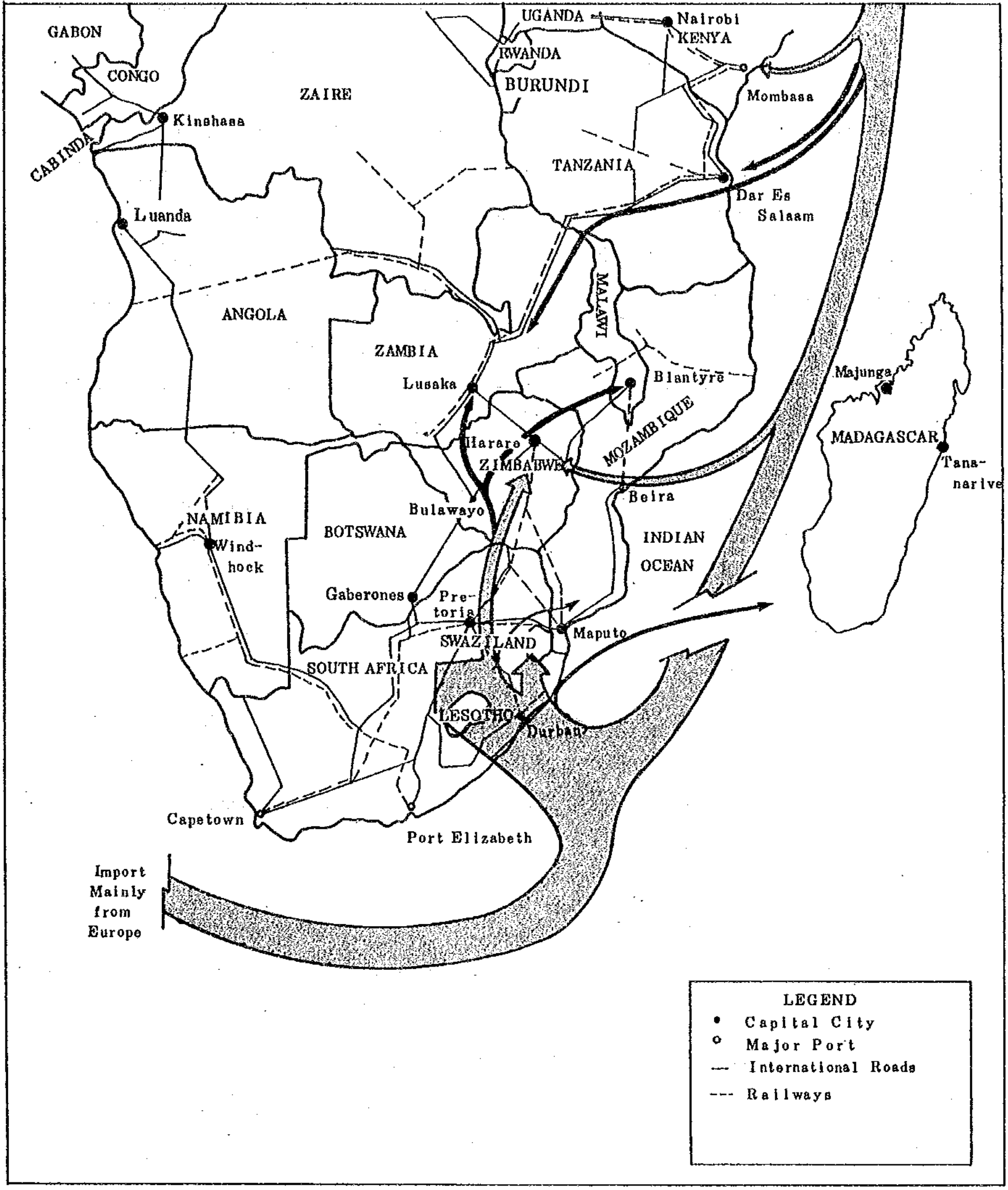


Figure 5–4 Citric Acid Movement in Southern Africa

5–4 Plant Production Capacity and Sales Prices

5–4–1 Market Domain and Plant Production

Production capacity of the citric acid plant is estimated based on the potential demands for the first year of operation, or 1996. Market domains for the sales involve Zimbabwe, the Republic of South Africa and other small consuming countries, in which it will have advantages in terms of inland transportation and costs, when compared imports. Then, production capacity is determined, taking into consideration the imports of cheaper products from China and the nature of the market in the Republic of South Africa (presence of major suppliers and consumer loyalty). Selected countries and estimated potential sales are summarized in Table 5–6.

Table 5–6 Potential Sales, 1996

Country	Potential Sales (Tons/Year)
– Zimbabwe	820
– Republic of South Africa/SACU	2,115
– Madagascar	110
– Malawi	55
– Mozambique	50
– Zambia	110
Total	3,260

Total sales potential is estimated to be 3,260 metric tons in 1996 and the plant capacity is proposed to be 3,000 to 3,300 tons per annum.

5–4–2 Sales Prices

Ex-works prices (net receipts from sales in various countries) are calculated based on current market prices as shown below.

Country	Sales Price (Ex-works)
(1) Zimbabwe	2.26 US$/kg
(2) Republic of South Africa	1.47 US$/kg
(3) Zambia and Malawi	1.54 US$/kg
(4) Mozambique and Madagascar	1.40 US$/kg

5–5 Sales Plan

The premises of the sales plan are described below:

(1) Nominal production capacity is set at 3,000 metric tons per year.

(2) As the domestic demand increases, sales volume for export markets will be decreased in order of ascending sales prices.

(3) Sales capability, or market penetration, for the first few years after commencement of operation is also considered.

The resulting sales plan for both production volume and sales amount is shown in Table 5–7 together with the demand summary.

Table 5–7 Citric Acid Demand Summary/Sales Plan by Volume and Amount

<CITRIC ACID DEMAND SUMMARY IN SOUTHERN AFRICA> (Unit: ton)

Year	1990	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. Zimbabwe	620	909	970	1035	1105	1179	1233	1289	1348	1409	1474	1541	1612	1686	1763	1844	1930	2019	2112	2210	2313
2. RSA/SACU	3500	4693	4933	5188	5456	5741															
3. Other Countries																					
.Kenya	150	183	190	196	203	210															
.Madagascar	100	117	120	123	126	129															
.Zambia	100	117	120	123	126	129															
.Mozambique	45	53	55	57	58	60															
.Malawi	50	59	61	63	65	67															
.Tanzania	30	36	37	38	39	40															
.Zaire	25	30	31	31	32	33															
.Angola	-	-	-	-	-	-															
Total	4620	6197	6515	6852	7210	7588															

<SALES PLAN BY VOLUME> (Unit: ton)

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1. Zimbabwe	703	809	862	917	977	1020	1065	1113	1162	1213	1267	1324	1383	1444	1509	1577	1647	1721	1799	1880
2. Zambia	105	108	111	113	116	119	122	126	129	132	136	139	143	147	150	154	158	162	167	171
3. Malawi	53	55	57	58	60	62	63	65	67	69	71	73	75	77	80	82	84	87	89	92
4. RSA/SACU	1267	1776	1971	1911	1847	1799	1749	1697	1642	1585	1526	1464	1399	1331	1261	1187	1110	1029	945	857
5. Mozambique	48	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Madagascar	105	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2281	2905	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Capacity Utilization	76%	97%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Domestic Sales	31%	28%	29%	31%	33%	34%	36%	37%	39%	40%	42%	44%	46%	48%	50%	53%	55%	57%	60%	63%
Export Sales	69%	72%	71%	69%	67%	66%	64%	63%	61%	60%	58%	56%	54%	52%	50%	47%	45%	43%	40%	37%

<SALES PLAN BY AMOUNT>
Citric acid unit price
.Zimbabwe :2.26 US$/kg
.Zambia/Malawi :1.54 US$/kg
.RSA/SACU :1.47 US$/kg
.Mozambique/Madagascar:1.40 US$/kg

(Unit: x1000US$)

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
1. Zimbabwe	1588	1829	1947	2073	2208	2306	2408	2514	2626	2742	2864	2992	3125	3265	3410	3563	3723	3890	4065	4248	57388
2. Zambia	162	166	170	175	179	184	189	193	199	204	209	214	220	226	232	238	244	250	257	263	4172
3. Malawi	82	85	87	90	92	95	98	100	103	106	109	113	116	119	123	126	130	134	138	142	2188
4. RSA/SACU	1863	2611	2898	2809	2714	2644	2571	2494	2414	2330	2243	2152	2057	1957	1853	1745	1632	1513	1390	1260	43150
5. Mozambique	67	69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	137
6. Madagascar	147	151	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	298
Total	3909	4910	5102	5147	5194	5229	5265	5302	5342	5383	5426	5471	5518	5567	5618	5672	5728	5787	5849	5913	107332
Domestic Sales	41%	37%	38%	40%	43%	44%	46%	47%	49%	51%	53%	55%	57%	59%	61%	63%	65%	67%	70%	72%	
Export Sales	59%	63%	62%	60%	57%	56%	54%	53%	51%	49%	47%	45%	43%	41%	39%	37%	35%	33%	30%	28%	
Average Unit Price(US$/kg)	1.71	1.69	1.70	1.72	1.73	1.74	1.75	1.77	1.78	1.79	1.81	1.82	1.84	1.86	1.87	1.89	1.91	1.93	1.95	1.97	

Chapter 6 Agriculture in Zimbabwe

6–1 Current Agricultural Situation

6–1–1 Agricultural Situation

Maize has always been a prime agricultural product in Zimbabwe. Recently, however, the types of crops have been diversified, and the areas used for crops such as sugarcane, cotton, tobacco, coffee, tea and fruit have been increased. The productivities of these crops have been much improved and the production has reached a level which makes it possible to export them.

The total population of Zimbabwe was reported to be about 9.12 million in 1988. Of the total, 6.3 million are in the agricultural sector accounting for 70% of the population.

6–1–2 Agricultural Policy

In the Second 5–Year National Economic Development Plan (1991–1995), the government intends to buy the land owned by large-scale commercial farmers, to promote a resettlement plan by transferring the land to communal peasant farmers, and to maintain the price of white maize stable.

More than one million families have migrated into the communal farm land so far; most of them have a standard of living which is less than the average as most of the communal areas have low productive land. The earning gap between successful families and unsuccessful ones has tended to increase even in the communal areas.

The government is planning to buy a further 5 million hectares of land from the large-scale commercial farmers and to have another 110,000 families resettled into this land.

There are substantial problems in the distribution of enough food for poor populations in Zimbabwe, although the situation is not critical nation-wide. It is anticipated that the food problems for poor families will become worse due to price inflation. Food price hikes have been seen in certain communal areas since transportation and distribution networks have not yet been well developed. The government is going to cope with this serious problem by deregulating the stringent controls on the movement of agricultural products, as well as liberalization programs.

6–1–3 Farm Types by Scale

Farm types in Zimbabwe can generally be divided into the following three sectors:

(1) Large Scale Commercial Farming

In general, large scale commercial farms have been owned by European people since before independence. The number of families is about 4,500.

(2) Small Scale Commercial Farming

Small scale commercial farms are owned by native commercial farmers, of which the number of families is about 10,000.

(3) Communal Peasant Farming

Communal peasant farms are owned by native subsistence farmers in communal areas, of which the number of families is about 780,000.

6–1–4 Agricultural Organization

To accelerate and promote the development of agriculture, the government established the following agencies in the Ministry of Agriculture and Land:

- Department of Research & Specialist Services
- AGRITEX
- Veterinary Services Department

Particularly for agro-economic activities, the following three sectors organize and operate their own cooperatives:

- Commercial Farmer's Union (CFU) for large scale commercial farmers
- Zimbabwe National Farmer's Union (ZNFU) for small scale commercial farmers
- National Farmers' Association of Zimbabwe (NFAZ) for communal peasant farmers

6-1-5 Natural Conditions

(1) Soils

Most of the soils in Zimbabwe are sandy and have comparatively high permeability with low water retentivity and low fertility. In particular, the nitrogen, phosphate and sulfur content is insufficient in many areas. Some areas are composed of red clay soil, loam and vertisol, which contain very small amounts of available water due to the low content of organic substances. In general, farm lands with a shallow ploughing layer in Zimbabwe tend to suffer from drought, and fertility is low as can be expected for sandy soil.

(2) Rainfall

In Zimbabwe, the climate can be divided into two distinct seasons, e.g., dry season (May to September) and rainy season (October to April).

Even in the rainy season, only limited areas have an annual rainfall of more than 1,000 mm, and these include the eastern mountainous area, Harare area and a part of Masvingo and Shurugwi provinces. Two thirds of the country, where the elevation ranges from 900 to 1,500 m, has an annual rainfall between 600 and 1,000 mm. Most of the farm land as well as grass land exists in this zone. Areas with an annual rainfall of less than 600 mm are located in the southern and western regions, and most of them are grass land.

