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PRELIMINARY COST ESTIMATION
OF NON-FERROUS
METAL PRODUCTION PROCESSES

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ABSTRACT

This thesis describes the new development of capital and total product cost models for the preliminary cost estimation of non-ferrous metal production processes. It is intended that the cost models are used to produce quick estimates and capable of being applied to various situations for screening alternatives during the early stages of process development. In addition, the cost models are incorporated into computer programs written in BASIC.

First, a thorough investigation into the technological background of non-ferrous metal production processes with their economic aspects is given and the cost elements which make up the capital investment of a non-ferrous metal production process are defined. Then, existing estimating techniques are reviewed according to the estimate classification practised by American Association of Cost Engineers (AACE). Particular attention is given to pre-design estimating techniques and their shortcomings or limitations are identified. From the analysis, proposals for a new analogous cost estimating techniques are presented, with careful attention being paid to the definition of the factors in the cost correlations. The derived cost models were tested on recent cost data for primary and secondary production processes, which showed good accuracy results.

In parallel with the research, total product cost model is also derived. However, this general model is applicable to the primary production of non-ferrous metal smelting processes as it is mainly based on cost data obtained from primary industries.

Although the cost models are derived from limited data (difficulty was encountered in cost data collection, which led to the overall cost-capacity technique), the test results showed promising accuracies. Therefore, suggestions are given for future work when sufficient data are available.

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LIST OF DIAGRAMS

CHAPTER ONE

INTRODUCTION

In an economy where profits tend to be squeezed by costs and competition is keen, a good set of tools for appraising proposals for capital expenditure is a valuable asset. Therefore, any organisation considering to invest in development and construction of a process plant will carry out a detailed investment appraisal, if their firms are to remain highly competitive in today's market.

In the most basic terms, the aim of investment appraisal is to develop a realistic estimate in terms of capital costs, operating costs, economic legislation, sales revenue, and profitability for a project, so that the benefits expected to accrue from such investment can be forecasted. This research study is concerned with two of the features of investment appraisal, that is the development of reliable capital and operating cost models for the non-ferrous metal production processes including copper, zinc, lead and tin.

In the chemical and petrochemical industries where competition is most extreme, it requires sophisticated and accurate methods of costs estimating. This requirement applies to both the manufacturing organisations and contracting organisations; the former's prime objective is to provide data for appropriation of capital whilst the latter's prime objective is to establish a cost which will be competitive enough to secure contract award and will have an accuracy commensurate with risk which is being undertaken. Thus, generally speaking, the manufacturing organisations need to concentrate on flowsheets and other analytical methods of estimating whilst the contracting organisations concentrate on definitive and/or detailed estimating. Obviously, both groups are required to produce other types of estimate under certain conditions. Many existing estimating techniques, which are well-known to the chemical and petrochemical industries, have been classified by the American Association of Cost Engineers (AACE) in 1958 as follows:-

1) Order of Magnitude Estimates
2) Study Estimates
3) Preliminary Estimates
4) Definitive Estimates
5) Detailed Estimates

Each of the above groups has different accuracies and serves different purposes.

Obviously, cost estimates are required for a process right from its initial conception, through its development stages of metallurgical and detailed mechanical engineering design, to its final construction and start-up, in order that it may constantly be monitored and evaluated. Before manufacturing organisations commit themselves to build the plant, however, they need cost estimates capable of screening alternative process routes in order to select their optimum production unit. In addition, it is desirable for them to complete this screening study as early as possible, certainly before detailed process design is required, in order that valuable time, money and engineering manhours are not wasted. In the early stages of process development, usually, limited amount of process information is available including a conceptual flowsheet, process capacity, materials of construction, operating conditions together with the location and planned-construction completion date of the plant. Pre-design cost estimates, which are usually based on this limited information, have considerable importance in process development studies by providing major screening criteria to decide whether or not to proceed with more experiments or design. Thus, this research project will concentrate its study on pre-design cost estimating with the aim of producing rapid cost-estimating models that are capable of being applied to the various situations encountered during the early stages of process development.

