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# THE ECONOMICS OF PRODUCING SINGLE CELL PROTEIN BY YEAST FERMENTATION USING N-PARAFFINS AS A SUBSTRATE 1/

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CONTENTS



ANNEXES

# INTRODUCTION

One of the most interesting process developments in recent years has been the fermentation of hydrocarbons to produce proteins by single cell reproduction.

The objective of this paper is to present the economics of producing single cell proteins grown on high purity n-paraffins substrates using yeast as the microorganism. The SCP produced is then of suitable quality for direct use as a protein feed supplement for animals.

This process has been investigated by many companies and commercial production of a large scale 100,000 tons per year plant in Italy by LIQUICHIMICA BIOSINTESI is expected by middle 1974. Another commercial plant which was announced by a ANIC-BP combine, is expected to follow sometime in 1975.

The major SCP processes which use n-paraffin substrates exhibit similar processing operations. The main differences between them lies in the various engineering solutions adopted and differences in the varieties of yeasts used, operating conditions, and composition of the culture media. Hence it can be seen that it is possible to present a technico-economic evaluation which is applicable to the major processes producing yeast from n-paraffins.

The economic data presented in this paper has been derived from experience gained during the development of the LIQUICHIMICA BIOSINTESI plant in Italy; however it has been modified in order to cover a wider range of values. It has been recalculated considering ranges of values which fit specific know-hows, plant sites and conditions.

# I ECONOMIC EVALUATION OF SCP MANUFACTURE

The calculations indicating the economic characteristics of producing SCP are given in Tables 1 to 6 and have been broken down in Direct Manufacturing Costs, Overheads, Capital Costs, Mature Year Profit, and Projected Cash-Flow Statement.

These calculations have been developed using reference data which may or may not coincide with the specific know-hows available. These data are however sufficiently representative of SCP processes and represent a sound basis for the economic evaluation.

The calculations of the direct manufacturing cost is itemized in Table 1 and is based on the following assumptions:

- Process yield equal to 870 kg of n-paraffins for 1 ton of SCP including process and mechanical losses.
- Cost of n-paraffins equal to 15 ¢/kg.
- Cost of chemicals and utilities based on price in West Europe.
- Average cost of operating personnel equal to 760 $/month-man.
- Packaging cost equal to 0.2 ¢/kg based on the assumption that the majority of the product will be shipped in bulk.

The calculations show the cost of the n-paraffin raw material to be the most important cost item followed by the utilities and chemicals costs which both account for 35.5% of the direct manufacturing cost.

The data in Table 1 includes costs of operating an activated sludge waste treatment plant for treating plant effluent.

An estimation of the overheads necessary to develop a total operation to manufacture and market the SCP is given in Table 2. The following assumptions have been made:

- Amortization of the investment figured on 10 year life for equipment and 20 year life for industrial building and offsites considering an interest rate of 7%.
- General and Administrative expenses included in the Company overheads associated with the manufacturing operation have been estimated as 3% of gross sales.
- Factory administration including factory costs not considered in direct labour costs such as shipping, receiving and quality control. The cost has been estimated to be 30% of direct labour.
- Taxes and insurance costs have been estimated at 2.5% of fixed capital.
- Running Royalties and sustaining research required to maintain the product once production has been initiated, have been estimated as 10 $/ton.

Table 3 shows a breakdown of the Capital Investment Costs including chemical inventories and paid up royalties. Investment costs list offsites which include unloading, storage and shipping facilities as well as a waste treatment facility but the utilities generating systems have been excluded as they have been included in the utilities price.

Table 4 shows the calculation of working capital and has been broken down into:

- Accounts receivable
- Raw material inventory
- Work in process inventory
- Finished goods inventory

Table 5 presents the mature year profit derived from the economic data presented. This table shows the after-tax return on investment calculated as the ratio of the mature year profit to the total capital employed. A fixed tax rate was assumed equal to 15% and a selling price equal to 424 $/ton resulting in a return on investment of 15.8%.

Finally Table 6 develops a projected cash flow statement which calculates the number of years required to regenerate, via profit and depreciation, the total investment of the fixed assets and pre-operating expenditures necessary to get the project into operation. This payout time equals 4.2 years.

## II STUDY OF THE VARIATIONS IN RETURN ON INVESTMENT WITH CHANGES IN OPERATING VARIABLES

The variations in the return on investment when process, capital and earnings variables deviate from their reference values has been illustrated in Figure 1 to 15.

These diagrams show how the profitability of producing SCP varies as functions of the specific operating variables, capital costs and plant site location.

The sensitivity of the retun on investment to changes in the cost of feedstock shown in Figure 1, was calculated from Equation (1)

$$\frac{R}{R_o} = \frac{P/C_o}{P/C_o - 1} - \frac{C}{C_o} \cdot \frac{1}{P/C_o - 1} \qquad (1)$$

where:

R = Return on investment

P = Average unit price

C = Total fixed and variable costs per unit of production.

Figure 2 shows the variation in the selling price of SCP for changes in raw material costs at different fixed values of return on investments.

It should be noted that the total feedstock cost is a function of both the unit raw material price and the SCP yield. The raw material price is only dependant on changes in the costs encountered in supplying normal paraffins. The cell yield is dependant on the efficiency of the microorganism used in utilizing the carbon as an energy source. The yield is also a function of the molecular weight of the n-paraffins used as substrate. The selectivity of the microorganism strongly influences the economics of SCP production as it influences both the power required for oxygen transfer and the cooling required to remove the heat developed during the fermentation cycle.

This follows from the equation:

$$\text{n-paraffins} + O_2 + \text{inorganic salts } NH_3 \text{ etc.} \longrightarrow \text{cells} + CO_2 + H_2O$$

Figure 3 shows the approximate variations in utilities costs as a function of SCP yield.

Figure 4 shows the approximate variations in capital investment costs as a function of SCP yield.

Figure 5 shows the approximate variations in SCP yield as a function of the molecular weight of the n-paraffins (expressed as a percentage of the reference value).

The sensitivity of the return on investment due to changes in chemical costs and utilities costs can also be calculated from equation (1) and is illustrated in Figures 6 and 8 while Figures 7 and 9 illustrate the variations in selling price for changes in utilities costs and chemical costs at different fixed levels of return on investment.

It should be noted that the variation in utilities costs and chemical costs are due to changes in both unit consumptions and purchased costs. While many chemicals are used during the production of SCP, only 3 or 4 can show any real significant cost change.

Figure 10 shows the sensitivity of the return on investment to changes in capital development cost. This is calculated according to equation (2)

$$\frac{R}{R_o} = \frac{I_o}{I} \cdot \frac{i}{i-1} - \frac{1}{i-1} \qquad (2)$$

where:

$$i = \frac{S\,(P - C_V) - O}{I_o\,(K + 2/n)}$$

R = Return on investment

I = Average depreciation investment

S = Number of units sold

P = Average price per unit

$C_v$ = Variable cost of a unit of sales

O = Fixed operating cost unrelated to investment

$2I_o/n$ = Annual straight line depreciation, considered such as fixed cost, with n equal to the years of project life

$KI_o$ = Other fixed cost directly related to investment such as property taxes, insurance and fixed maintenance.

Figure 11 shows the variation in selling price of SCP with changes of capital costs for different fixed values of return on investment.

Figure 12 shows the sensitivity of return on investment with respect to variations in selling price. These variations have been calculated according to equation (3)

$$\frac{R}{R_o} = \frac{P}{P_o} \cdot \frac{P_o/C}{P_o/C - 1} - \frac{1}{P_o/C - 1} \qquad (3)$$

where:

| | |
|---|---|
| R | = Return on investment |
| P | = Average unit price |
| C | = Total fixed and variable costs per unit of production assuming that, when price changes from $P_o$ to P, sales volume, tax rate, operating and capital cost are not affected. |

Figure 13 shows the variation of return on investment for changes in sales volume. This has been developed from equation (4)

$$\frac{R}{R_o} = \frac{S}{S_o} (1 + f) - f \qquad (4)$$

where:

$$f = \frac{C}{S_o (P - Cv) - C}$$

where:

$R$ = Return on investment

$S$ = Number of units sold

$P$ = Average unit price

$C$ = Total fixed operating cost

$C_v$ = Variable cost of unit of sales

Figure 14 shows the variations in return on investment and pay-out time for changes in plant capacity. The curves show that both parameters are very sensitive to changes in plant capacity in the range below 50,000 tons per year, while they remain insensitive to changes in excess of 100,000 tons/year capacity.

Finally, Figure 15 shows the variations in rate of return of investment for changes in the economic life of the project. It has been assumed that during the first year the sales volume will only be 80% of the rated throughput to allow for reduced production during start-up. A salvage value has been assumed for the termination of the projects economic life. This will include the working capital and the land which shall be returned at the termination of the project.

It can be seen from Figure 15 that the interest rate of return remains constant after ten years while it exhibits rapid changes with respect to tho time prior to this.

## III EVALUATION OF RESULTS AND CONCLUSIONS

The following results are evident from the economic analysis of the process, capital and earnings related variables previously presented:

- The economics of manufacturing SCP is highly dependant on the price of n-paraffins. A 20% increase in the price of n-paraffins would decrease the return on investment from 15.8 to 11.6· while a decrease in price of the same amount will increase the return on investment to 20%. Hence any manufacturing operation will require a low cost n-paraffin without great variation. The composition should be within a critical boiling range and the use of n-paraffins with less than 15 carbon atoms is not recommended. A research effort should be devoted to improve the selectivity of the yeasts used.
- The SCP plant should be built in a location where large quantities of good quality water are available and where the cost of fuel is low.
- The economics of producing SCP are most sensitive to changes in the selling price. Conservative selling price assumptions are recommended when evaluating the feasibility of operation when profitability may seem tight under certain circumstances.
- SCP plants are capital intensive and sensitive to sales volume. A decreased of 20% in sales will drastically reduce the return on investment. However market penetration should be conserva-

tively evaluated. Preplanning design for future expansions should be kept to a minimum while the plant design must be suitable for trouble free operation.