6-2 Agricultural Production

Annual production of grains, including maize, wheat, sorghum and so on, is 2.0 to 3.0 million tons in normal years. In a drought year, the production of maize falls to only 0.9 million tons, resulting in a supply shortage of about 0.3 million tons. However, the net shortage is considered to be very small because there are stocks of 0.39 million tons of maize. The average annual production of maize from 1984 to 1986 was about 2.2 million tons and the breakdown of the domestic supply of 1.7 million tons, is as follows: feed (0.36 million tons), seed (0.04 million tons), loss (0.24 million tons) and food consumption (1.06 million tons). The total production in the last 5 years has shown a gradual decrease but the supply for domestic consumption has been secured, except in the drought year of 1987 in which the production was only 930,000 tons.

For sorghum, the annual production reached a peak of 0.35 million tons in 1985, but has decreased to as low as 0.1 million tons in recent years due to a fall in the demand for the crop. The demand for wheat has been increasing, and the production of wheat has expanded from 0.2 million tons to about 0.3 million tons per year. Production of cassava also increased from 50,000 tons to 90,000 tons. Production of sweet potatoes is expected to maintain the same level of 1,000 tons.

Sugarcane production has amounted to about 3.6 million tons consistently for a number of years as it is controlled by the sugarcane mills near the plantations. By applying an irrigated farming technique, developed by the sugar mills, the yield is very high compared to the world standard. It is said that sugarcane in Zimbabwe produces a higher yield of sugar than that of other countries.

Production of cash crops such as coffee, tea, tobacco, cotton, and fruits has been steadily increasing year by year.

6–3 Agricultural Development of Raw Materials for Citric Acid

(1) Problem Areas in Common

Farming zones suitable for upland crops (maize, sweet potato, etc.) are those with an annual average temperature of 17.5-20°C and an annual rainfall of 650-1,000 mm. These zones consist of various types of soils ranging from sand to clay loam. Drought damage has occurred once in four years due to the shallow ploughing depth and low content of readily available moisture.

Countermeasures to reduce the drought damage will take rather a long time and a lot of funds will be needed to secure irrigation water for everyday use. To alleviate drought damage, it is more practical and effective to proceed with countermeasures such soil improvement by fertilizers, deep ploughing, increasing available moisture in soils, effective use of rainfall and minimizing evaporation losses.

(2) Maize

About 6,000 tons of maize is required to produce 3,000 tons of citric acid. Compared to the total production of maize in the country, the required quantity is quite small.

The production of maize is tending to gradually decrease with considerable annual fluctuations. This can be attributed to the fact that the area planted by the highly productive large scale commercial farms has been reduced while that of the small scale communal ares with lower productivity has been increased. In other words, large scale farms are equipped with irrigation facilities and are more reliable, but the small scale farms are rainfed and less reliable.

If some of the suggested countermeasures are undertaken for rainfed farming, higher productivity is expected.

(3) Sweet Potatoes

To produce 3,000 tons of citric acid from sweet potato starch extraction residues, about 200,000 tons of sweet potatoes are needed. The present annual production of sweet potatoes amounts to only 1,000 tons, which is absolutely below the required quantity.

If the production of sweet potato is to be increased to 200,000 tons a year, 83,000 hectares of farm land are required assuming an estimated unit yield of 2.4 tons per hectare. If a production yield of 10 tons per hectare was possible with improved farming techniques, 20,000 hectares of farm land would have to be secured.

For these reasons, it is considered almost impossible to increase the production of sweet potatoes to 200,000 ton a year.

(4) Cassava

To produce 3,000 tons of citric acid from cassava starch extraction residues, about 150,000 tons of cassava are required. The present annual production amounts to only 90,000 tons, far below the required quantity. Considering the present yield of about 4 tons per hectare, about 40,000 hectares of land would be needed for the production of 150,000 tons a year.

Chapter 7 Raw Materials

7–1 Selection of the Raw Materials

Commercial production of citric acid is done by fermentation technology using carbohydrate materials. When the commercial production in Zimbabwe is considered, the provision of carbohydrate materials at cheap prices and in sufficient quantity is essential. Beet molasses prevails as the fermentation material for citric acid in Europe, while sweet potato or cassava starch extraction residues are used in Asia. Cornstarch available at low prices and in large quantities is used mainly in U.S.A. for citric acid production. Citric acid is produced by certain kinds of black molds which are called Aspergillus niger. Among the molds some specific fungi, which have superior fermentation properties, are selected and cultured to suit the specific carbohydrate material and process to be used. Hence the know-how for citric acid fermentation technology consists of appropriate combinations of fungi, carbohydrate materials and processes. In Japan, Kyushu Kako Co., Ltd. and Satsuma Kako Co., Ltd. produce citric acid from sweet potato residues, whilst Iwata Chemical Co., Ltd. manufactures citric acid from cornstarch. Although not realized on a commercial production basis, Waseda University has been developing citric acid production using sugar materials.

In these circumstances, the following raw materials were selected for subsequent studies:

- Sweet potato starch residues
- Cassava starch residues
- Cornstarch
- Raw sugar, concentrated juice (sugarcane syrup) and "B" molasses extracted from sugarcane in the raw sugar production process
- Process molasses and affination syrup extracted from raw sugar in the sugar refining process

Cornstarch is used for citric acid production by the submerged liquid culture fermentation process, whereas the other raw materials listed above are used for solid culture fermentation. The solid culture fermentation process seems preferable for citric acid production in Zimbabwe because it is a more labor intensive and capital saving process than the submerged liquid culture fermentation process. Good prospects for solid culture fermentation, however, have not been obtained from the studies due to the current availability of raw materials as described below:

(1) Sweet potato starch residues

Current production of sweet potatoes in Zimbabwe is only 1,000 tons per year or may be less and cultivation technology for sweet potatoes on a large commercial scale is still in a very premature stage. Also no sweet potato starch industry exists in Zimbabwe nor is there any demand. It will be difficult to create good prospects for a sweet potato starch industry.

(2) Cassava starch residues

The prospects for large scale cassava production would be even more difficult than that of sweet potato production. Test cultivation of cassavas has just been started recently in Zimbabwe.

(3) Raw sugar, concentrated juice (sugarcane syrup) and "B" molasses

These materials are available in Zimbabwe. All of the cane molasses, however, are already utilized for the production of ethanol which is mixed in gasoline. With increasing demand some supplemental amount of molasses is imported from Zambia. Thus it will not be suitable to use molasses for citric acid production unless there is a decrease in ethanol production or an increase in the import of molasses.

Concentrated juice is almost as expensive as raw sugar because it is a direct material for making raw sugar. So the concentrated juice is not suitable for the promotion of a process development.

(4) Process molasses and affination syrup

For the same reasons, process molasses is already utilized and affination syrup is an expensive material because raw sugar can be also recovered from the syrup.

It is concluded that all the above raw materials, except cornstarch, are not appropriate for commercial scale citric acid production.

On the other hand the study concluded that cornstarch may be employed as a citric acid raw materials for the submerged fermentation process although there is a constraint in the current supply situation as described below.

7–2 Cornstarch

At present Food & Industrial, a division of Delta Consolidated Ltd., is the sole producer of cornstarch in Zimbabwe. Their sales price for cornstarch seems a little high and the quality seems slightly inferior also as the current production is small and dependent on a rather old method. The price of cornstarch ranges from Z$ 1,341 to 1,528 per ton, depending on the use. The main reasons for the high price are the high purchasing price for maize, which is controlled by GMB (Grain Marketing Board), and the small production capacity of 1,000 tons per month. Also the dry milling process used in this facility results in an inefficient recovery of by-products, such as corn oil and gluten meal which causes an increase in the price. Control of the yellow maize price by GMB has been deregulated since April, 1990 and direct purchase from producers is now possible. Food & Industrial is planning to expand their production capacity by establishing a modern wet milling facility in place of the existing dry milling process in a few years time.

Currently the capacity of the Food & Industrial plant is almost fully utilized to supply the domestic cornstarch market. To meet the new demand for citric acid production, an expansion of the existing plant or a new plant is a prerequisite. In this event the wet milling method, which may provide better quality for citric acid production, will certainly be used.

There are no substantial differences between white maize and yellow maize for cornstarch production. There is good variety of yellow maize in Zimbabwe that can yield a harvest of 10 to 12 tons per hectare by specialized commercial farmers. This yield is much higher than the 7 tons per hectare achieved in US, a major maize exporting country. Hence, cornstarch is thought to be the most suitable raw materials for citric acid in Zimbabwe.

7–3 Sub-Materials

Chemicals, such as ammonium nitrate, potassium dihydrogen phosphate and magnesium sulfate, are necessary as nutrients for citric acid fermentation using Aspergillus niger. Ammonium nitrate is produced by Sable Chemical Industries Ltd. in Zimbabwe and other chemicals will have to be imported. The amounts of these imported chemicals are not so large and no restrictions are foreseen.

After fermentation the citric acid solution is neutralized with slaked lime and collected in the form of calcium citrate. This calcium citrate is then dissolved in sulfuric acid and then refined. This part of the process requires large amounts of slaked lime and sulfuric acid. Both slaked lime and sulfuric acid are produced in Zimbabwe. Sufficient sulfuric acid is produced with a well maintained quality. However the quality of the slaked lime must be improved for citric acid use.

Activated carbon is used for decolorization of citric acid in the recovery process. In Zimbabwe, bone charcoal is manufactured for the decolorization of sugar but it is not suitable for the decolorization of citric acid.

Filter aid is also used in the recovery process. The subsidiary materials, including slaked lime, activated carbon and filter aid, are to be imported. They are rather cheap and easily available in international markets.

7-4 Packaging Materials

Citric acid is a hydroscopic material which requires good packaging when it is shipped out. In Zimbabwe there are several packaging/bag manufacturers for grains, coffee, sugar and so forth. If requested, they are able to make suitable bags for citric acid.

Chapter 8 Plant Site and Infrastructure

8–1 Selection of the Plant Site

Compared with capital-intensive and large-scale plants in the chemical industry, the scale of citric acid plants is rather small. The required daily quantity of raw material, e.g. cornstarch, is about 12 tons for the production of 3,000 tons of citric acid per year, and so the transportation and storage of materials will not cause any restrictions on siting. Also electric power and water consumption are not so large. So the citric acid plant may be constructed anywhere provided a certain infrastructure is maintained.

Because citric acid is produced by fermentation of aerobic molds, agitation and aeration of the liquid culture solution in the fermentation vessel are essential. Stoppage of the agitation and aeration as a result of power failures will change the nature of the molds. So a reliable power supply is one of the essentials for the selection of the site.

Cornstarch has been selected as the principal raw material for this project as described in Chapter 11 "Project Scheme". This chapter also briefly describes other plant sites for all the candidate materials studied in Chapter 7 "Raw Materials".

If sweet potato starch residues are considered as the raw material, the outskirts of Harare city and places adjoining the sugar factories of Triangle Ltd. and Hippo Valley Estate Co. are suitable for the citric acid plant as both areas are good for sweet potato farming in geological and meteorological terms. The infrastructure in Harare is the most integrated and many industries have developed there. At places adjoining the sugar factories, electric power and steam may be provided from the two factories.

Test cultivation for cassava has been conducted at the Binga area.

As the infrastructure in Binga is not well maintained, the Hwange area near Binga must be considered as a better location.

Places adjoining Triangle Ltd. and Hippo Valley Estate Co. are the best locations for citric acid production using raw sugar, sugarcane syrup or "B" molasses.

For citric acid using process molasses or affination syrup, places close to sugar refining factories in either Harare or Bulawayo should be selected.

For citric acid production from cornstarch, a site next to the Zimphos factory has been selected as described below:

8-2 Plant Site in the Case of Cornstarch

Food & Industrial is the sole cornstarch producer in Zimbabwe as stated in Chapter 7, and it is located in Chitungwiza city. Since they do not produce sufficient cornstarch for an assumed new citric acid plant at present, an expansion or a new plant is necessary to meet the demand.

The commercial production of maize in Zimbabwe is done in the Harare area and Mashonaland which is located to the north-east of Harare. A new cornstarch plant, therefore, would probably be constructed in one of these areas. Of these areas, production of cornstarch is expected to be based in Harare or the surrounding cities, Chinhoy/Banket area, and Bindura/Glendale area. All of them have a well maintained infrastructure for the citric acid plant, but Harare has the most advanced infrastructure, and is best for securing engineers/technicians and transportation.

The industrial belt of Harare city, particularly in the south-west part of the city, has developed along the railway extending east and west in the south of Harare. However adequate open space will not easily be acquired there, but the south-east part of the city has enough space for a citric acid plant. In this study, the plant site has been determined to be in the vacant area adjacent to the existing Zimphos superphosphate factory in Mukuvisi district of Harare for the following reasons:

(1) Zimphos produces sulfuric acid, which is necessary for citric acid production. Safety for sulfuric acid transportation is much better and its cost will be much lower in comparison with other places.

(2) Zimphos has huge stock pile of gypsum, which is produced as a by-product of superphosphate. A large volume of gypsum is also produced by the citric acid process and this can be stocked in the same place.

(3) A railway and trunk roads are near the site.

(4) Electric power lines, city water and sewage pipes can be easily extended to the site.