Before involving in the development of capital and total product cost models, a thorough investigation into the technological background of non-ferrous metal production processes with their economic aspects is essential. Thus, Chapter 2 examines the primary production of non-ferrous metals including flowsheets, resources, industrial smelting processes, refining,economic considerations and conclusions. In addition, though secondary recovery of non-ferrous metals is in its infancy, it has become increasingly in importance. Therefore, Chapter 3 will examine secondary recovery of non-ferrous metals covering secondary sources, charge preparation, current smelting processes, problems in smelting secondary sources, economic benefits of secondary recovery and its conclusion summarizing the differences between primary and secondary production processes.

Chapter 4 examines the elements of capital cost estimation. This covers the definition of capital investment; discussion of various types of capital cost estimates according to different accuracies and purposes, and their limitations in use; review of cost indices showing how the historical data can be updated for the cost estimating purposes, what they consist of and limitations of their use; breakdown of fixed-capital-investment items for a non-ferrous metal production process giving an insight of the essential cost structure of the plant; and conclusion summarizing the essential points of Chapter 4.

Chapter 5 then describes the development of capital cost estimating model after surveying and absorbing the background information as already described in Chapter 2, 3, and 4. It covers the basic requirements of cost model derivation, identification and selection of those factors which influence the fixed capital investment, cost model development, model testing and cost model comparison. The capital cost models derived in the research are only based on the cost-capacity data given in Appendix A, in which a correlation was proved to be significant within 95% confidence limit.

In parallel with the research on developing capital cost estimating model, an overall general total product cost model is also derived. Its derivation including direct labour and utilities cost models and together with the survey of operating cost elements is given in Chapter 6. However, this general model is only applicable to the primary production of non-ferrous metal smelting processes. It is because very little information is known about the energy consumed by the collection, transportation, physical separation, mechanical processing, and smelting of secondary metals. Nevertheless, it is considered that it can be used to calculate total product cost as a rough guidance for secondary recovery.

An example of economic evaluation of a non-ferrous metal smelting process illustrating how the input data such as process capacity, process steps, etc. are selected for the cost models is described in Chapter 7. This chapter includes process description, smelting costs, and profitability.

In order for this research to be of practical as well as of effective use, the cost models derived are incorporated into computer programs written in BASIC, which can generate the necessary analytical information in a fraction of a minute instead of a day normally required by means of manual calculation, and thereby allow the evaluator to concentrate upon his primary functions of analysis and interpretation. Chapter 8 describes such computer programs effectively employed for the economic evaluation of non-ferrous metal smelting processes.

Chapter 9 covers discussion and conclusion. It summarizes the research results in tabulated form and factors that are employed in the cost modesl; the derivation of total product cost model and research objectives.

The final chapter takes into consideration of the major problem confronted in the research work. To aid future research on this area of cost estimating, a few suggestions (cost data standardisation and theory) will be described with the intention to overcome this problem or barrier and consequently improving the cost-estimating technique.

CHAPTER TWO

PRIMARY PRODUCTION OF NON-FERROUS METAL INCLUDING COPPER, ZINC, LEAD AND TIN

At some stage in the production of metals, the value of minerals in the ore must be chemically transformed. For example, in the copper flowsheet (Figure 2.1), no chemical change takes place until after ore called concentrate (containing from 20-40% Cu, 50-60% Zn, 50-70% Pb and 20-70% Sn for copper, zinc, lead and tin concentrates). The research is concerned with preliminary cost estimation of non-ferrous metal production processes starting from concentrate handling to refined metal. Nevertheless, there are, generally, two routes of processing from ore to refined metal, i.e. Pyrometallurgy and Hydrometallurgy (Pyrometallurgy deals with process streams that are concentrated with respect to metal content and that undergo very rapid chemical reactions owing to elevated temperature, whereas Hydrometallurgy deals with far less concentrated process streams because of the dilution with many volumes of water for each volume of concentrate feed; many leaching reactions suffer from slow kinetics). The former is only dealt with in the research.