- The optimum plant capacity is indicated to be 100,000 tons/yr on the basis of the technology available. Larger plant capacity will become attractive in the future when the design of fermentors larger than those presently available will be developed.

Some of the existing processes, including LIQUICHIMICA BIOSINTESI, display economic characteristics exceeding the reference data presented in this paper. It is forecast that the production of SCP using yeast as a microorganism and n-paraffins as a substrate has an excellent future and will be a powerful tool to alleviate the shortage of proteins in the world. It will provide the animal feed industry with large quantities of high quality proteins at a constant specification, available on long term contracts.

Production of SCP will not be inhibited by the climatic conditions which can so calamitously effect agricultural crops. Equally important is that the area of land needed for SCP production is much less than that required for production of either animal or vegetable proteins. This can be critical in overpopulated areas when the availability of land for agriculture is low.

## TABLE 1

## REFERENCE DATA

## DIRECT MANUFACTURING COST

**(Plant Capacity: 100,000 tons/year)**

| | | Price | Thousands Dollars/ year | Dollars/ ton | % Direct Manuf. Cost |
|---|---|---|---|---|---|
| **Raw Material** ........................... | | | 13050.0 | 130.500 | 57.5 |
| n-paraffins | | 15.0 ¢/kg | | | |
| **Chemicals** ............................. | | | 3825.2 | 38.252 | 16.8 |
| Chemicals for Effluent Treating .......... | | | 88.7 | 0.887 | 0.4 |
| Utilities ................................ | | | 4142.0 | 41.42 | 18.3 |
| Electric power | 500 Kw/t | at 1.33 ¢/Kw | | 6.650 | |
| Fuel | 5 $10^6$Kcal/t | at 167 ¢/$10^6$Kcal | | 8.350 | |
| Steam | 10500 kg/t | at 0.20 ¢/kg | | 21.000 | |
| Cooling water | 1200 $m^3$/t | at 0.41 ¢/$m^3$ | | 4.920 | |
| Raw water | 50 $m^3$/t | at 1.00 ¢/$m^3$ | | 0.500 | |
| Direct Labor ............................. | | | 731.4 | 7.314 | 3.2 |
| Operating labor | | | 365.7 | 3.657 | |
| Maintenance labor | | | 365.7 | 3.657 | |
| Indirect Labor ........................... | | | 146.3 | 1.463 | 0.6 |
| Supplies ................................. | | | 529.1 | 5.291 | 2.3 |
| Operating supplies | | | 122.1 | 1.221 | |
| Maintenance supplies | | | 407.0 | 4.070 | |
| Packaging ................................ | | | 200.0 | 2.000 | 0.9 |
| **Direct Manufacturing Cost** .............. | | | 22712.7 | 227.127 | 100.0 |

TABLE 2

REFERENCE DATA

OVERHEADS

(Plant Capacity : 100,000 tons/year)

| | Thousands Dollars/year |
|---|---|
| Depreciation | 4718.5 |
| General and Administrative Expenses | 1272.0 |
| Factory Administration | 109.7 |
| Taxes and Insurance | 1025.0 |
| Research and Development (1) | 1000.0 |
| | 8125.2 |

(1) Including running royalties

## TABLE 3

## REFERENCE DATA

## INVESTMENT COST ESTIMATE

(Plant Capacity : 100,000 tons/year)

| | Thousands Dollars | % Total Estimate |
|---|---|---|
| Land | 680 | 1.6 |
| Site Development | 1100 | 2.7 |
| Industrial Buildings | 1500 | 3.7 |
| Offsites | 7000 | 17.1 |
| Total | 10280 | 25.1 |
| Process Units | 28500 | 69.5 |
| Chemicals Inventory | 420 | 1.0 |
| Royalties | 1800 | 4.0 |
| Total | 30720 | 74.9 |
| Total Investment Cost | 41000 | 100.0 |

Notes:

1. Investment cost of utilities generation facilities has been included in the utilities price.
2. Catalysts are not required

# TABLE 4

## REFERENCE DATA

## WORKING CAPITAL

(Plant Capacity: 100,000 tons/year)

| | | Thousands $ |
|---|---|---|
| **Accounts Receivable** ............................ | | 3819.816 |
| Product | SCP | |
| No. of days | 30 | |
| Production | 100,000 T/yr | |
| Selling price | 424 $/ton | |
| Operating days/yr | 333 | |
| **Raw Material Inventory** .......................... | | 1175.675 |
| Raw materials | n-paraffins | |
| No. of days | 30 | |
| Consumption | 87000 T/yr | |
| Raw material cost | 150 $/ton | |
| Operating days/yr | 333 | |
| **Work-in-Process Inventory** ..................... | | 409.244 |
| Product | SCP | |
| No. of days | 6 | |
| Production | 100,000 T/yr | |
| Direct manufacturing cost | 227.13 $/ton | |
| Operating days/yr | 333 | |
| **Finished-goods Inventory** ...................... | | 2778.195 |
| Product | SCP | |
| No. of days | 30 | |
| Production | 100,000 T/yr | |
| Direct manufacturing cost + overhead | 308.38 $/ton | |
| Operating days/yr | 333 | |
| | Total | 8182.930 |

# TABLE 5

## REFERENCE DATA

## MATURE YEAR PROFIT

(Plant Capacity: 100,000 tons/year)

| | Thousands Dollars/yr | Dollars/ ton | %Gross Sales |
|---|---|---|---|
| Gross Sales ........................ | 42400.0 | 424.00 | 100.0 |
| Sales deductions & expenses | 2400.0 | 24.00 | 5.7 |
| Net Sales ........................ | 40000.0 | 400.00 | 94.3 |
| Direct manufacturing cost ........ | 22712.7 | 227.13 | 53.6 |
| Raw material cost | 13050.0 | 130.50 | |
| Direct labor (1) | 365.7 | 3.66 | |
| Indirect labor | 146.3 | 1.46 | |
| Maintenance | 772.7 | 7.73 | |
| Supplies | 122.1 | 1.22 | |
| Utilities | 4142.0 | 41.42 | |
| Chemicals | 3913.9 | 39.14 | |
| Packaging | 200.0 | 2.00 | |
| Merchandise Margin .............. | 17287.0 | 172.87 | 40.7 |
| Overheads .................... | 8125.2 | 81.25 | 19.2 |
| Depreciation | 4718.5 | 47.18 | |
| General & administrative | 1272.0 | 12.72 | |
| Factory administration | 109.7 | 1.10 | |
| Taxes & insurance | 1025.0 | 10.25 | |
| R. &D. | 1000.0 | 10.00 | |
| Total Product Cost .............. | 33238.0 | 332.38 | 78.5 |
| Before-Tax Profit ............... | 9162.0 | 91.62 | 21.5 |
| Taxes (15%) | 1374.0 | 13.74 | 3.2 |
| Net Profit ...................... | 7788.0 | 77.88 | 18.3 |
| Total capital employed ........ | 49182.9 | | |
| Fixed capital | 41000.0 | | |
| Working capital | 8182.9 | | |
| After-Tax Return on Investment .. | 15.8 % | | |

(1) Excluding maintenance labor.

# TABLE 6

## REFERENCE DATA

## PROJECTED CASH-FLOW STATEMENT

(Plant Capacity: 100,000 tons/year)

| | Thousands of Dollars | | | | |
|---|---|---|---|---|---|
| | Yr. 1 | Yr. 2 | Yr. 3 | Yr. 4 | Yr. 5 |
| Percent of capacity (T/yr) | 80 | 100 | 100 | 100 | 100 |
| Net profit after taxes | 4784 | 7788 | 7788 | 7788 | 7788 |
| Depreciation | 4718 | 4718 | 4718 | 4718 | 4718 |
| Tax savings on sum-of-digits-depreciation (1) | 64 | | | | |
| Total source of funds (2) | 9566 | 12506 | | | |
| Pre-operating expenses (after taxes) | 1000 | | | | |
| Fixed assets | 41000 | | | | |
| Working capital/yr | 8183 | | | | |
| Total application of funds (3) | 49283 | | | | |
| Net cash flow (4) | -39717 | | | | |
| Cumulative cash flow (5) | -39717 | -27211 | | | |
| Payout time equals | 4.2 years | | | | |

Notes:
(1) Straight-line depreciation - sum-of-the-years-digits depreciation.
(2) Net profit after tax + straight-line depreciation + tax saving x (1 - tax rate).
(3) Preoperating expenses (after taxes) + fixed assets + incremental working capital.
(4) Total source of funds - application of funds.
(5) Sum of all previous annual net cash flow + the current net cash flow.