(5) A major citric acid market is located at a distance of 20 to 30 kilometers, which is desirable for transportation.

8-3 Electric Power

Electric power is supplied by ZESA (Zimbabwe Electric Supply Authority) in Zimbabwe. 330 kV transmission networks extend to major cities. There are two 330 kV lines, owned by CAPC (Central Africa Power Company), supplying Harare city from the hydropower stations at Kariba dam and in Zambia. These circuits are interconnected to Hwange power station through Sherwood substation.

Harare has a thermal power station for back up and emergency use. The proposed citric acid plant can receive a stable power supply from ZESA.

8–4 Water Supply and Sewage

Zimbabwe has a rainy season and dry season. There are plenty of reservoirs which store water for the dry season. The central government is responsible for the construction and maintenance of such water sources, whereas the municipal government manages the local water supply and sewage. In the Harare area there are plenty of small water storage ponds, in addition to the large lakes such as Robertson lake and McILwaine lake which provide enough water. Both industrial and public water are supplied through the same distribution pipelines. Factories discharge waste water into the municipal sewers after simple treatment.

8–5 Transportation

Paved trunk roads in Zimbabwe are well maintained, and extend to all major cities. However, because of track shortages, the transportation of equipment and materials largely depends on railways, whereas passengers and commuters rely on buses for transport. Railways in Zimbabwe are operated by NRZ (National Railways of Zimbabwe), and extend to all major cities with a single track railway system. Also this railway network connects to the port of Beira in Mozambique via Machipanda, the port of Maputo in Mozambique via Chicualacuala, and the port of Durban in the Republic of South Africa via Beitbridge. Of these the port of Maputo is the nearest port from Harare. Railway lines from Harare to Maputo are often interrupted by the rebellion in Mozambique. Currently, therefore, the transportation of most materials relies on the route through Durban.

Chapter 9 Environmental Protection

This chapter describes measures and facilities regarding the environmental protection of the citric acid plant. Facility cost is explained in Chapter 13 "Plant Cost".

The proposed citric acid plant creates substances with some environmental impact as shown in Table 9–1. Among these substances, the waste water is of most concern for environmental protection, as it contains organic materials and would show a high figure of BOD (Biochemical Oxygen Demand). Specifically, the large amount of waste water generated by the fermentation process will show a high BOD figure, as the waste water contains a large amount of organic materials, such as the culture medium remaining at the end of fermentation, and part of the unused phosphorus and potassium. This waste water will cause eutrophication of rivers, lakes and marshes if discharged without treatment. Also the treatment of the boiler exhaust gas is necessary to prevent air pollution.

In order to plan environmental protection measures for the citric acid plant, several studies were conducted to find out how the waste characteristics conform with Zimbabwe standards. Effective utilization of wastes was also considered as far as possible.

9–1 Environmental Protection Acts of Zimbabwe

The environmental protection laws of Zimbabwe have evolved from the Atmospheric Pollution Prevention Act and Water Pollution Prevention Act enacted by the former Rhodesia government in 1971. The Atmospheric Pollution Prevention Act regulates the substances, areas and processes, but does not provide limits for gases, dust and smoke. When a plant or factory is constructed, an environmental impact assessment must be submitted to the Ministry of Health. The Ministry evaluates the application by comparison with protection measures taken in other similar plants and the environment at the plant sites.

The Water Pollution Prevention Act classifies rivers into two zones with different specifications for controlling waste water and effluent water in each zone. Harare city has its own standards for industrial effluents which are discharged into the city sewage system.

Table 9–1 Kinds, Quantities and Properties of Wastes from a Citric Acid Plant

Kinds of Waste	Amount Discharged	Properties
<<Air Pollution>>		
Boiler exhaust gas	3,668 – 6,927 Nm^3/h	Dust concentration: 17.1 g/Nm^3
<<Water Pollution>>		
Waste water	135 m^3/d	pH : 6 – 9 BOD : 10,000 mg/ℓ COD : 16,000 mg/ℓ SS : 200 – 300 mg/ℓ
Floor drains and cleaning water	100 m^3/d	pH : 6 – 9 BOD : 500 mg/ℓ SS : 20 mg/ℓ
Waste water from the cooling tower	900 m^3/d	pH : 6 – 9 BOD : 15 mg/ℓ SS : 10 mg/ℓ
Domestic waste water from plant employees	0.2 m^3/d/head	pH : 6 – 9 BOD : 200 mg/ℓ SS : 200 mg/ℓ
Domestic waste water from company residences	0.2 m^3/d/head	pH : 6 – 9 BOD : 200 mg/ℓ SS : 200 mg/ℓ
<<Waste>>		
Waste mycelium	9 t/d	Water cont. : 80%
Gypsum	17 t/d	Water cont. : 25%
Waste carbon	513 kg/d	Water cont. : 65%
Coal ash	2 – 3.2 t/d	Water cont. : 20%
Excess sludge	45 m^3/d	Water cont. : 99%
Dust removed from boiler exhaust gas	1 – 2.3 t/d	Water cont. : 5%
Incineration ash	7 – 72 kg/d	Water cont. : 5%

9–2 Atmospheric Pollution Control

The proposed citric acid plant is provided with a boiler for the generation of steam used for the sterilization, crystallization and drying processes. A coal fired boiler will be used as petroleum products are not so plentiful in Zimbabwe. Thus the removal of fly ash and soot in the exhaust gas from the boiler will be a principle concern. Although there are no regulations to control the dust, an approval from the Ministry of Health is a prerequisite for plant construction. Based on interviews conducted during the field survey and the anticipated amount and quality of dust in the waste gas, approval for the installation of a coal fired boiler in the citric acid plant will be granted if the dust removal ratio of the boiler is more than 90 percent and the chimney is designed to be 20 meters or higher.

In general, cyclones can efficiently remove dusts and are also widely used in Zimbabwe. The study showed that the collection efficiency of a cyclone is more than 90 percent for dust particles greater than 10 micro-millimeters and more than 91 percent overall for dust. The area required for installation of the cyclone will be about 40 square meters (8 meters by 4.7 meters).

9–3 Water Pollution Control

Waste water from the citric acid plant will be discharged into the sewage systems of Harare city after certain treatment. Such waste water has a high BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) values and a high SS (Suspended Solid) concentration, but contains no toxic substances. Harare city has its own regulations for industrial effluent water discharged into the city sewage systems, but there are no specific values for BOD and COD (there is only a lenient SS value). Hence if the plant is only to follow the about regulations, no specific controls for water pollution are necessary.

Eutrophication is increasing in lake McILwaine because industrial effluent water, public waste water and agricultural chemicals flow into the lake through the sewage treatment system. This lake is one of the water sources for Harare city and the eutrophication is causing social problems at present. Therefore to avoid increasing the burden on the lake, the waste water from the citric acid plant should be treated in a proper way. By referring to the regulations of Harare city as well as to specified values adopted in Japan, the following standards were established:

- pH : 6–9 (specified by Harare city)
- BOD : 600 mg/liter (specified in Japan)
- SS : 60 mg/liter (specified in Japan)

Among the various sources of waste water from the citric acid processes, the separation process creates the most concentrated waste water, which will have figures that exceed the standard values listed above. Since the BOD concentration is as high as 10,000 mg/liter, the raw waste water is to be diluted by the water discharged from the cooling tower (265 m^3/day) to give 3,385 mg/liter before it is sent to the biological treatment plant. The treatment process is as follows:

- Primary treatment : Screening process, with a bar spacing of 0.5 mm
- Secondary treatment : Batch type lagoon process
  BOD volumetric loading of 0.3 kg/m^3–day

There are three types of biological treatment processes, i.e. activated sludge process, aerobic digestion process and lagoon process. The improved batch type lagoon process should be adopted for the treatment of the waste water in this project. In this process, the waste water is treated in a single activated sludge tank. Inflow of the raw waste water, aeration process, sedimentation process and discharge of the treated water are continuously repeated in this tank. The advantages of this process are summarized as follows:

(1) The structure is simple and the construction cost is lower than that of the other processes.

(2) The treatment efficiency is higher than the ordinary lagoon process.

(3) It is possible to save aeration power by an automatic control system which will respond to fluctuations of the inflow load. Also a steady performance can be achieved.

(4) It is possible to completely mix sludge in the lagoon tank by vertical and horizontal aeration. The power required for the mixing operation is lower than that of a standard activated sludge process.

(5) Nitration and de-nitrification can be achieved by varying the aeration using an automatic control system.

Other waste water can be discharged into the sewage system as the BOD values are lower than the specified limits.

9–4 Wastes

Wastes created from the citric acid plant are summarized in this section. The utilization of wastes is desirable. However, as the amount of the wastes is quite large, incineration of excess wastes is also considered.

(1) Waste mycelium

The amount of waste mycelium is about 9 tons per day, and it has a water content as high as 80 percent. After reducing the water content to 30 percent or so, the waste mycelium can be reused as compost for agricultural applications.

(2) Gypsum

The largest amount of waste discharged from the citric acid plant is the 17 tons/day of gypsum. Gypsum can be utilized for cement, gypsum board, plaster, calcined gypsum, agricultural use, etc.

(3) Coal ash

About 2 to 3.2 tons of coal ash is discharged daily. The coal ash can be utilized as an agent for mixing in cement and fertilizers, and as a foundation strengthening agent.

(4) Flue dust

About 1.0 to 2.3 tons of flue dust are discharged by the dust collector. This dust can be utilized as a foundation strengthening agent.

(5) Excess sludge

Excess sludge is a well digested organic sludge and does not smell badly. The excess sludge can be pumped up from the lagoon tank by a submersible pump and can be spread on farmland as a fertilizer.

(6) Incinerator ash

The principle use for waste activated sludge is as a fertilizer. If there is not sufficient area of farmland near the plant site, the excess of waste activated sludge is to be incinerated. About 3.5 kilograms of ash is produced from the incineration of the waste activated carbon, the amount of ash discharged is about 72 kilograms per day. The ash can be utilized in the same way as the coal ash.

Chapter 10 Citric Acid Fermentation Tests

10–1 Objective and Methods of the Fermentation Tests

Citric acid is produced by a fermentation process using carbohydrates as raw materials. The fermentation process utilizes microorganisms and the combination of raw materials and fermentation process (fungi and fermentation conditions) greatly influences the performance of the plant and the yield of citric acid. All commercialized technologies have been developed through the process of research and development into fermentation conditions to match a specific species of fungus with abundantly available and inexpensive raw materials. The fungi are selected and improved to suit the specific raw material. Appropriate combinations of raw materials and fermentation processes can be derived from previous experiments to some extent. However, there are a lot of unknowns in fermentation. Therefore, if an existing technology is to be applied to a specific raw material, fermentation tests must inevitably be conducted. Combinations of raw materials available in Zimbabwe at present or in the near future and fermentation technologies commercialized in Japan are as follows:

(1) The submerged culture fermentation process using cornstarch

(2) The solid culture fermentation process using sweet potato starch extraction residues and cassava starch extraction residues

For the purpose of investigating the possibility of commercial citric acid production in Zimbabwe, fermentation tests were carried out by two companies who are actually producing citric acid commercially using the above mentioned raw materials and fermentation processes. Also sugar products obtainable at reasonable prices in Zimbabwe such as crude sugar, concentrated cane juice, and cane molasses can be used as raw materials for citric acid production, although the applicable process is still in the laboratory stage. For the purpose of investigating the possibility of citric acid production using sugar products, fermentation tests were conducted by Waseda University which is developing the abovementioned process.

10-2 Fermentation Tests using Cornstarch

In this study, the compatibility of fermentation technology (fungi and fermentation conditions) used in Japan and cornstarch manufactured in Zimbabwe (two brands of cornstarch; STARCON and STARTEX-45) was reviewed. Fermentation tests were conducted in the following manner:

(a) Analysis of the sample materials
(b) Fermentation tests in flasks
(c) Reviews and analyses of the fermentation test results and the establishment of better fermentation conditions
(d) Re-test of fermentation in flasks
(e) Jar fermentation test using 30 liter jars

The results of the analysis of the two kinds of cornstarch revealed that Zimbabwean cornstarch contained more protein and is considered slightly inferior as a raw material for citric acid. Also, the high electrical conductivity means that there are considerable amounts of electrolytes as impurities and this will present some problems. After chemical analysis of the raw materials, fermentation tests using Erlenmyer flasks were conducted. Conditions of the fermentation tests were the same as those adopted for the commercial plant. Yields of citric acid production (after 7 days of fermentation) are shown below. These figures were in fact inferior to the results of fermentation tests using Japanese cornstarch as a raw material. Especially in the case of STARTEX-45, an overgrowth of fungi occurred and the production of citric acid was low. However, from the results of the fermentation tests, it was judged that, by changing fermentation conditions, both cornstarches could be used as raw materials for citric acid production.