The main purposes of this chapter are two-folds: Firstly, the current and developing technology of primary production of non-ferrous metals including copper, zinc, lead and tin will be reviewed in order to familiarize the reader with the technology as well as the economic aspects. Consequently, the reader will be capable of selecting the best alternative from the existing processes for the production of each metal. Secondly, from the above review, I will be able to detect the important and relevant factors that influence the capital cost of a process.

The chapter covers flowsheets, resources, industrial smelting processes, refining, economic considerations and conclusions.

2.1 <u>Flowsheets</u>

The process or combination of processes which is used in a metallurgical plant is illustrated conveniently by means of a flowsheet. Figure 2.1 illustrates the general flowsheet of copper production from a low grade copper sulphide ore. If flowsheets for different copper smelters are examined, they usually show some variations which may due to differences in the composition of the ore, in the local supply of energy either as fuel or electric power, in the demand of quality for final products and in the size of the plant for the market. General flowsheets for the production of zinc, lead and tin are shown in Figures 2.2, 2.3 and 2.4. These differ again considerably from the copper flowsheet. Thus, we may deduce that every metal and every locality requires its own extraction process.

2.1.1 <u>Unit Processes And Unit Operations</u>

If the flowsheets are examined closely it is seen that they consist of combinations of steps or operations,