Figure 1

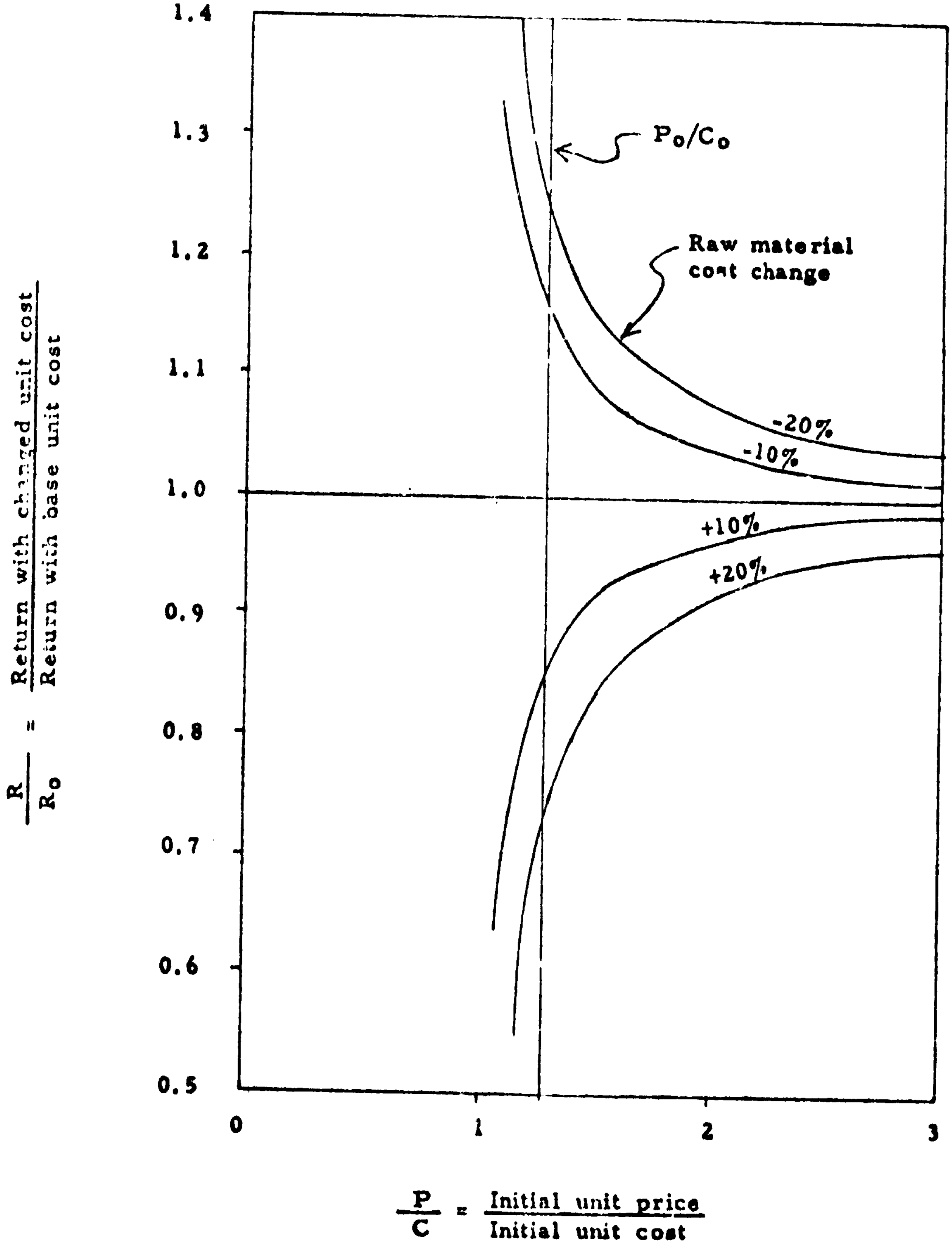

1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0
1
2
3
Po/Co
Raw material cost change
-20%
-10%
+10%
+20%
R/Ro = Return with changed unit cost / Return with base unit cost
P/C = Initial unit price / Initial unit cost

Figure 2

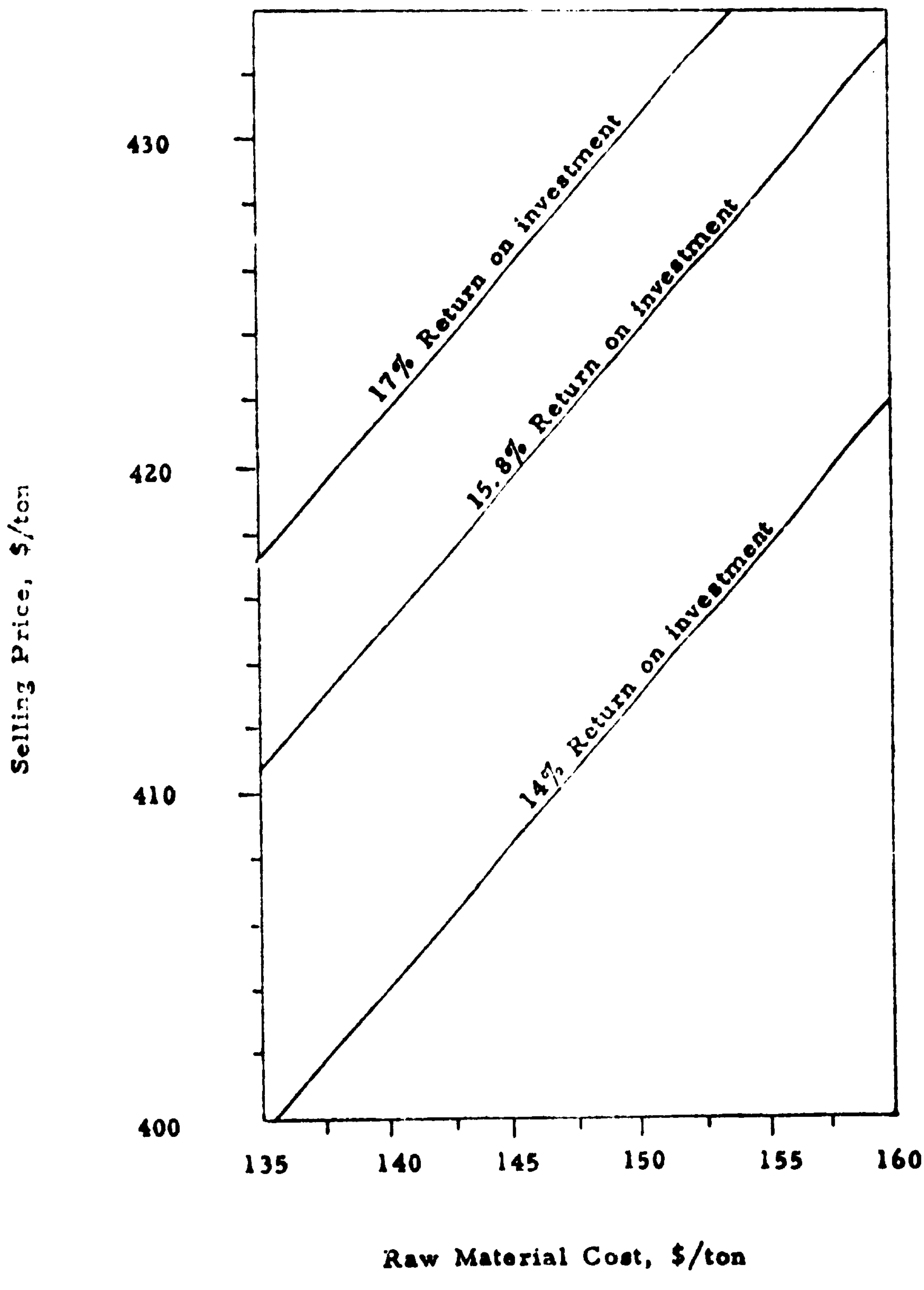

Selling Price, $/ton
430
420
410
400
17% Return on investment
15.8% Return on investment
14% Return on investment
135
140
145
150
155
160
Raw Material Cost, $/ton

Figure 3

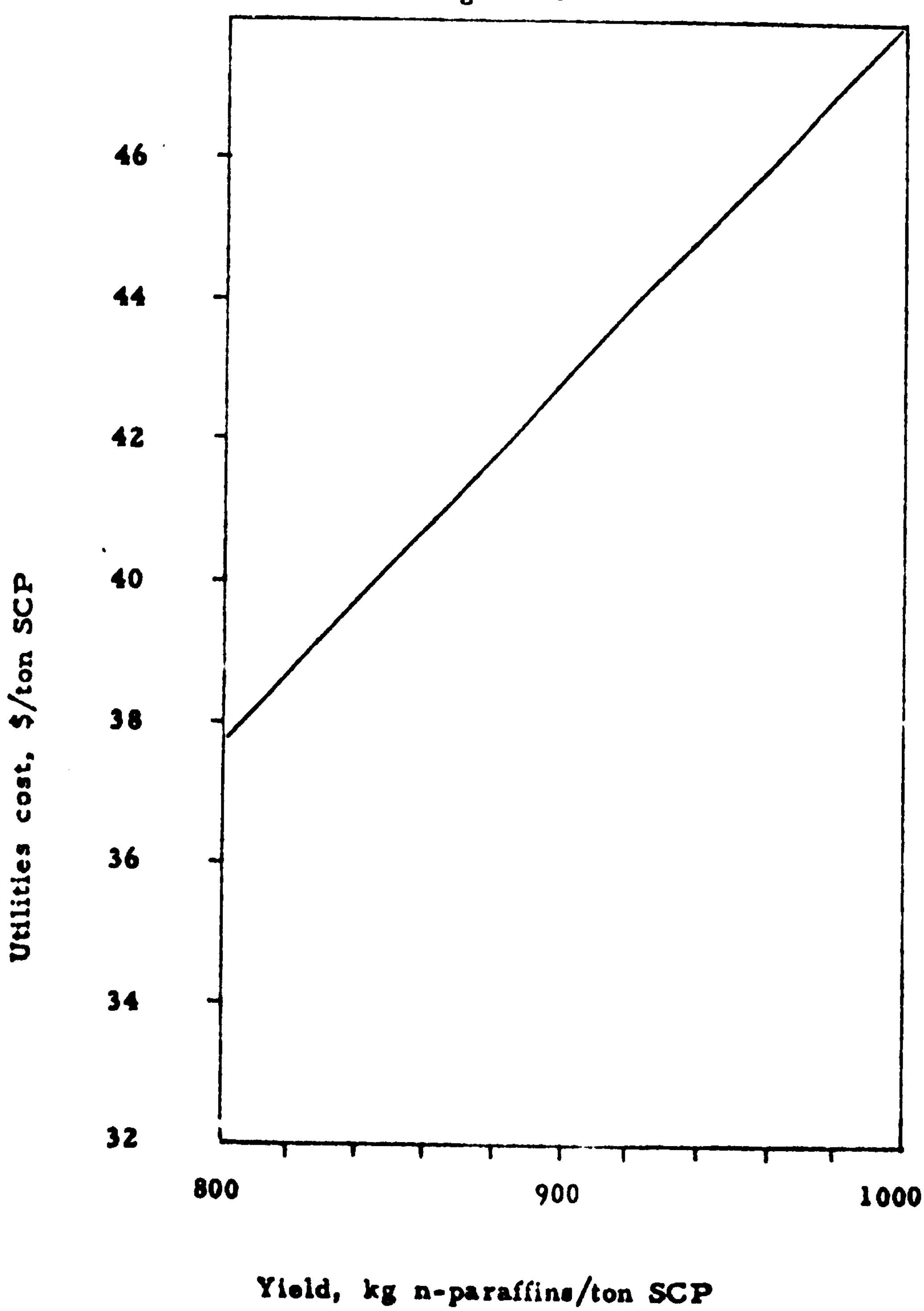

46
44
42
40
38
36
34
32
Utilities cost, $/ton SCP
800
900
1000
Yield, kg n-paraffins/ton SCP