Yields of citric acid production (first flask test)

– STARCON	Yield against total sugar	:	77.00%
	Yield against consumed sugar	:	84.18%
– STARTEX-45	Yield against total sugar	:	66.13%
	Yield against consumed sugar	:	71.99%

Based on the results of the first round of fermentation tests in flasks, the second fermentation test in flasks was carried out. This time, in order to suppress the overgrowth of fungi, some of the fermentation conditions were changed. As a result, considerable improvements were observed as shown below:

Yields of citric acid production (second flask test)

– STARCON	Yield against total sugar	:	78.40%
	Yield against consumed sugar	:	86.22%
– STARTEX-45	Yield against total sugar	:	75.67%
	Yield against consumed sugar	:	84.51%

As a result of the flask tests, it was judged that Zimbabwe cornstarch could be used as the raw material for citric acid production, and confirmation tests were carried out on a larger scale using jar fermenters. The results of the jar fermentation tests were almost the same as the results of tests using Japanese cornstarch as shown below:

Yields of citric acid production (Jar fermentation test)

– STARCON	Yield against total sugar	:	81.98%
	Yield against consumed sugar	:	89.71%
– STARTEX-45	Yield against total sugar	:	80.45%
	Yield against consumed sugar	:	90.09%
– Japanese cornstarch	Yield against total sugar	:	83.98%
	Yield against consumed sugar	:	90.14%

As a result of the flask fermentation tests and the jar fermentation tests, it was confirmed technically that Zimbabwean cornstarch could certainly be used as the raw material for citric acid production by the submerged culture fermentation process. Zimbabwe cornstarch contains more protein, ash, and metal substances such as iron, than Japanese cornstarch, however, it was proved that these impurities would not be critically detrimental to the citric acid fermentation process.

10–3 Fermentation Tests using Sweet Potatoes and Cassavas

The dried slices of sweet potatoes and cassavas shipped from Zimbabwe were processed for making sweet potato starch extraction residues and crushed whole sweet potato and cassava chips for the tests. A series of fermentation tests was carried out by scaling up from tests in (a) petri dishes, (b) 500 m ℓ beakers, and (c) a fermentation tray, placing the tray in an actual fermentation room in a factory. Because the amount of cassava collected in Zimbabwe was small, the fermentation tests in beakers and a tray were not carried out for cassava.

(1) Fermentation tests using sweet potato starch extraction residues

Fermentation tests were carried out using Petri dishes, and adding Japanese rice bran and wheat bran as nutrients for a period of 7 days. Yields of citric acid production against total sugar were as follows:

- Yield for sweet potato starch extraction residue, with added rice bran : 80.7%
- Yield for sweet potato starch extraction residue, with added wheat bran : 74.7%

As the results of the Petri dish tests were good, fermentation tests using 500 m ℓ beakers with increased amounts of the sample material were carried out. The method of the test was the same as that applied for the Petri dish test, but in order to increase the aeration characteristics of the culture medium, a small amount of Zimbabwe bagasse was added. Yields of citric acid production against total sugar were as follows:

- Yield for sweet potato starch extraction residues + bagasse and rice bran : 79.3%
- Yield for sweet potato starch extraction residues + bagasse and wheat bran : 75.5%

The results of the fermentation tests using 500 m ℓ beakers were good. Therefore, a fermentation test was carried out using a tray actually used for commercial production and placing the tray in a fermentation room of a factory. The test method used for the tray test was basically the same as the fermentation method used for commercial production. However, in view of the fact that the amount of the sweet potato starch extraction residues was limited, one fifth of the tray (about 50 cm long by 35 cm wide by 12 cm high) was separated by a partition plate and filled with a culture medium of the starch extraction residues mixed with a small amount of bagasse. The fermentation test was carried out in the fermentation room. The yield of citric acid production against total sugar was 80.2%. The average yield in Japan is about 85%.

(2) Fermentation test using cassava starch extraction residues

The fermentation tests were carried out using cassava starch extraction residues to which were added Japanese rice bran or wheat bran as a nutrient and bagasse as a substance to improve the aeration characteristics of the culture medium. The test methods were similar to those applied for the sweet potato starch extraction residues. The yields of citric acid production against total sugar were as follows:

- Yield for cassava starch extraction residues + rice bran : 85.4%
- Yield for cassava starch extraction residues + rice bran + bagasse : 87.7%
- Yield for cassava starch extraction residues + wheat bran : 77.6%

(3) Fermentation test using crushed whole sweet potato

A fermentation test was carried out using crushed whole sweet potato as a raw material, bagasse as a carrier and rice bran as a nutrient. The yield of citric acid production became highest 96 hours after the start of fermentation reaching a value of 81% (for Petri dish test) and of 77.5% (for beaker test), both against total sugar. When whole sweet potato was used, excess heat generation due to excess nitrogen content was observed.

(4) Fermentation test using crushed whole cassava

A fermentation test was carried out using crushed whole cassava as a raw material, bagasse as a carrier and rice bran as a nutrient. The yield of citric acid production was highest 120 hours after the start of the test. The yield against total sugar was 85.4% in the case of the Petri dish test and 82.5% in the case of the beaker test. The fermentation of whole cassava was very active and generated a considerable amount of heat, although the nitrogen content in cassava was lower than in sweet potatoes.

(5) Conclusion

Good results were obtained from the fermentation tests conducted using sweet potato starch extraction residues which were processed in a laboratory from sweet potatoes and cassava harvested in Zimbabwe. In the case of cassava, the fermentation tests using 500 m ℓ beakers and an actual tray were not carried out because the amount of cassava collected in Zimbabwe was small. Good results were obtained by the fermentation test using Petri dishes and it is judged that commercial production of citric acid would be possible using the cassava starch extraction residues as a raw material. An additional test was also conducted using a culture medium with added bagasse, because, judging from the condition of the starch extraction residues, it was assumed that the addition of bagasse as a carrier would improve fermentation test results. The results of the fermentation test were far better than anticipated. It was also confirmed by fermentation tests using crushed whole sweet potato and cassava that good results could be achieved by using a suitable carrier. As excess heat generation was observed due to an excessive content of nitrogen and other nutrients, it will be necessary to make studies to find conditions which suppress fermentation activity so as to reduce the heat generation when designing a large scale fermentation plant for commercial production. Judging from the above, it is concluded that citric acid production using sweet potato and cassava is technically possible and feasible. Wheat bran can be used as a nutrient for the solid culture fermentation process, although the fermentation test showed results somewhat inferior to those for rice bran.

10–4 Fermentation Tests using Sugar Related Materials

The fermentation tests were carried out using the following raw materials and a carrier which were collected during the field survey.

(1) Carrier

- Bagasse

(2) Sugar related raw materials

- Crude sugar
- Affination syrup which is obtained in the process of refining crude sugar
- Condensed sugarcane syrup
- Process molasses which are obtained from the process of refining crude sugar.
- "B"molasses, mother liquor after extracting crude sugar twice by crystallization

The yield of citric acid production against total sugar were as follows:

Raw material	Yield
– Crude sugar	80.6%
– Affination syrup	39.5%
– Condensed sugarcane syrup	62.3%
– Process molasses	74.5%
– "B" molasses	25.0%

From the results of the above tests, the semi-solid culture fermentation method using crude sugar seems to be technically possible. The results of the fermentation test using the condensed sugarcane juice and the process molasses were also comparatively good.

Chapter 11 Project Scheme

11–1 Plant Capacity

This feasibility study establishes a target territory for the citric acid market in Zimbabwe and other Southern African countries. This inevitably is based on a number of uncertain factors concerned with marketing and sales which may affect the introduction of a largely export oriented citric acid plant.

It is estimated that the domestic market for citric acid in Zimbabwe in 1996 (planned operation commencement year), will be about 900 tons per year. Demand for citric acid in the Republic of South Africa in 1996 is forecast at 4,700 tons per year, while the demand in other neighbouring countries is estimated to be 600 tons per year. Thus the total demand for citric acid will be about 6,200 tons in 1966. The potential sales expected for the subject plant will be 3,300 tons per year, which corresponds to 53% of the total area demand.

From the viewpoint of economics, the production capacity of a citric acid plant should preferably be as large as possible. On the other hand, after constructing a large scale plant, if the product is not sold as planned and the plant is obliged to operate at reduced capacity, the financial burden of the project will be increased. This kind of situation should be avoided by all means. The plant capacity has been, therefore, determined at 3,000 tons per year, which is somewhat on the conservative side of anticipated sales for this project.

11–2 Selection of Raw Materials

As the raw materials for citric acid production, the following materials have been considered for this project:

(1) Sweet potato starch extraction residues
(2) Cassava starch extraction residues
(3) Cornstarch
(4) Sugarcane molasses
(5) Sugar intermediate products such as concentrated cane juice and crude sugar

Of these materials, citric acid production using sweet potato starch extraction residues or cassava starch extraction residues uses the solid culture fermentation process. The initial investment for this method is lower than that of the submerged culture fermentation process. Also, it is a labor intensive operation. Thus the solid culture process can be recommended for application in Zimbabwe. So the priority was placed on a process using sweet potato starch extraction residues or cassava starch extraction residues. However, these are not produced in Zimbabwe, and only a small amount of sweet potatoes and cassavas are available; these are harvested by primitive cultivation methods on a small scale. Therefore, sweet potato and cassava were deleted from the list of candidate raw materials for this project.

All available sugarcane molasses are used as the raw material for producing ethanol for blending into gasoline and some amounts are imported from Zambia to make up shortages. A citric acid plant using crude sugar or concentrated cane juice has not been developed yet and costs for these materials are higher than the price of molasses. For these reasons sugarcane molasses, crude sugar and concentrated cane juice are not suitable.

After discussing the selection of raw materials, cornstarch remains as the practical raw material for this project.

The production of maize in Zimbabwe is approximately one million tons per year, although it has declined slightly in recent years. The harvest of maize is high in Zimbabwe and its maize production is competitive by world standards. The required amount of maize for this project is about 6,000 tons per year and there will be no constraints in supplying this amount of maize.

The annual production of cornstarch in Zimbabwe amounts to 12,000 tons. Currently, there is no surplus capacity to supply the 4,100 tons of cornstarch required for the annual production of 3,000 tons of citric acid, but an expansion of the existing plant or installation of a new cornstarch plant is greatly expected since the domestic demand for cornstarch is large. The price of cornstarch in Zimbabwe is high at present, but it will become lower.

Thus, cornstarch was finally determined as the raw material for this project.

11–3 Comparison of Processes for Citric Acid Production

11–3–1 Solid Culture Method

The fermentation tests using the starch extraction residues, processed from Zimbabwe's sweet potatoes and cassavas, and Japanese rice bran showed yields against total sugar of about 80% for the sweet potato starch residues and about 85% for the cassava starch residues respectively. Thus, citric acid production by the solid culture fermentation process using either material is technically possible.

However, the raw materials, sweet potato starch extraction residues and cassava starch extraction residues, and the nutrient, rice bran, are not available in Zimbabwe. So, the solid fermentation process was abandoned for this project.

11–3–2 Submerged Culture Method

The submerged culture fermentation plant is a modern chemical plant and consists of raw material feed tanks, fermentation tanks, pumps, air compressors, heat exchangers, filters, valves, etc. Therefore, the investment cost of the plant is higher than the solid culture process plants and electric consumption is large.

Several kinds of raw materials can be used in the submerged culture fermentation process, such as cornstarch, beet molasses, cane molasses, and sweet potatoes. A number of plants are in operation around the world using this process. Each plant owner develops proprietary fungi for his own use.

The following raw materials are used by the citric acid producers:

- Cornstarch : Iwata Chemical, Cargill, Pfizer, Miles
- Beet molasses : Sturge
- Cane molasses : Bayer
- Sweet Potato : China (licensed by Vogelbusch)

The fermentation tests using two kinds of cornstarch made in Zimbabwe showed a yield of about 81% against total sugar, or a yield of about 90% against consumed sugar, which are almost the same yield figures as those obtained in commercial production in Japan. Therefore, it is concluded that citric acid production by the submerged fermentation process using the cornstarch has good prospects.

In Zimbabwe the cost of electricity is low. Thus, it was decided to adopt the submerged fermentation process for this project.

11–4 Environmental Protection

The citric acid plant using the submerged fermentation process will create organic waste water from the separation process and waste gas from the steam boiler, which will require certain environmental protection measures. For the waste water treatment, an improved lagoon type process is to be installed, and for the waste gas treatment, cyclones are to be furnished. Also other wastes, such as mycelium and gypsum, are to be utilized as much as possible.

11–5 Plant Site

As a result of a field survey around Norton city, Chitungwiza city and the Mukuvisi area in the suburbs of Harare city, a location next to the Zimbabwe Phosphate Industries plant in the Mukuvisi district was determined to be the most suitable site for establishing the citric acid plant.

This location has several favorable conditions: namely, it is not far from the maize collecting area or cornstarch producing area; a railway siding can be extended for transport of raw materials and products; the ground of the site is very firm; and, high-voltage power lines, industrial water systems and sewage system can be easily extended into the site.

11–6 Summary of the Project Scheme

The scheme for this project is summarized as follows:

- Plant capacity : 3,000 tons per year as citric acid monohydrate, complying with BP standards
- Raw material : Cornstarch made in Zimbabwe
- Process : Submerged culture method
- Plant site : Mukuvisi district, about 10 km east from the center of Harare city

Based on the above project scheme, the conceptual design, plant construction cost estimates, operating plan, financial analysis, and so forth were conducted.