Figure 4

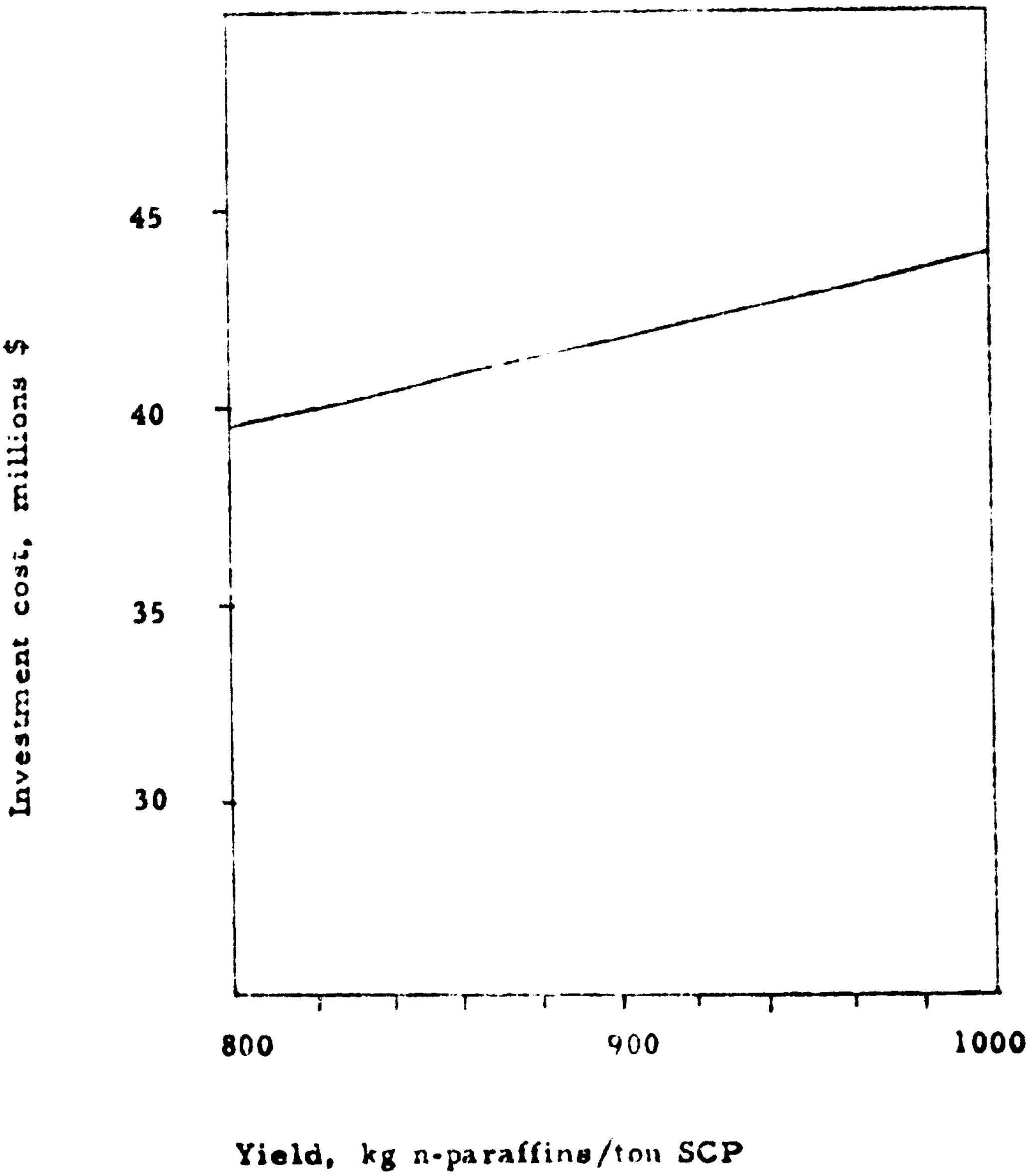

45
40
35
30
Investment cost, millions $
800
900
1000
Yield, kg n-paraffins/ton SCP

Figure 5

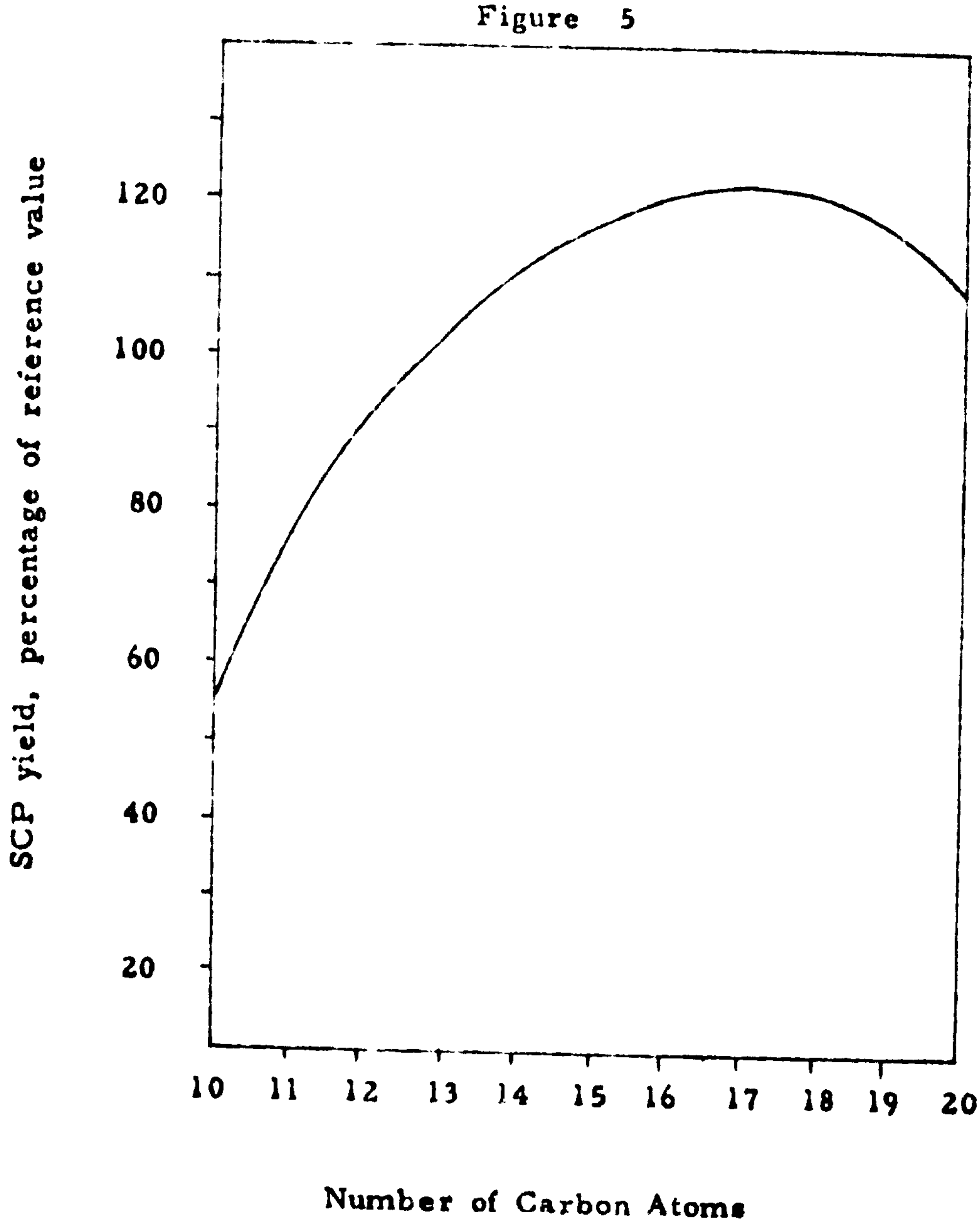
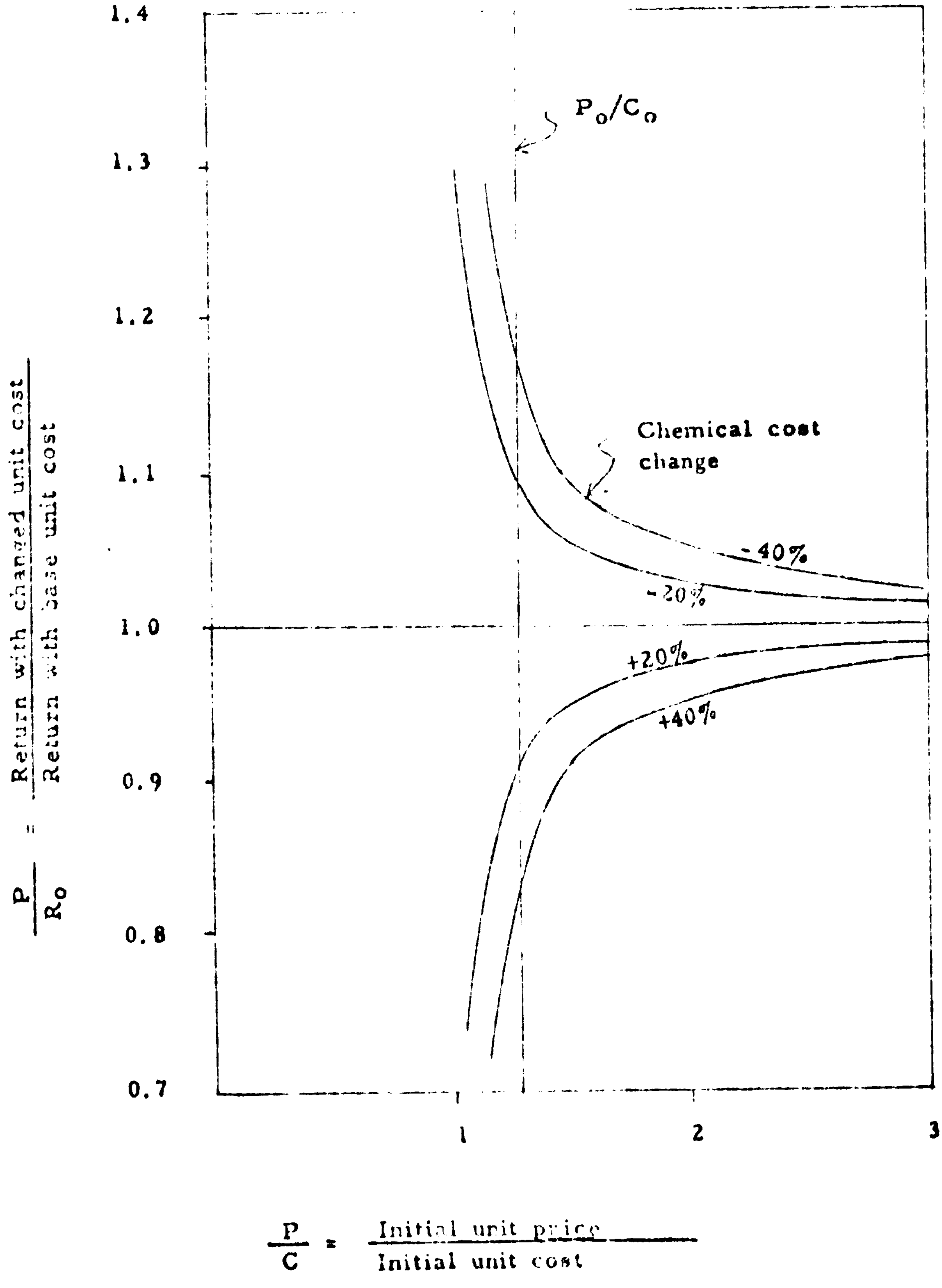

SCP yield, percentage of reference value
120
100
80
60
40
20
10
11
12
13
14
15
16
17
18
19
20
Number of Carbon Atoms

Figure 6



$P_o/C_o$
Chemical cost change
-40%
-20%
+20%
+40%
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
1
2
3
$\frac{P}{R_o}$ = $\frac{\text{Return with changed unit cost}}{\text{Return with base unit cost}}$
$\frac{P}{C}$ = $\frac{\text{Initial unit price}}{\text{Initial unit cost}}$

Figure 7

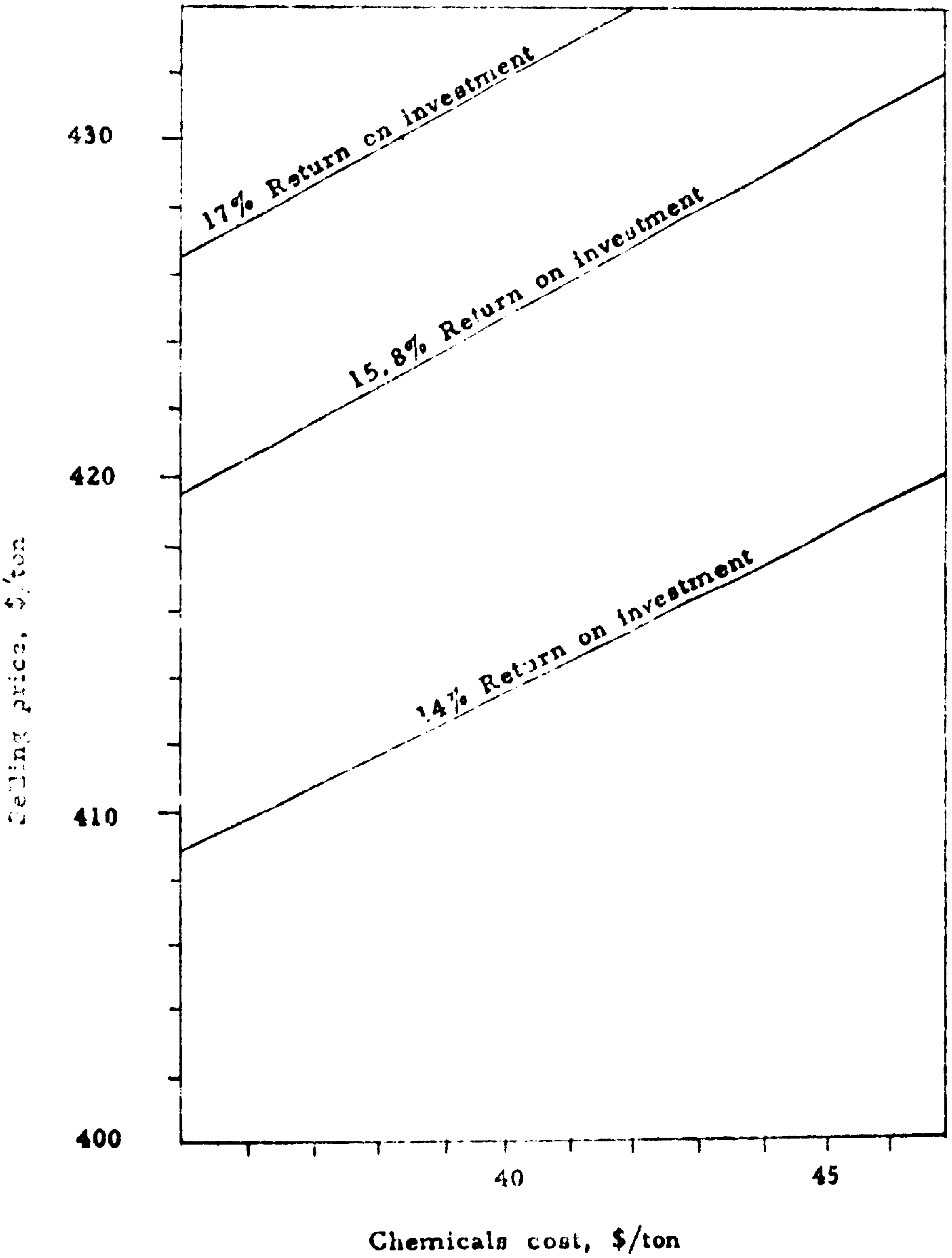
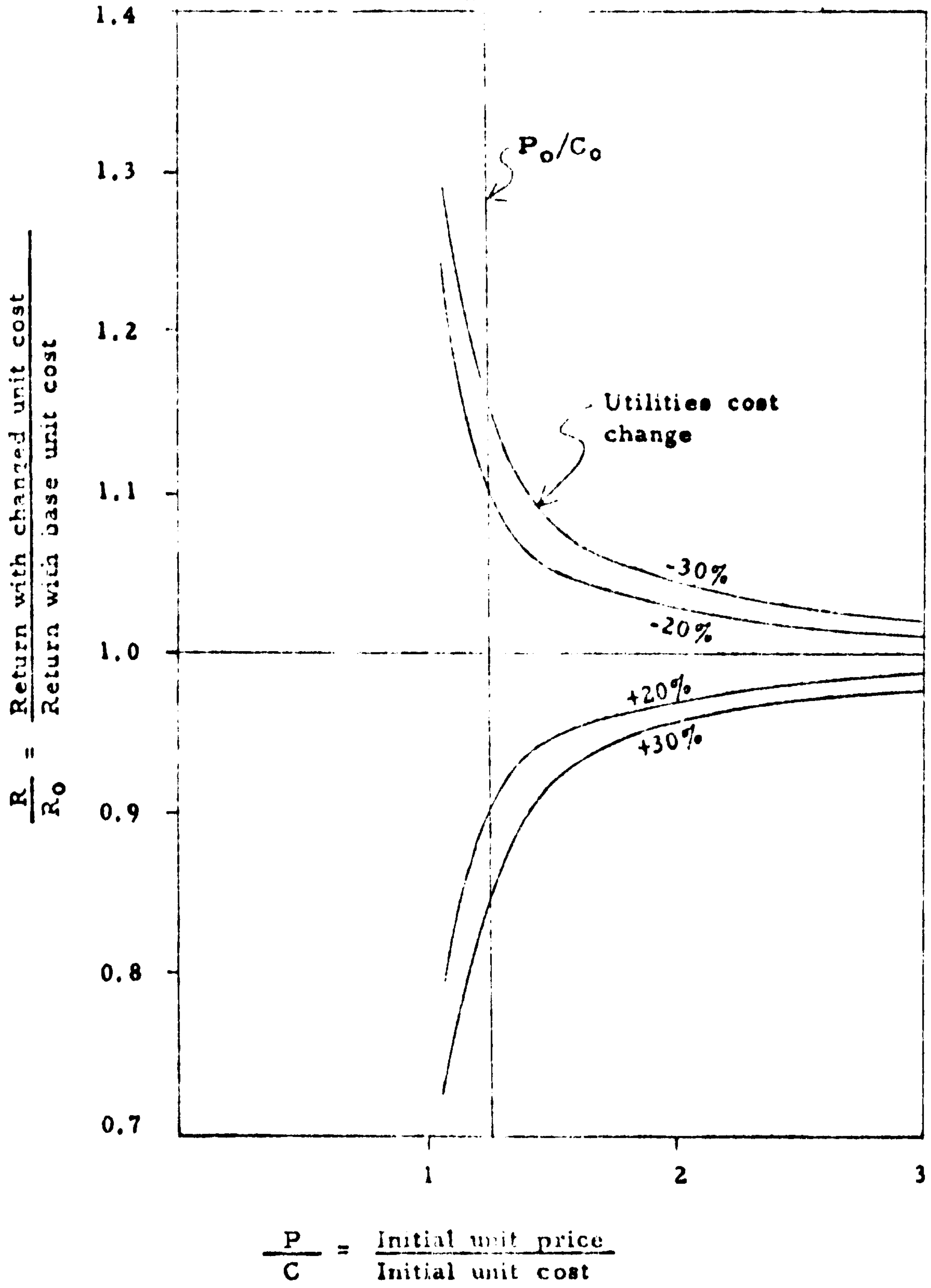
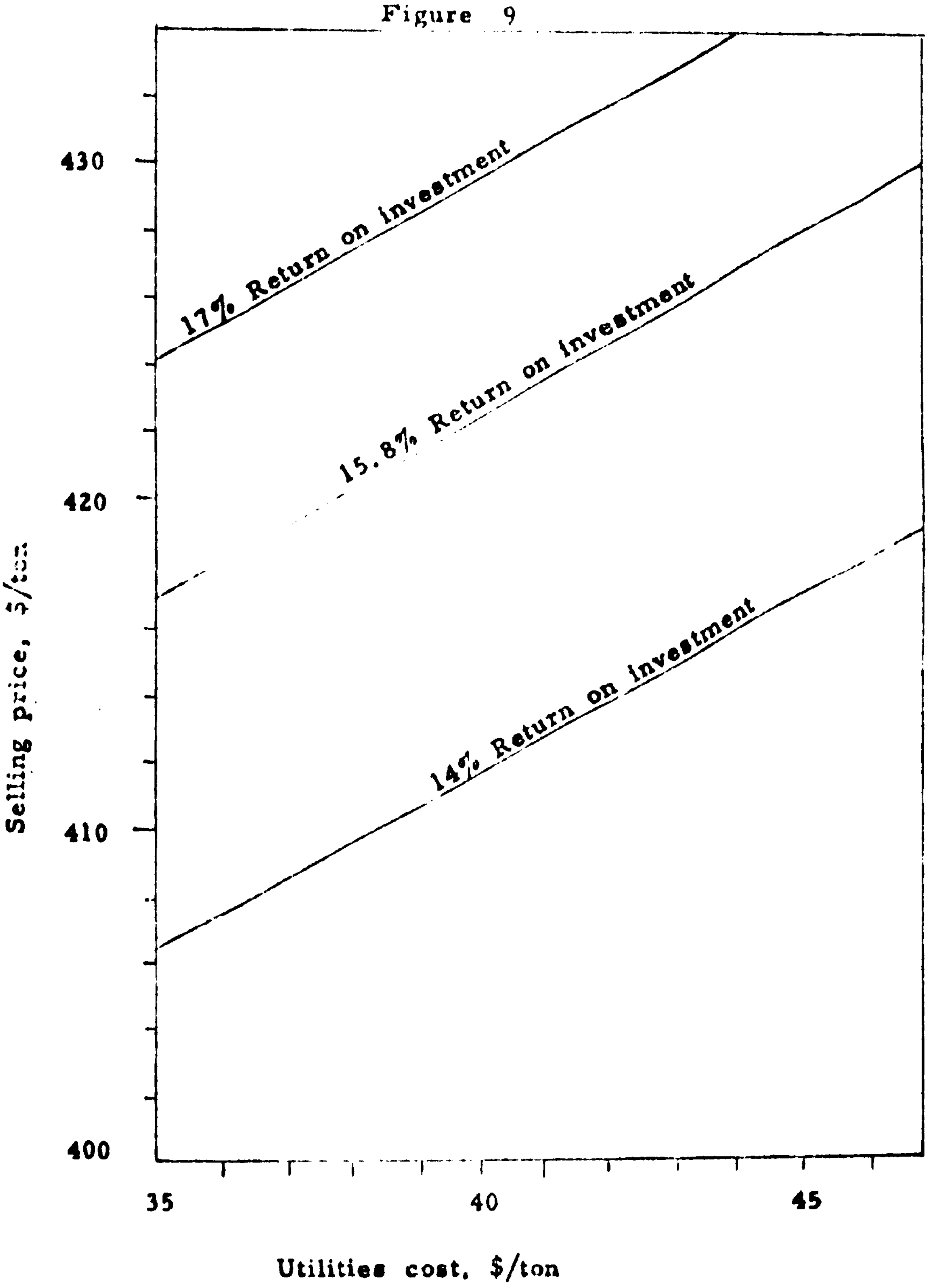