Chapter 12 Conceptual Design of the Plant

This chapter describes the conceptual design of a plant which produces 3,000 tons per year of high quality citric acid monohydrate based on the project scheme as described in Chapter 11.

12–1 Assumptions of the Plant Design

The project site for the citric acid plant has been selected in an area adjacent to the Zimphos Company located in Mukuvisi district, in the south eastern part of the city of Harare. Infrastructures are well developed in this district; transportation by railways and roads is convenient, the possibility of electric power failure is rare and soil is firm.

The conceptual design of the plant is based on the results of the fermentation test as described in Chapter 10. The design is based on a philosophy of easy operation, maintenance and administration through batch operation. The following are the major assumptions used for the conceptual design of the plant:

(1) Production capacity : 3,000 tons per year of citric acid monohydrate
(2) Fungus : Aspergillus niger
(3) Raw material : Cornstarch made in Zimbabwe (brand name STARCON)
(4) Product specification : Complying with the BP (British Pharmacopoeia) specifications
(5) Package : Packed in 50kg bags (4 layers of paper and 1 layer of polyethylene sheet)
(6) Electricity : Supplied by ZESA (two-incoming lines)
(7) Process water and waste water
    Process water : Municipality water
    Cooling water : Circulating system through cooling tower
    Waste water : After treatment to satisfy environmental regulations, discharged to the public sewage system

(8)Instrumentation and control : Major processes controlled by an automatic control system (others operated manually)

12-2 Outline of the Production Process of Citric Acid

(1) Outline of the fermentation Process

For the fermentation process, a pure strain of citric acid generating fungus is cultured in a plant laboratory and then inoculated and cultured in three different sizes of fermenters in sequence. In this way citric acid accumulates in the liquid culture medium in the main fermenters for commercial production. In the fermentation process, the important operations are sterilization of the raw materials by steam and prevention of contamination by miscellaneous fungi. A characteristic of this process is that heat is generated as fermentation progresses and a considerable amount of water is required for cooling. The fermentation process consists of the following processes:

The plant is designed to be equipped with 3 main fermenter units, one first seed tank and one second seed tank. The main fermenters are operated at 3 batches every 7 days. The operating cycle of both seed tanks is at intervals of 48 or 72 hours, to suit the operating cycle of the main fermenters.

(a) Liquefaction of cornstarch

28,540 kgs of cornstarch, the amount required for fermenting one batch of citric acid, is mixed with water and a starch milk solution of 30% concentration is prepared. After adding the enzyme amylase into the starch milk solution, it is heated to 90°C by injecting steam and sent to the Reaction Tank where the starch is liquefied by the action of the enzyme at high temperature.

(b) Flask seed culture

A milky solution is prepared by mixing 50 grams of cornstarch, 0.05 grams of the enzyme amylase and 800 m ℓ of water. After the starch is liquefied at a temperature of 90 °C, nutrients and water are added to bring the volume of the solution to 1,000 m ℓ. 330 m ℓ of the solution is poured into each of 3 Erlenmyer flasks of 2 liters volume and sterilized in an autoclave at high temperature. Aspergillus niger is inoculated in this medium and culture proceed for 45 hours at 35°C.

(c) First seed fermentation

48 kgs of a solution of liquefied cornstarch and nutrients are introduced to the First Seed Tank and a fermentation medium of 680 liters is prepared by adding water. After being sterilized by injecting steam, the medium is cooled. The seed in the three Erlenmyer flasks is inoculated in the sterilized medium in the tank and the medium is fermented with aeration under agitated conditions for 36 hours at 35°C.

(d) Second seed fermentation

6,743 kgs of a solution of liquefied cornstarch and nutrients are introduced into the Second Seed Tank and a fermentation medium of 9.4 kℓ is prepared by adding water. After the fermentation medium has been sterilized by injecting steam, it is cooled. The seed in the First Seed Tank is inoculated in the sterilized medium and the medium is fermented with aeration under agitated conditions for 36 hours at 35°C.

(e) Main fermentation

Hot water and nutrients are charged into the Medium Make-up Tank to give a volume of 10 kℓ. The nutrient solution in the Medium Make-up Tank, liquefied cornstarch solution in the Reaction Tank and the hot water are sterilized continuously and transferred to the Main Fermenter while cooling. The volume of the fermentation medium in the Main Fermenter is maintained at 168 kℓ. The second seed is inoculated in the medium in the Main Fermenter and fermentation takes place with aeration under agitated conditions for 160 hours at 35°C.

(2) Outline of the Separation Process

In the separation process, citric acid is first crystallized and separated as calcium citrate which has low solubility. Then the separated calcium citrate is decomposed by sulfuric acid to give a citric acid solution which is concentrated to obtain citric acid crystals. The separation process consists of the following processes:

In designing the separation process, it is intended to minimize the loss of citric acid by circulating the mother liquor and the washing water as much as possible.

(a) Transfer of the fermented broth

After fermentation is complete, the whole contents of the Main Fermenter are transferred to the Broth Tank.

(b) Filtration of the mycelium

Filter aid is coated onto the Mycelium Filter and the mycelium is separated from the broth under vacuum conditions.

(c) Crystallization of calcium citrate (neutralization)

The filtered solution and the secondary mother liquor are charged into the Neutralization Tank and heated to 50°C by steam. By adding a slaked lime slurry and adjusting the pH value to 5.0 with agitation, calcium citrate is obtained, which crystallizes due to its low solubility.

(d) Separation of calcium citrate

The slurry containing crystallized calcium citrate is transferred to the filter, where the crystals and the solution are separated. The separated solution is sent to the Waste Water Treatment Facility.

(e) Acidic decomposition of calcium citrate

Sulfuric acid is added to the separated calcium citrate and by decomposing the calcium citrate, free citric acid and calcium sulfate (gypsum) slurry are obtained.

(f) Separation of free citric acid and calcium sulfate

The slurry mentioned above is sent to the Centrifuge and free citric acid and the calcium sulfate is separated. The separated calcium sulfate is discharged as the by-product gypsum.

(g) First evaporation of citric acid

The free citric acid solution mentioned above is added to the first mother liquor, the second crude citric acid crystals and the final mother liquor and concentrated under reduced pressure.

(h) First crystallization of citric acid

The concentrated citric acid solution is cooled down to 35°C while agitating. A small amount of seed crystals is added and the solution is further cooled below 20°C and crystals of citric acid monohydrate are produced and separated.

(i) Separation of the first crude citric acid monohydrate

The slurry of citric acid monohydrate is sent to the centrifuge, where the first crude citric acid monohydrate crystals and the first mother liquor are separated. The separated first mother liquor is sent to the first evaporation process and the second crystallization process.

(j) Recovery of the second citric acid crystals

After 40% volume of the first mother liquor is concentrated under reduced pressure, the solution is cooled and the citric acid monohydrate is produced and separated. The slurry of citric acid is sent to the Centrifuge, where the second citric acid crude crystals are sent to the first concentration process and the second mother liquor is sent to the calcium citrate crystallization process.

(k) Decolorization of citric acid solution

The first crude crystals and the final mother liquor are sent to the Decolorization Tank. After heating to 80°C, activated carbon is added to decolorize the solution which takes 30 minutes.

(l) Filtration of citric acid

The decolored citric acid solution is filtered at an elevated temperature. The separated activated carbon waste is discharged as waste carbon.

(m) Final crystallization of citric acid

The decolored filtrate is cooled while agitating. A small amount of seed crystals is added to the solution. The solution is cooled below 20°C and crystals of citric acid are formed and separated.

(n) Separation of final crystals of citric acid

The slurry of crystallized citric acid is sent to the centrifuge, where the final citric acid crystals and the final mother liquor are obtained. The final mother liquor is sent to the decolorization process and the first concentration process.

(o) Drying of citric acid

The separated citric acid is sent to the Dryer continuously by conveyors and dried by hot air at 60°C.

(p) Packaging of citric acid

After removing off-size crystals, the citric acid crystals are packed in 50 kg bags.

(3) Flow sheet

The block flow diagram is shown in Figure 12–1.

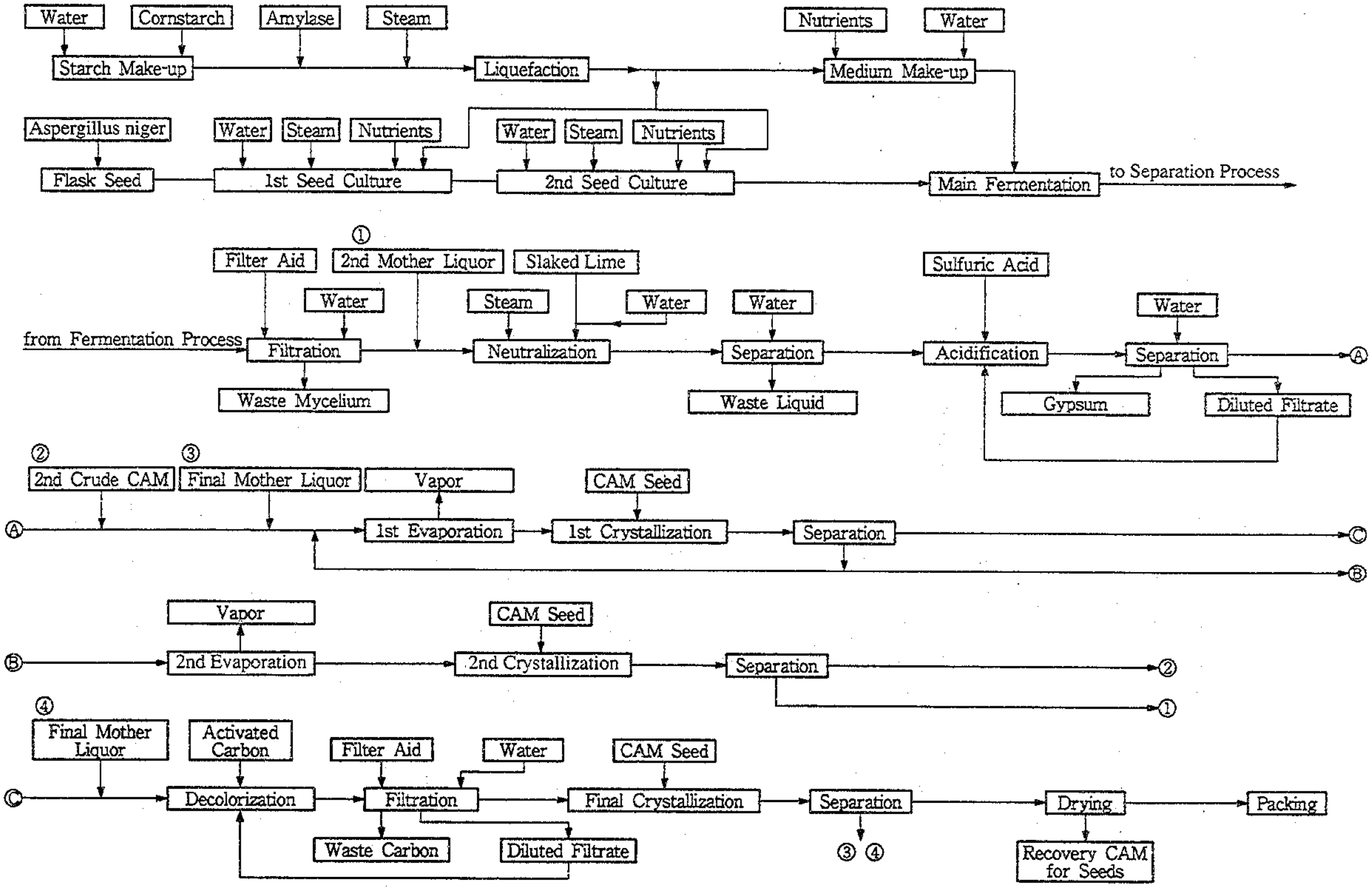


Figure 12–1 Block Flow Diagram

12-3 Raw Materials

Raw materials required for producing citric acid are summarized as follows:

(1) Cornstarch

Cornstarch with the brand name of STARCON, which gave a better yield of citric acid in the fermentation tests, will be used as the raw material.

(2) Sulfuric acid

Concentrated sulfuric acid made by Zimphos Company will be used.

(3) Slaked lime

It is desirable that the slaked lime used for citric acid production should contain the smallest amounts possible of magnesium, iron, silica and other impurities. Magnesium reduces the recovery yield of the product, iron affects the color of the product and silica increases the ash content of the product. Slake lime produced in Zimbabwe contains a large amount of the impurities and cannot be used for this process. The slaked lime produced in Zambia (the brand name: Ndola Lime) can be used for this project. However, it is desirable to use a better quality slaked lime.

(4) Activated carbon

Bone black carbon made in Zimbabwe for the use of the sugar refining industry contains a lot of impurities which are soluble in citric acid. Therefore, it cannot be used for this project. Import of activated carbon of a suitable quality is recommended.

(5) Others

In addition to the raw materials mentioned above, filter aid, the enzyme amylase and nutrients such as ammonium nitrate, and potassium diphosphate are required for this process. Ammonium nitrate made in Zimbabwe can be used as a nutrient. All other materials are to be imported.

12–4 Unit Consumption

Calculation of the material balance is based on the fermentation yield of 82% in accordance with the fermentation test and on the refining yield of 90% in accordance with the actual figure of Japanese commercial plants. Thus, the overall yield is set at 73.8%. Unit consumption of the raw materials required for producing one tons of the product is as follows:

– Cornstarch	:	1,359kg
– Sulfuric acid	:	1,000kg
– Slaked lime	:	750kg
– Filter aid	:	110kg
– Ammonium nitrate	:	29kg
– Potassium diphosphate	:	17kg
– Activated carbon	:	10kg
– Other nutrients	:	3.7kg

The utilities required for producing one ton of citric acid are 1.2 tons of coal for steam generation, 145 m^3 of water and 4,000 kWh of electricity. The volume and kinds of the by-products and the wastes are shown in Chapter 9.

12–5 Plot Plan

The plant consists of the production facilities (fermentation process, separation process, utility facilities, warehouses), environmental protection facilities and other facilities such as the administration office, laboratory, parking lot, road, open space and green belt. The required area for the plant is about 27,250 m^2.

The buildings for the fermentation process and the separation process are designed as reinforced concrete structures with a column span of 7 meters by 7 meters.

12–6 Facilities

(1) Fermentation process facility

The fermentation process consists of the cornstarch liquefaction unit, three kinds of aeration and agitation fermenters and others. The fermentation tanks are equipped with devices for sterilizing the fermentation medium, for eliminating microorganisms and dust from the feed air and for cooling.

(2) Separation process facility

In order to separate and refine citric acid effectively with a high yield and high efficiency, the separation process consists of a number of items of equipment for mycelium filtration, crystallization, separation, concentration, solution, decolorization, filtration, drying, transfer operations, and packaging. The separation process via calcium citrate is unique amongst refining processes in the chemical industry. However, most of the equipment in the separation and refining processes is widely utilized in similar processes for other chemical products.

Chapter 13 Construction Costs

13–1 Chemical Engineering Industry in Zimbabwe

Zimbabwe has had a considerable amount of experience in civil construction and building construction and the capability of designing and construction in this field has been well proven. However, construction of chemical plants in Zimbabwe is different from ordinary construction. Since the chemical industry market is not large enough, there is no chemical engineering firm in Zimbabwe that specializes in the design and construction of chemical plants. For the construction of chemical plants in Zimbabwe, in most cases consultant and engineering firms that specialize in architecture and civil construction become the main contractors and they, in turn, subcontract to equipment makers for each unit of the process by individual contracts.

13–2 Construction Works

(1) Procurement of equipment and materials

(a) Outline of equipment

In the production process of citric acid, the fermentation process consists of combinations of so-called specialized equipment for biotechnology such as fermenters, air filters and the continuous sterilization unit. These pieces of equipment are designed and manufactured based on biochemical engineering know-how. All of the equipment used for the fermentation process is made of stainless steel for the purpose of preventing contamination by microorganisms and to avoid corrosion by citric acid. The equipment for other processes is the same as that widely used for ordinary chemical processes and consists of the centrifuges, the evaporators, the crystallizers, the dryers and so on.

(b) Procurement of equipment and materials

For this study, equipment and materials made in Zimbabwe have been considered as much as possible. However, it is planned to import the following equipment; the main fermenters (240 kℓ in volume), the continuous sterilization unit, the evaporators, the centrifuges, the air compressors, most of the stainless steel products and the major laboratory equipment.

(c) Transportation of the equipment

For this project, it is planned to import the equipment and materials required for the construction of the plant through the port of Durban in the Republic of South Africa. Since the railway in Zimbabwe is narrow gauge and not suitable for transporting large pieces of equipment, the inland transportation of the equipment will be by large trailer trucks.

(2) Installation and pipe work

The largest pieces of equipment used for the citric acid plant are the main fermenters, about 5.3 meters in diameter, 15 meters in length and 65 tons in weight. In the light of the actual construction experience of large thermal power plants and various heavy and chemical industries in Zimbabwe, installation of the equipment required for this plant should not present any serious problems.

For the fermentation process, a unique design and construction know-how is required to avoid contamination by unwanted microorganisms. The detailed contents cannot be illustrated on drawings so the supervision of experienced engineers is required at the construction site. If irregularities are produced on the inner surface of the pipe by welding distortions, these uneven parts cause contamination by microorganisms. Therefore, it is very important to hire highly skilled welders for the pipework.

Regarding insulation work, the weather in Zimbabwe is mild in general. Hot and cold insulation work are relatively easy. This plant produces food additives, so insulating materials which contain asbestos will not be used.

(3) Electrical and instrument work

Recently, many chemical plants have adopted a computer control system. However, a sophisticated electrical or electronic instrument system is not required for this plant. Conventional electronic instruments have been adopted in view of easy maintenance and local availability of replacement parts. Using conventional instruments will have the advantage that the experience in instrument work accumulated in Zimbabwe can be used.

(4) Construction and civil work

Soil around the city of Harare is very firm and there are no earthquakes. The Mukuvisi district, where it is planned to locate the plant, is on firm ground consisting of gravel and coarse sand and piling is not required for the construction of the plant buildings.

Large sized rolled steel sections normally used for the construction of the buildings have to be imported and therefore in this study the buildings and structures are all made of reinforced concrete, to avoid the use of steel sections. Domestic bricks are to be used for the walls. Since Zimbabwe is not a seismic country, the reinforced concrete structure will be adequate.

(5) Construction schedule

The construction period for this kind of plant is generally about two years after signing a construction contract. It is possible to construct this plant in two years if there is no shortage of materials and funds. In Zimbabwe, it is reported that there are shortages of cement, stainless steel, piping materials and sheet glass and good preparations will be necessary prior to the commencement of the construction work.

The overall construction schedule is shown in Figure 13–1.

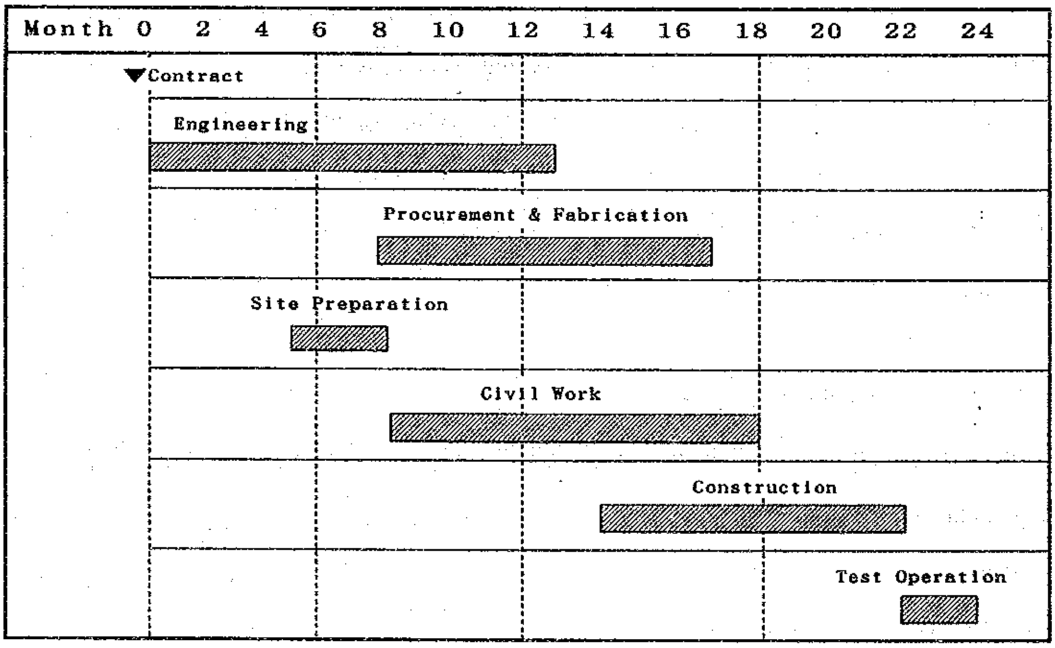


Figure 13–1 Master Schedule

13–3 Estimation of Construction Costs

The estimation of the construction costs is based on the cost information obtained during the field survey conducted in 1991. The estimation of the Zimbabwe local currency portion is based on local data and information as far as possible. There are some items for which local data and information were not available due to insufficient statistical data, price fluctuations due to inflation and the devaluation of the local currency, the extreme price differences due to difference of distribution routes and so on. The cost of those items, for which local data were not available, has been estimated based on Japanese price data and information. Imported items are estimated based on procurement in Japan, ocean freight to Durban, and road transport by truck from Durban to Harare. The construction work is estimated assuming that local consultant and engineering firms will do the entire construction work under the supervision of specialists dispatched from a process licenser.

The local currency portion is estimated in Zimbabwean dollars (Z$) and the foreign portion is estimated in Japanese Yen and converted to U.S. dollars using the following conversion rates:

- US$1 = 3.15 Z$
- US$1 = 132 Yen

The results of the cost estimates are summarized in Table 13–1. In the cost of this plant, the following have been excluded: the cost for extending roads, and the charges allotted for connecting water and electricity from outside the plant. The training fee for operators and the test operation costs are separately estimated in Chapter 15 "Total Capital Requirement".

Table 13–1 Total Plant Costs, US$

Item	Foreign Scope	Local Scope	Total
Land Aquisition & Site Preparation Cost	0	641,889	641,889
License Fee	1,000,000	0	1,000,000
Engineering Fee	1,072,000	299,000	1,371,000
Machinery & Equipment	6,369,000	3,887,000	10,256,000
Spare Parts and Spare Pumps	191,000	154,000	345,000
Inland Transportation Cost (Durban to Beitbridge)	0	131,000	131,000
Surtax	0	1,338,200	1,338,200
Inland Transportation Cost (Beitbridge to Harare)	0	72,000	72,000
Installation & Piping Costs	0	2,739,000	2,739,000
Electrical & Instrument Costs	0	1,430,000	1,430,000
Civil & Building Costs	0	3,342,000	3,342,000
Insulation & Painting Costs	0	318,000	318,000
Supervision	429,000	99,000	528,000
Contingency	196,800	625,594	822,394
TOTAL	9,257,800	15,076,683	24,334,483

Chapter 14 Implementation of the Project

In this chapter, the construction, education and training, and operation schedule which are important for the implementation of the project are described.

14–1 Design and Construction of the Plant

It is planned that the design and construction of the plant should be carried out by Zimbabwean contractors as far as possible. Since the design and construction of a citric acid plant require some specific technical expertise, unique to biotechnology, all of the work cannot be done completely by the Zimbabwean contractors. The work required to complete the plant consists of:

(1) Supply of process technology
(2) Basic design
(3) Detailed design
(4) Manufacture of equipment
(5) Construction work at site

The work (1) and (2) will be carried out in the country which supplies the technology. As for item (4) manufacture of the major equipment, it will be taken care of by the foreign suppliers. For item (5) construction work at site, it will be advantageous to use the Zimbabwean contractors in view of their technical level and labor costs.

For item (3) detailed design, it is planned that the detailed design work will be done by Zimbabwean companies under the supervision of the foreign engineering firm who carried out the basic design.

14–2 Operation Plan

14–2–1 Number of Operating Days

Much of the equipment in this plant will be operated on a batch cycle. However, the plant is designed to operate continuously for 333 days per year. The operation is basically by 3 shifts using 4 shift groups of operators. 32 non-operating days per year have been assumed and these days are for the annual maintenance period (usually about two weeks) and the start-up period after the annual maintenance work.

14–2–2 Operating Ratio and Plant Production

It would be desirable to operate the plant at its designed capacity from the initial start-up of the plant. However, due to initial problems with equipment and lack of experience on the part of the operators, the plant cannot be operated as designed during the initial start-up period. Also, it will be very difficult to sell all of the 3,000 tons of the product from the first year. Therefore, the operating ratio and the production have been assumed as follows:

First year of operation : 76.2%, 2,286 tons
Second year of operation : 97.2%, 2,916 tons
Third and subsequent years : 100.0%, 3,000 tons

The number of fermentation batches will be 109 for the first year, 139 for the second year and 143 for the third and later years. Therefore, the fermentation batches will be prepared once every three days for the first year, and 3 batches every seven days for the second year and thereafter.

14–3 Organization and Staff

14–3–1 Organization and Duties

The organization required for the management and operation of the citric acid plant is shown in Figure 14–1.