17% Return on investment
15.8% Return on investment
14% Return on investment
430
420
410
400
40
45
Selling price, $/ton
Chemicals cost, $/ton

Figure 8



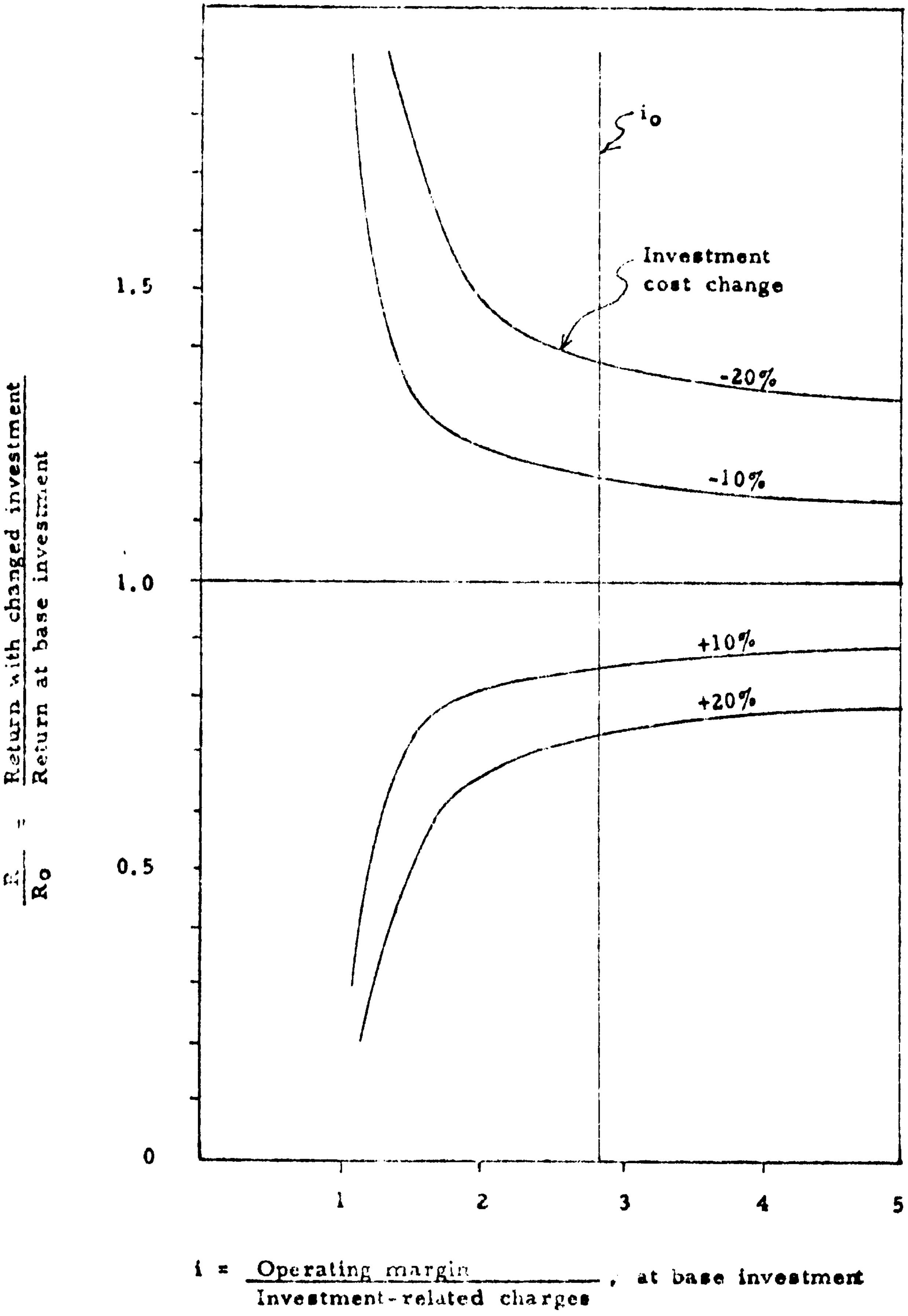
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
$\frac{R}{R_o} = \frac{\text{Return with changed unit cost}}{\text{Return with base unit cost}}$
$P_o/C_o$
Utilities cost change
-30%
-20%
+20%
+30%
1
2
3
$\frac{P}{C} = \frac{\text{Initial unit price}}{\text{Initial unit cost}}$

Figure 9



17% Return on investment
15.8% Return on investment
14% Return on investment
430
420
410
400
Selling price, $/ton
35
40
45
Utilities cost, $/ton

Figure 10



$i_o$
Investment cost change
-20%
-10%
+10%
+20%
1.5
1.0
0.5
0
1
2
3
4
5
$\frac{R}{R_o}$ = $\frac{\text{Return with changed investment}}{\text{Return at base investment}}$
i = $\frac{\text{Operating margin}}{\text{Investment-related charges}}$, at base investment