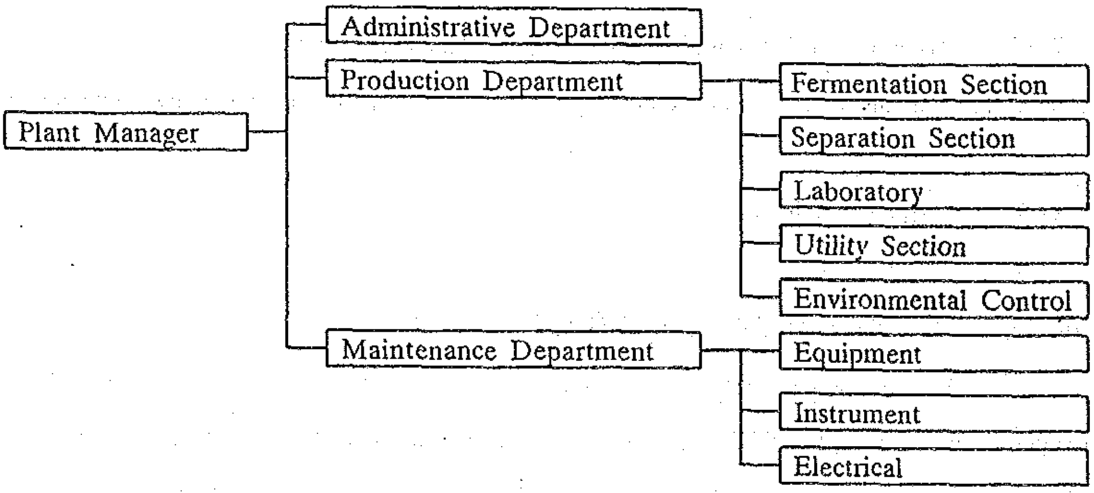


Figure 14–1 Organization Chart of a Citric Acid Production Plant

14–3–2 Personnel Plan

The number of the staff required for the operation of the plant is 114 persons as shown below and the total number is 115 persons including one plant manager.

(1) Production Department

• Manager	1
• Fermentation process	23
• Separation process	29
• Laboratory	7
• Utilities	19
• Environmental protection	12
Sub-total	91 persons

(2) Maintenance Department

• Manager	1
• Engineer	3
• Technical workers	4
• Workers	2
Sub-total	10 persons

(3) Administration Department

• Manager	1
• Clerks	7
• Guards	5
Sub-total	13 persons

These people are the staff directly required for operation of the plant and the number does not include the staff for welfare and management.

14–4 Operating Guidance and Training Program

In Zimbabwe, there is no plant similar to this citric acid production plant and it will be extremely difficult to hire experienced operators from other factories. Therefore, the education and training of employees are very important. For this project, it is planned to conduct education and training in operation technology for a period of three and half months starting half a month prior to commencement of the start-up operation by sending the technical experts from the process owner. The team of technical experts will consist of 4 persons (one for the fermentation process, one for the separation process, one for the laboratory, and one for utilities and environmental control). The education and training program conducted by the technical experts will be carried out in 4 different classes, one class for each of the specialties mentioned above. Staff for the maintenance department will be educated and trained in appropriate classes. The training program will be divided into three phases; (1) at the end of mechanical completion, (2) test period using water only and (3) actual start-up test period. After completion of the start-up test using actual solutions, a proving test will be carried out in accordance with the instruction of the team of technical experts to confirm the plant is operating correctly and then the operation technology and technical know-how will be transferred.

If any emergency situation such as a stoppage of utilities occurs during plant operation, this will not only affect the production of citric acid, but also may damage the equipment.

Necessary steps must be taken to avoid secondary or tertiary damage to the plant by exercising the appropriate judgment. In the last stage of the education and training program, guidance and training for emergencies will be given.

Chapter 15 Total Capital Requirement

15–1 General

In this chapter, the total capital requirements for this project are calculated by adding the pre-operational cost, the initial working capital and the interest during construction to the estimates of the plant costs described in Chapter 13. In calculating the total capital requirements, the following conditions are assumed:

(1) Exchange rates

In calculating the capital requirements, the following currency exchange rates for 1991 are applied as it is difficult to predict the future currency rates.

US$ 1.0 = Z$ 3.15 = 132 Yen

(2) Price

All costs and prices are calculated in 1991 prices.

(3) Taxes

For this project, it is assumed that all taxes are exempted, except the surtax (cif price × 20%) levied on imported equipment and materials.

(4) Sources of funds

Of the required funds for implementation of this project, it is assumed that one third is raised by the owner's equity, the foreign currency portion is financed by a long term loan from foreign countries and the balance is financed by a long term loan from the domestic banks in Zimbabwe. The interest during the construction period is added to the principle of the loan. The terms and conditions of the long term loan from the foreign country cannot be defined because the lending organization is not decided. For this study, two cases are assumed, namely, Case 1 for an interest rate of 10.75% per year and Case 2 for an interest rate of 4.5% per year for the purpose of calculating the financial analysis. The loan conditions for Zimbabwe domestic banks are set at an interest rate of 20% per year according to information provided during discussions with IDC.

As this interest rate is based on the Zimbabwe dollar, it should be converted to the rate applicable for US dollars. The details are described is the next chapter.

15–2 Total Capital Requirement

The total capital requirement consists of the plant cost, the pre-operational cost, the initial working capital and the interest during the construction period. The total capital requirement and the capital financing plans are summarized in Table 15–1 (for Case 1) and Table 15–2 (for Case 2).

Table 15–1 Total Capital Requirements (Case-1)

(Unit: US$ in Thousand)

Project Year	–2		–1		Total
	I	II	I	II	
Application of Funds					
Foreign Currency Portion					
Plant Construction Cost	1,388.7	2,777.3	4,166.0	925.8	9,257.8
Pre–operation Cost	0.0	0.0	0.0	212.0	212.0
Initial Working Capital	0.0	0.0	0.0	0.0	0.0
Interest during Const.	37.3	151.3	346.0	507.2	1,041.8
Sub-total	1,426.0	2,928.6	4,512.0	1,644.9	10,511.6
Local Currency Portion					
Plant Construction Cost	1,507.7	3,769.2	6,784.5	3,015.3	15,076.7
Pre-operation Cost	35.7	35.7	40.7	416.5	528.6
Initial Working Capital	0.0	0.0	0.0	103.4	103.4
Interest during Const.	6.5	31.7	87.3	148.4	273.9
Sub-total	1,549.9	3,936.6	6,912.5	3,683.6	15,982.6
Total Application	2,975.9	6,765.2	11,424.5	5,328.6	26,494.2
Source of Funds					
Equity	977.4	2,194.1	3,663.7	1,557.7	8,392.8
Foreign Loans	1,426.0	2,928.6	4,512.0	1,644.9	10,511.6
Local Loans	572.5	1,642.5	3,248.8	2,126.0	7,589.8
Total	2,975.9	6,765.2	11,424.5	5,328.6	26,494.2

Table 15-2 Total Capital Requirements (Case-2)

(Unit: US$ in Thousand)

Project Year	-2		-1		Total
	I	II	I	II	
Application of Funds					
Foreign Currency Portion					
Plant Construction Cost	1,388.7	2,777.3	4,166.0	925.8	9,257.8
Pre-operation Cost	0.0	0.0	0.0	212.0	212.0
Initial Working Capital	0.0	0.0	0.0	0.0	0.0
Interest during Const.	15.6	62.8	142.4	205.2	426.1
Sub-total	1,404.3	2,840.2	4,308.4	1,343.0	9,895.9
Local Currency Portion					
Plant Construction Cost	1,507.7	3,769.2	6,784.5	3,015.3	15,076.7
Pre-operation Cost	35.7	35.7	40.7	416.5	528.6
Initial Working Capital	0.0	0.0	0.0	103.4	103.4
Interest during Const.	6.5	31.7	87.3	148.4	273.9
Sub-total	1,549.9	3,836.6	6,912.5	3,683.6	15,982.6
Total Application	2,954.2	6,676.8	11,220.9	5,026.7	25,878.5
Source of Funds					
Equity	977.4	2,194.1	3,663.7	1,557.7	8,392.8
Foreign Loans	1,404.3	2,840.2	4,308.4	1,343.0	9,895.9
Local Loans	572.5	1,642.5	3,248.8	2,126.0	7,589.8
Total	2,954.2	6,676.8	11,220.9	5,026.7	25,878.5

Chapter 16 Financial Analysis

16–1 Financial Analysis

This chapter describes the financial analysis or the project viability of the citric acid plant, with a production capacity of 3,000 tons per year using the submerged culture fermentation process and cornstarch. In the evaluation, profit/loss and cash positions from the operations of the project are studied by making production cost accounting tables, profit and loss statements, fund flow tables and balance sheets. Also, cash flow tables are prepared to calculate the internal rate of return based on the Discounted Cash Flow (DCF) method.

16–2 Major Premises

(1) Project life

– Construction period	:	2 years
– Operating period	:	20 years

(2) Costs and prices

All the costs and prices are based on constant 1991 prices and calculations are carried out in US dollars without inflation. Any costs estimated in local Zimbabwean dollars or in Japanese Yen are converted to U.S. dollars at the following exchange rates:

US$ 1 = Z$ 3.15 = 132 Japanese Yen

(3) Sales and production plan

The sales plan prepared in the market study is shown in Table 16–1. The production plan is made based on the sales plan. The ex-works prices of citric acid for each area in the market are shown as follows:

– Domestic market in Zimbabwe	:	2.26 US$/kg
– Zambia and Malawi	:	1.54 US$/kg
– Republic of South Africa and South African Customs Union	:	1.47 US$/kg
– Mozambique and Madagascar	:	1.40 US$/kg

Table 16–1 Sales Plan, tons/year

Year	Zimbabwe	Zambia	Malawi	RSA/SACU	Mozambique	Madagascar	Total
1	703	105	53	1,267	48	105	2,281
2	809	108	55	1,776	49	108	2,905
3	862	111	57	1,971	0	0	3,000
4	917	113	58	1,911	0	0	3,000
5	977	116	60	1,847	0	0	3,000
6	1,020	119	62	1,799	0	0	3,000
7	1,065	122	63	1,749	0	0	3,000
8	1,113	126	65	1,697	0	0	3,000
9	1,162	129	67	1,642	0	0	3,000
10	1,213	132	69	1,585	0	0	3,000
11	1,267	136	71	1,526	0	0	3,000
12	1,324	139	73	1,464	0	0	3,000
13	1,383	143	75	1,399	0	0	3,000
14	1,444	147	77	1,331	0	0	3,000
15	1,509	150	80	1,261	0	0	3,000
16	1,577	154	82	1,187	0	0	3,000
17	1,647	158	84	1,110	0	0	3,000
18	1,721	162	87	1,029	0	0	3,000
19	1,799	167	89	945	0	0	3,000
20	1,880	171	92	873	0	0	3,016

Note: RSA/SACU means Republic of South Africa & South African Customs Union.

(4) Corporate tax

In accordance with the taxation rule set forth in July, 1991 which will be effective from April 1992, the corporate tax rate will be 42.5%. If a loss is encountered, the loss can be carried over for tax calculation.

(5) Depreciation

All assets are depreciated by the straight line method as follows:

- Plant and machinery : 5% (salvage value of 5%)
- Buildings : 5% (salvage value of 10%)
- Pre-operation cost : 100% (no salvage value)

(6) Financing plan

The financing plan for this project is not finalized yet at this point in time. As explained in Chapter 15 "Total Capital Requirement", it is planned that one third of the total cost excluding the interest during construction will be covered by equity, a long-term loan from a foreign bank, for the procurement of equipment abroad, and the balance by a long term loan from Zimbabwean banks. The interest during the construction will be capitalized into the principle of each loan. Two cases for loan conditions from foreign lending institutions are assumed as follows:

	Case 1	Case 2
– Interest	10.75% p.a.	4.50% p.a.
– Repayment	15 years, 30 installments	15 years, 30 installments
– Grace period	3 years from commencement of operation	5 years from commencement of operation

The loan conditions for the local currency will be as follows according to discussions with IDC.

- Interest : 20%
- Repayment : 7 years, 14 installments
- Grace period : Zero

The interest rate mentioned above is determined based on Zimbabwean dollars. It must be changed to the rate in U.S. dollars, taking into account the exchange rate fluctuation. In this study, the interest rate of 4.6% on a U.S. dollar basis is adopted by deducting the past average devaluation figure of 15.4% (1980 to 1990) from the domestic interest rate of 20%.

In case a shortage of funds occurs after the commencement of operation, a short-term loan with an interest rate of 18% p.a. will be required. Since this interest rate is for Zimbabwean dollars, 15.4% p.a. is deducted in the same way as for the long-term loan, and 2.6% p.a. interest rate on a U.S. dollar basis is applied for the short term loan.

16–3 Operating Costs

(1) Material and utilities costs

Material costs necessary for the production of citric acid are summarized in Table 16–2.