Figure 11

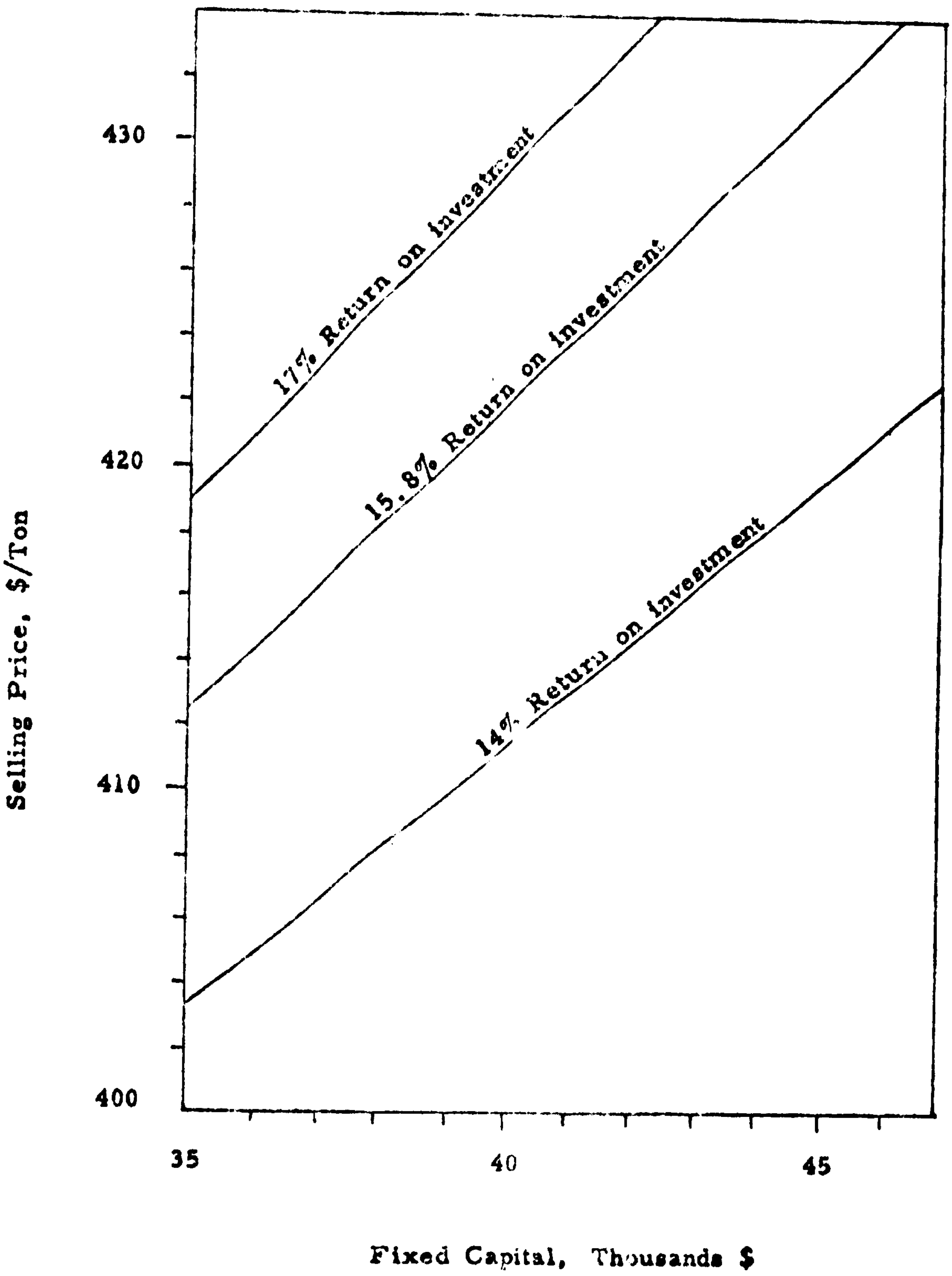

17% Return on investment
15.8% Return on investment
14% Return on investment
430
420
410
400
Selling Price, $/Ton
35
40
45
Fixed Capital, Thousands $

Figure 12

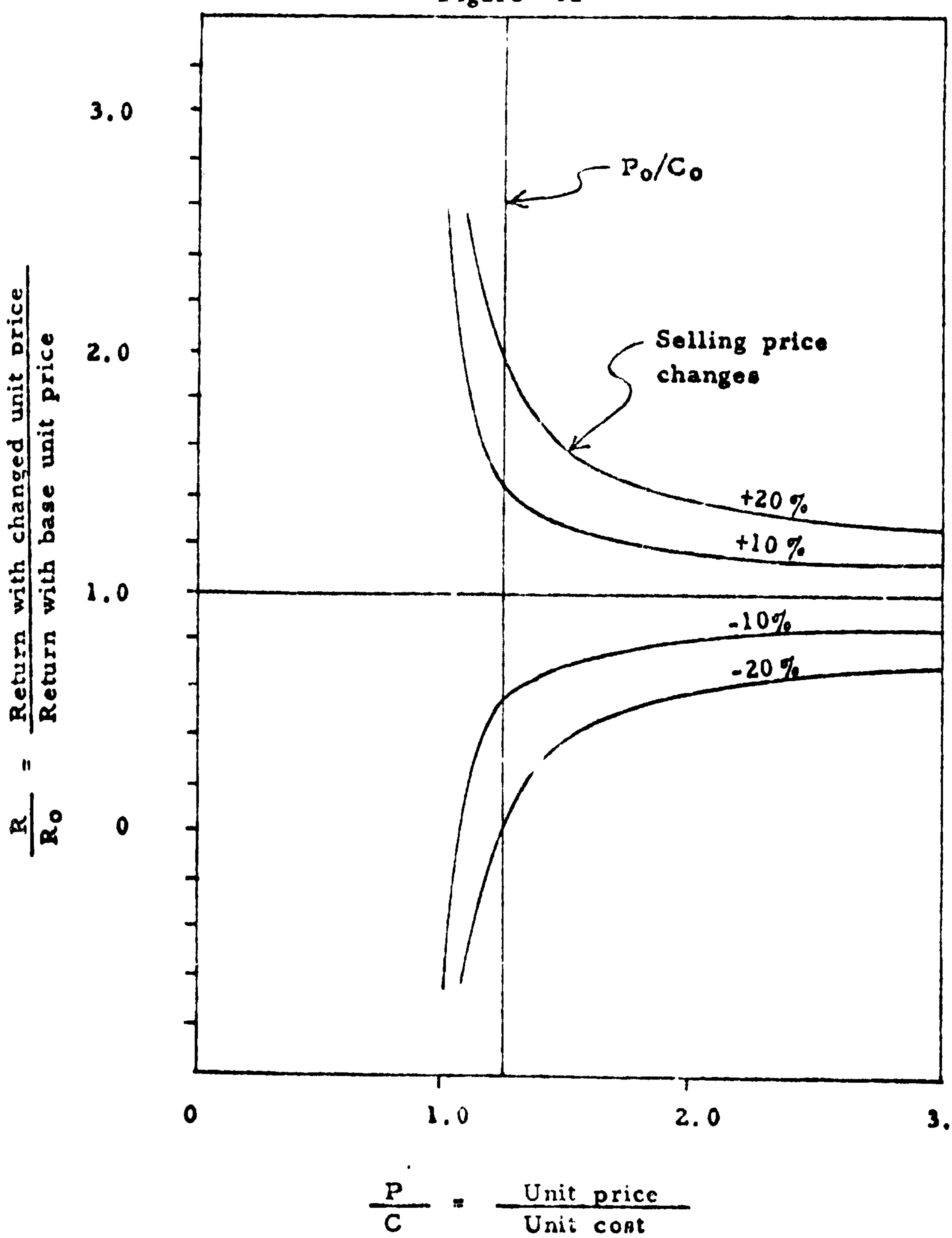

3.0
2.0
1.0
0
$P_o/C_o$
Selling price changes
+20 %
+10 %
-10%
-20 %
$\frac{R}{R_o}$ = $\frac{\text{Return with changed unit price}}{\text{Return with base unit price}}$
0
1.0
2.0
3.0
$\frac{P}{C}$ = $\frac{\text{Unit price}}{\text{Unit cost}}$