Table 16-2 Raw Material and Utility Costs

	Unit Consumption (tons/ton-CAM)	Unit Price (Z$/ton)	Cost (Z$/ton-CAM)
Cornstarch	1.359	562	763.758
Sulfuric Acid	1.000	610	610.000
Slaked Lime	0.750	308	231.000
Activated Carbon	0.010	880	8.800
Filter Aid	0.110	920	101.200
Ammonium Nitrate	0.029	430	12.470
Potassium Phosphate	0.017	700	11.900
Other Nutrients	--	--	2.380
Amylase	0.0014	22,000	30.800
Bag for Packing	20 bags	2	40.000
Electricity	4,000 kWh	5.97 Z¢/kWh	238.800
Water	145	50 Z¢/ton	72.500
Coal	1.2	133.32	159.984

(2) By-product credit

Gypsum is produced at the rate of 1.86 times the weight of citric acid. Gypsum is to be sold at 25 Z$/t as a by-product and this is deducted from the operation costs. Sales of wastes other than gypsum are not considered.

(3) Labor cost

The number of employees for the operation of the plant amounts to 115. Annual labor cost is estimated to be Z$ 2.4 million. For the first year of operations, an operation supervisor is to be hired, which will cost US$ 191,000.

(4) Administration charge

The administration charge is set at 25% of the labor cost, excluding the cost of the foreign supervisor.

(5) Maintenance costs

The annual maintenance cost is set at 2% of the plant construction cost excluding the cost of the land and site preparation.

(6) Insurance premium

The annual insurance premium is set at 0.35% of the plant construction cost excluding the cost of the land and site preparation.

16–4 Results of the Financial Analysis

(1) Case 1

The average production cost of citric acid throughout the project is calculated to be 1.87 US$/kg (the 1 st year: 2.93 US$/kg and the last year: 1.60 US$/kg) that is larger than the average unit sales price of 1.81 US$/kg. In this case, shortages of funds continue throughout the project and a debt of US$ 0.26 million is left at the last year. The cash from the operation at the last year is negative; financially it is not sound. IRROI (Internal Rate of Return on Investment) shows 2.9% before corporate tax deduction and 1.5% after tax deduction, whereas the cash flow to calculate an IRROE (Internal Rate of Return on Equity) shows a minus flow for all years, and it is impossible to calculate the IRROE.

(2) Case 2

The average production cost of citric acid is 1.75 US$/kg (the 1 st year: 2.62 US$/kg and the last year: 1.60 US$/kg) in this case. In the 13th year, borrowing by a short-term loan is not necessary for the operation of the plant and US$ 8.30 million cash is left at the final year. In this case, the operation of the plant might be possible using the short-term loan, but enough profit cannot be gained. IRROE shows 0.9% before tax deduction and minus 0.1% after tax deduction. The IRROI figure is the same as Case 1 above.

16–5 Sensitivity Analysis

In the sensitivity analysis, the effects on the viability of the project of changing several predetermined parameters, i.e., product price, operating cost and plant cost, were studied for Case 2 keeping the other conditions constant. The sensitivity analysis results are summarized in Table 16–3.

Table 16-3 Summary of Sensitivity Analysis

	Base Case	Product Price 20% up	Operation Cost 20% down	Plant Cost 30% down
IRROI (b/tax)	2.9%	7.9%	6.5%	7.2%
IRROI (a/tax)	1.5%	4.9%	3.9%	4.5%
IRROE (b/tax)	0.9%	10.8%	8.2%	9.5%
IRROE (a/tax)	-0.1%	7.0%	5.1%	6.2%
Production Cost	1.75 US$/kg	1.75 US$/kg	1.50 US$/t	1.54 US$/t
Total Profit after Tax	2.0 MMUS$	14.8 MMUS$	10.8 MMUS$	9.5 MMUS$
Cum. Cash Surplus at 20th year	8.3 MMUS$	21.1 MMUS$	17.2 MMUS	14.0 MMUS$

16-6 Summary

The citric acid business in the world is in a severely competitive situation and currently, a restructuring of the industry is under way among the major producers. It is said that the major citric acid plants which can generate profits are those facilities which are already depreciated and those that have advantages of cheap raw materials, cheap subsidiary materials and cheap labor costs for international competition, and their production capacities are as large as several tens of thousand tons per year. Since the raw material costs and the labor costs in Zimbabwe are not so competitive, it will not be easy to enter into the markets as a new comer by constructing a 3,000 ton citric acid plant in Zimbabwe.

The results of the financial analysis show that the project is not feasible.

Chapter 17 Economic Analysis

17–1 Introduction

In this economic analysis, the appropriateness of the project is studied in the following manner:

(1) Economic benefits and costs are evaluated and an economic internal rate of return is calculated.

(2) The balance of foreign currency from the project is evaluated.

17–2 Major Premises

17–2–1 Economic Parameters

In this study, the following parameters are introduced to convert the prices and costs used in the financial analysis to economic prices and costs:

(1) Shadow exchange rate

The foreign exchange premium, for converting an official exchange rate to a shadow exchange rate, can be calculated to be 1.33 based on export/import statistics. The base case for this economic analysis, however, uses 1.5 for the premium for the following reasons (other study cases in the sensitivity analysis use 1.33 as the minimum and 2.00 as the maximum):

(a) A foreign exchange premium between 1.50 and 2.0 is usually used in Zimbabwe for the calculation of the shadow exchange rate.

(b) The calculated value of 1.33 is based on a simple method to supplement the lack of statistical data.

(c) A figure larger than 1.33 is expected when used solely to calculate the cost of the equipment and materials which are necessary for the plant constructions, although statistical data are not available.

(d) Zimbabwean materials for citric acid production are generally more expensive than international ones. Thus, a larger premium value than 1.33 is necessary for the difference between the official exchange rates and real exchange rates.

(e) If a different shadow exchange rate is used, comparison with other projects becomes difficult.

(2) Shadow wages

Of the whole labor force in Zimbabwe, only 37% earn cash according to a labor force study conducted in 1986/87. The remaining 63% of the population are communal peasant farmers or unemployed persons. By assuming the opportunity costs for them are zero, the shadow wage rate is calculated to be 0.37.

17–2–2 Economic Profits

The direct benefit brought by the project is from the sales of citric acid. As citric acid is an internationally traded item, the economic price of citric acid is equivalent to the border price. The economic price of citric acid for selling in each market is as follows:

- Zimbabwe : 1.53 US$/kg
- Republic of South Africa : 1.47 US$/kg
- Zambia/Malawi : 1.54 US$/kg
- Mozambique/Madagascar : 1.40 US$/kg

17–2–3 Economic Capital Requirements

In the financial analysis, capital costs required during the construction of the plant are divided into a foreign currency portion and a domestic currency portion. As the foreign currency portion is estimated on the assumption of free competition in the market, it can also be used in the economic analysis. For the domestic currency portion, transfer items are deleted, wages of unskilled workers are adjusted and these costs are modified using the shadow exchange rate. Based on the above method, the total economic plant costs are summarized in Table 17–1.

Table 17-1 Total Economic Plant Cost, US$

Item	Foreign	Local	Total
Land Aquisition & Site Preparation Cost	0	427,926	427,926
License Fee	1,000,000	0	1,000,000
Engineering Fee	1,072,000	199,333	1,271,333
Machinery & Equipment	6,369,000	2,591,333	8,960,333
Spare Parts and Spare Pumps	191,000	102,667	293,667
Inland Transportation Cost	0	135,333	135,333
Installation & Piping Cost	0	1,640,789	1,640,789
Electrical & Instrument Cost	0	920,300	920,300
Civil & Building Cost	0	1,965,519	1,965,519
Insulation & Painting Cost	0	186,089	186,089
Supervision	429,000	66,000	495,000
Contingency	196,800	391,731	588,531
TOTAL	9,257,800	8,627,022	17,884,822

After adjusting the pre-operation costs as well as the plant costs and after deleting the initial working capital and the interest during construction from the financial capital costs because they are transfer items, the total economic capital costs are calculated to be US$ 18,445,685.

17-2-4 Economic Operating Costs

(1) Variable operating costs

Market costs for domestic materials and utilities, except cornstarch and electricity, are converted to the economic variable operating costs in US dollar using the shadow exchange rate.

(2) Fixed operating costs

Fixed operating costs consist of the personnel expenses, administration cost, maintenance cost and insurance cost. The cost for guards in the personnel expenses is modified using the shadow wage, as the guards are considered to be unskilled workers, and then it is converted to US dollars using the shadow exchange rate. The economic administration cost is to be 25% of the calculated economic personnel costs. The economic maintenance cost is to be 2% of the plant cost, excluding land and land preparation costs, as is shown in Table 17-1. The insurance cost, interest and principle repayment for the long term loans and corporate tax are not considered in the economic analysis as they are transfer items.

17–3 Economic Internal Rate of Return

Based on the above assumptions, the economic internal rate of return (EIRR) is calculated to be 5.5% which is slightly better than the financial internal rate of return. The EIRR becomes 11.0% when the economic benefit is increased by 20%, while it becomes minus 2.5% when decreased by 20%. When the foreign exchange premium is changed to 1.33 and 2.0 to check the sensitivity, the EIRR becomes 3.7% and 9.4% respectively.

17–4 Foreign Exchange Balance

The foreign exchange balance on national basis from the implementation of this project through 20 years is as follows:

– In the case of commercial loans	:	plus US$ 56.83 million
– In the case of soft loans	:	plus US$ 63.92 million

17–5 Conclusion

The economic benefits brought by this project will be the saving of foreign currency for domestic citric acid consumption and the earning of foreign currency from the exports. The total amount of foreign currency earned and saved will be US$ 56.83 million or 2.3 times the plant cost in the case of a commercial bank loan and US$ 63.92 million or 2.6 times in the case of a soft loan. These amounts are accumulative figures for 20 years of plant operation and its contribution to improvements of the foreign currency balance on national basis is small.

Chapter 18 Conclusion and Recommendations

It became clear from the results of the fermentation tests that the production of citric acid is technically possible using cornstarch made in Zimbabwe. Also, there are no obstacles to establishing a citric acid industry in Zimbabwe in terms of technical transfer, supplies of materials and utilities, environmental measures and plant construction. Estimated annual demands for citric acid in the middle of the 1990s (1996) will be 6,200 tons in total in southern Africa; 900 tons in Zimbabwe, 4,700 tons in the Republic of South Africa, 110 tons in Zambia and so on. As European citric acid producers are well entrenched with major citric acid consumers in the Republic of South Africa, more than half the market in South Africa cannot be considered as being accessible to a proposed Zimbabwean citric acid producer. Also, exports to Europe cannot be considered because of the geographical location of Zimbabwe. So the plant capacity of this project can only be 3,000 tons, which is far smaller than the minimum size of a commercially viable plant which is said to be around 10,000 tons.

The world citric acid industry is now under the pressure of fierce competition and restructuring of the industry is underway because major producers have established large capital intensive facilities and producers in developing countries have entered into the market. Major citric acid producers in the world are tending to change from chemical companies to grain processing companies, which can provide the raw material cheaply. Recently even in China which supplies citric acid cheaply, small scale producers have stopped production because of a cut in export subsidies by the government. Under the circumstances, it is said that only large scale plants of a few tens of thousands tons capacity, for which the facilities are already depreciated, or plants, where very cheap raw materials and labor costs are available, can gain reasonable or marginal profits in the citric acid business.

The results of the financial analysis do not show a good profitability for the project. This is mainly attributed to the following inherent features of the industry of Zimbabwe, as well as the world market situation and limited market size mentioned above:

(1) Zimbabwean industry is diversified since the economy of Zimbabwe has been headed towards self-sufficiency. Most of the industry, however, is under a monopolistic or oligopolistic structure and prices of materials for citric acid production are considerably higher than international prices. For instance, the price of sulfuric acid in Zimbabwe (194 US$/ton) is as much as 2.59 times that in

U.S.A., the slaked lime price in Zimbabwe (98 US$/ton, imported from Zambia) 2.04 times that in U.S.A., and the coal price (42.32 US$/ton) 4.45 times that in the Republic of South Africa.

(2) Transportation of equipment and materials is expensive because of the inland location.

(3) Personnel expenses in Zimbabwe are not necessarily low when compared to those in other developing countries.

Thus, the entry of a new Zimbabwean company into the citric acid industry with a 3,000 tons plant will not be so easy and careful consideration and evaluation must be given to the implementation of the project.

On the otherhand, regarding sales in the domestic market, when this project is considered for the purpose of import substitution, expensive transportation costs and the high rate of commission charged by the domestic suppliers act favorably to maintain domestic citric acid prices at a high level. However, the volume of this portion is about one third of the total sales and the remaining two thirds have to be sold competitively in the market of foreign countries.

To make the project financially feasible, the following measures could be considered:

(a) To exempt surtaxes on the imported equipment and materials used for the plant construction.

(b) To reduce interest costs by the government having a share of the equity capital or by a government loan.

(c) To receive the most beneficial loan conditions from abroad.

(d) To find the most beneficial method of supplying the equipment and materials necessary for the plant construction.

(e) To make the raw material costs close to international market costs by further promoting corporate rationalization through the ongoing trade liberalization program and price decontrol.

(f) To provide a subsidy for citric acid exports to neighboring countries, if necessary.

(g) To consider capital sharing from consumers in other Southern African countries in order to make the citric acid industry stable in the region.

However, it will be very difficult to realize all of the above measures. It is concluded that the project is not feasible.

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