Figure 13

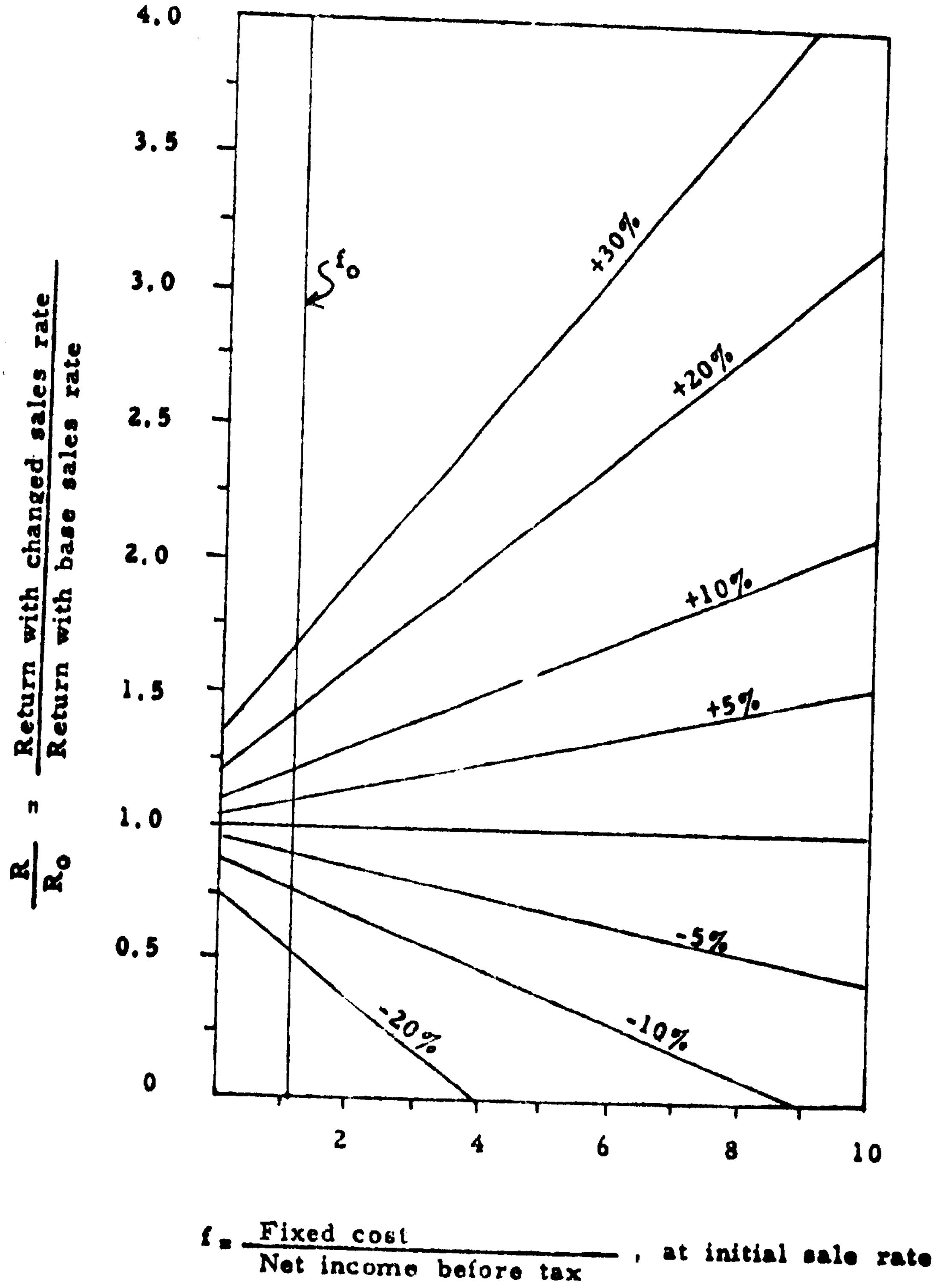
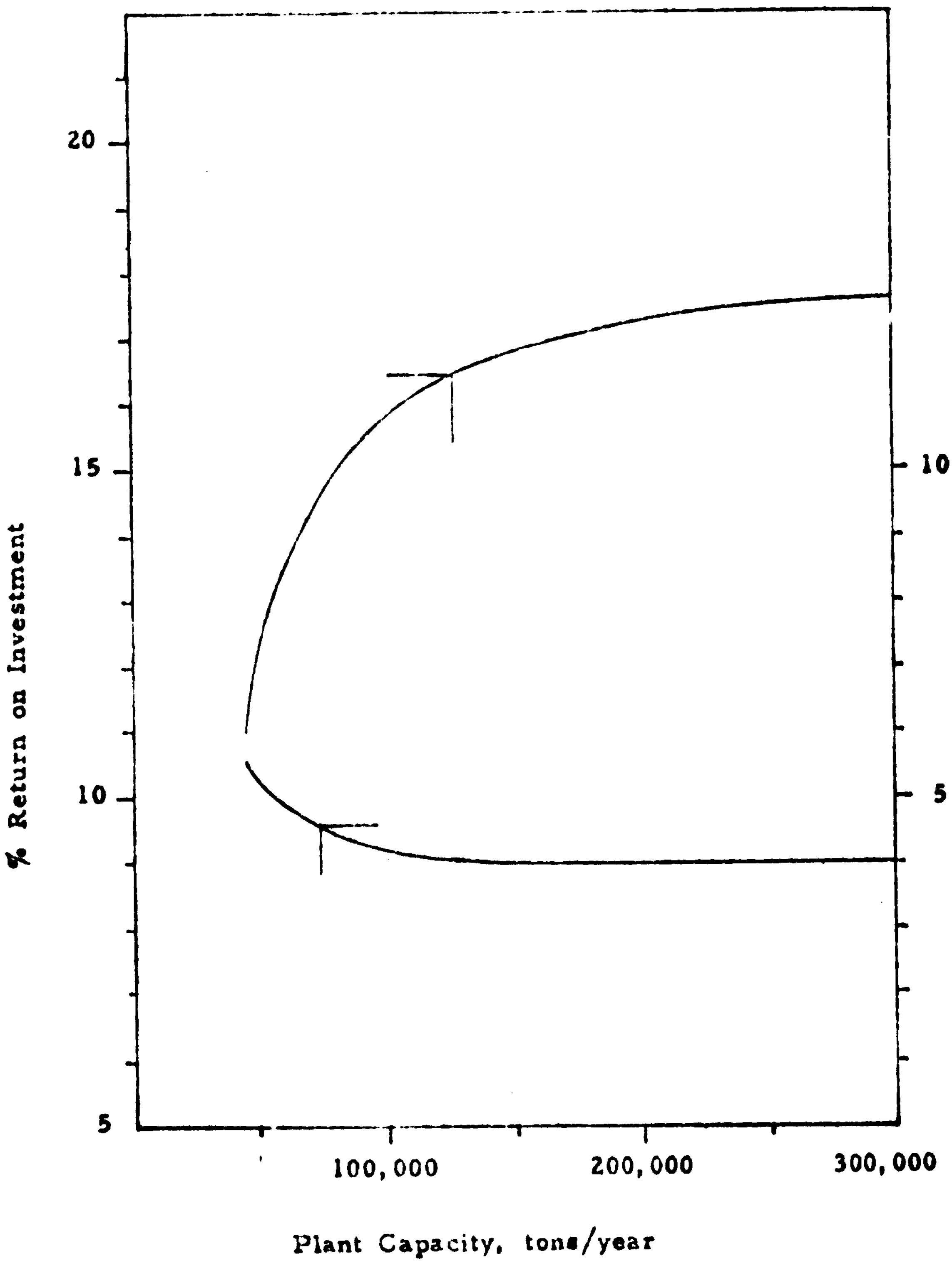
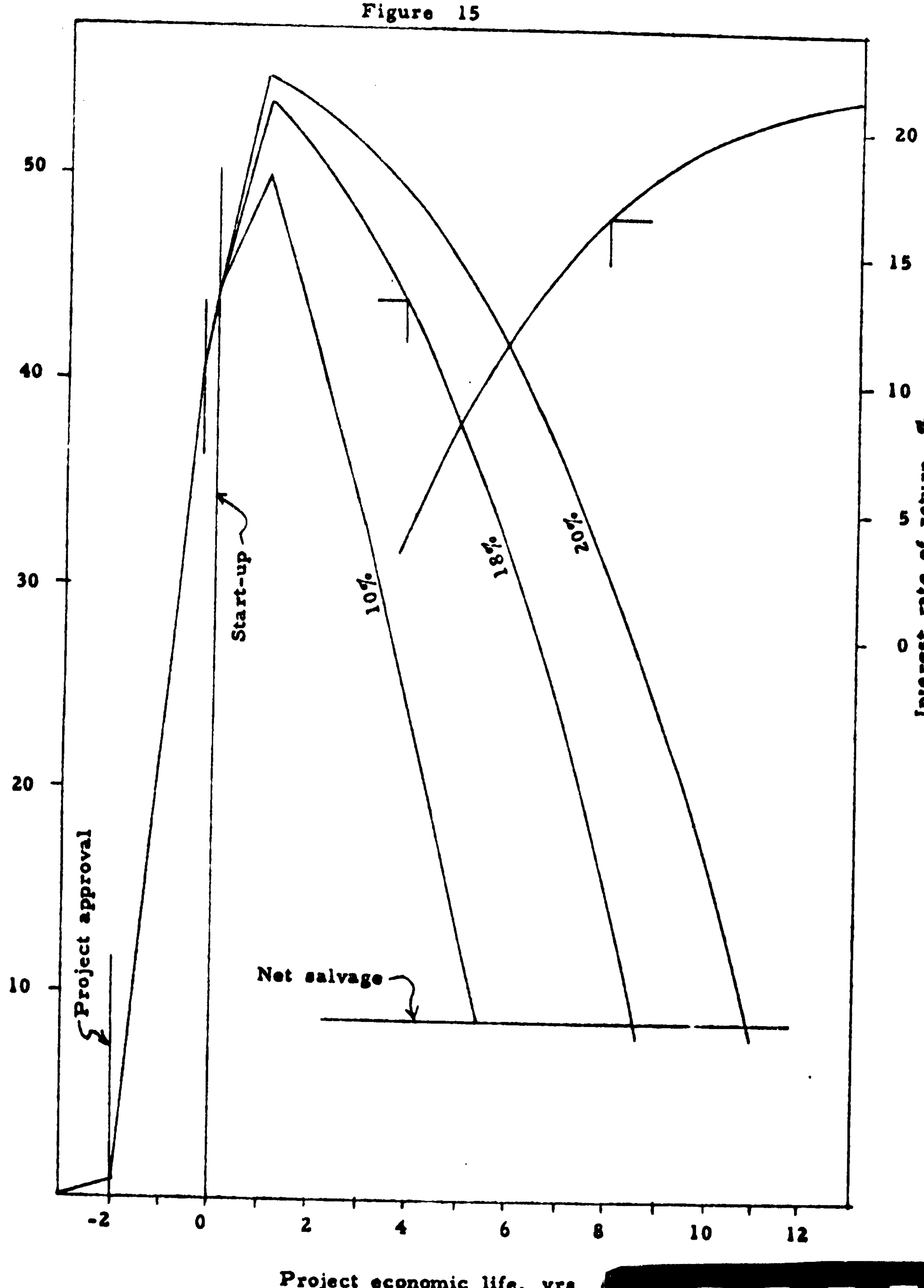

4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
$\frac{R}{R_o}$ = $\frac{\text{Return with changed sales rate}}{\text{Return with base sales rate}}$
$f_o$
+30%
+20%
+10%
+5%
-5%
-10%
-20%
2
4
6
8
10
f = $\frac{\text{Fixed cost}}{\text{Net income before tax}}$ , at initial sale rate

Figure 14



20
15
10
5
% Return on Investment
10
5
Payout Time, years
100,000
200,000
300,000
Plant Capacity, tons/year

Figure 15



50
40
30
20
10
20
15
10
5
0
Interest rate of return, %
Start-up
Project approval
10%
18%
20%
Net salvage
-2
0
2
4
6
8
10
12
Project economic life, yrs

2. 9. 74