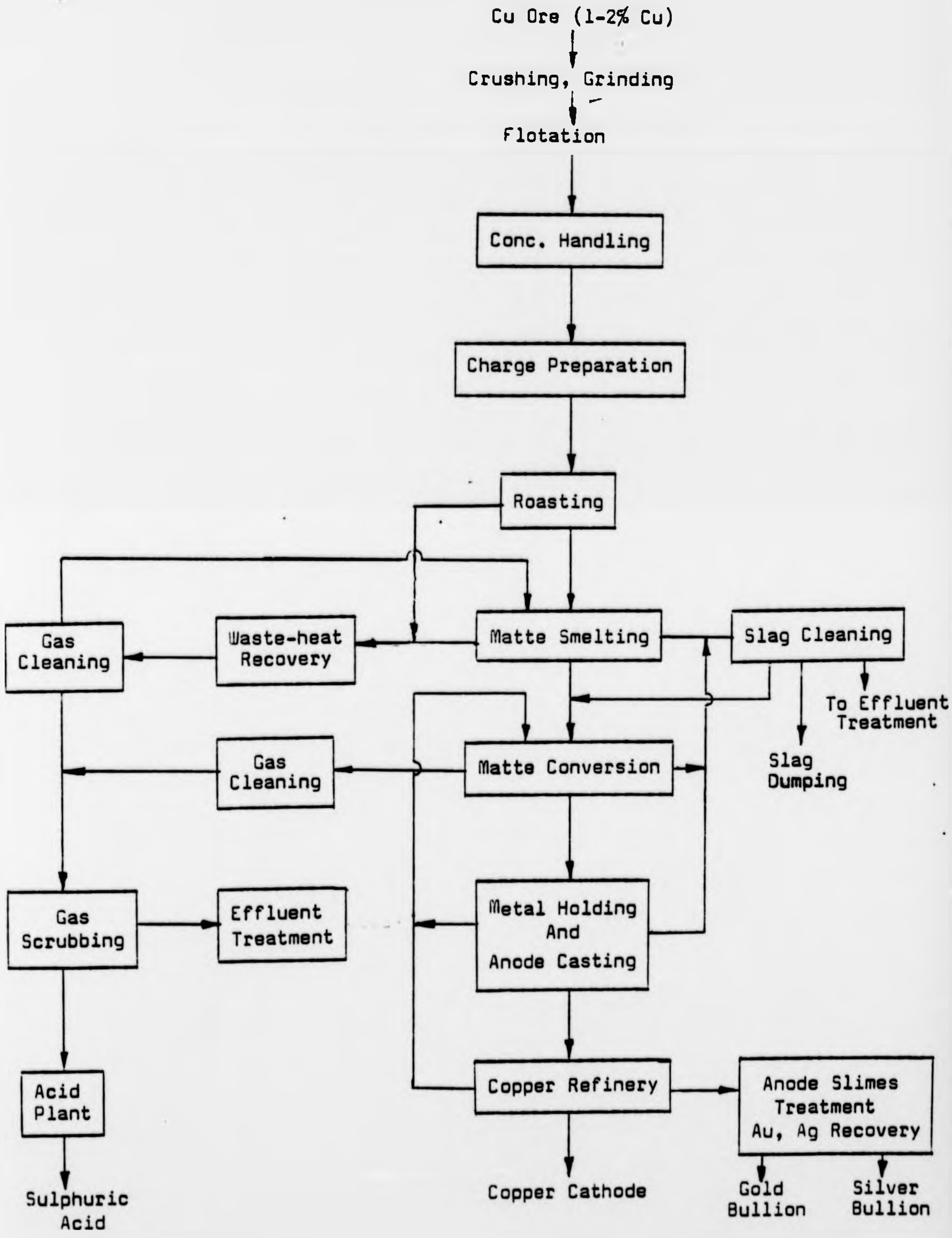


Figure 2.1 General Flowsheet Of Copper Smelter

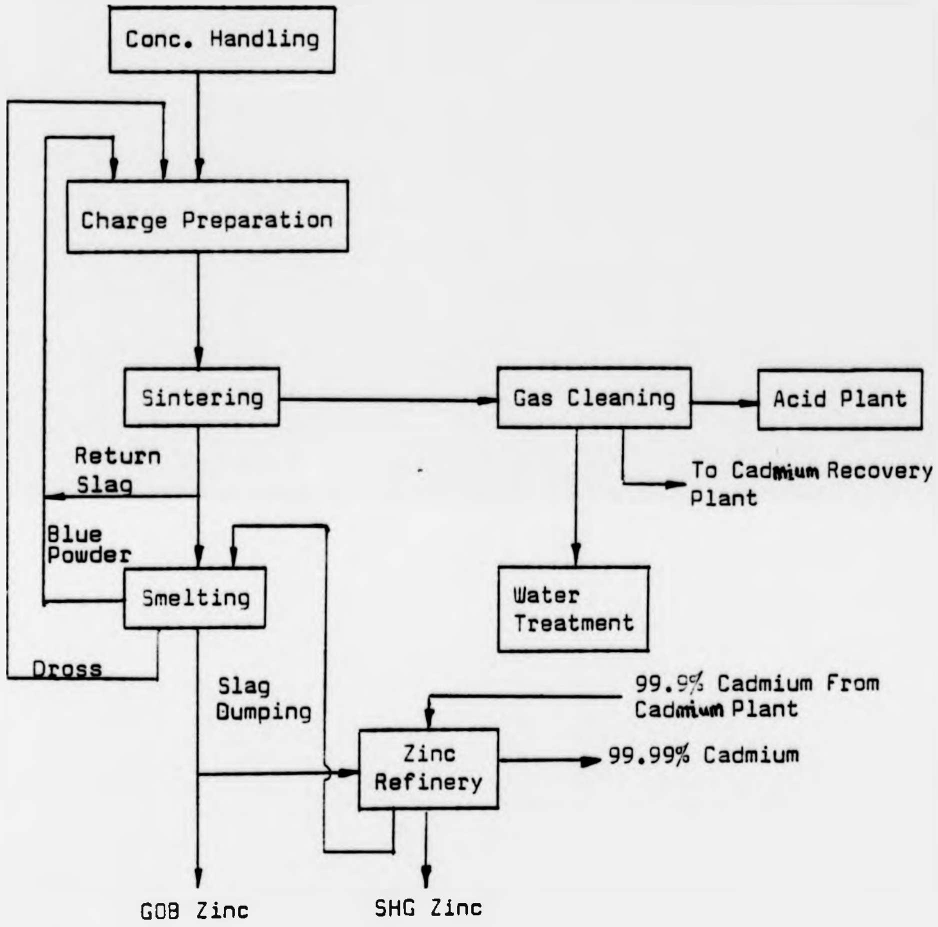


Figure 2.2 General Flowsheet Of Zinc Smelter

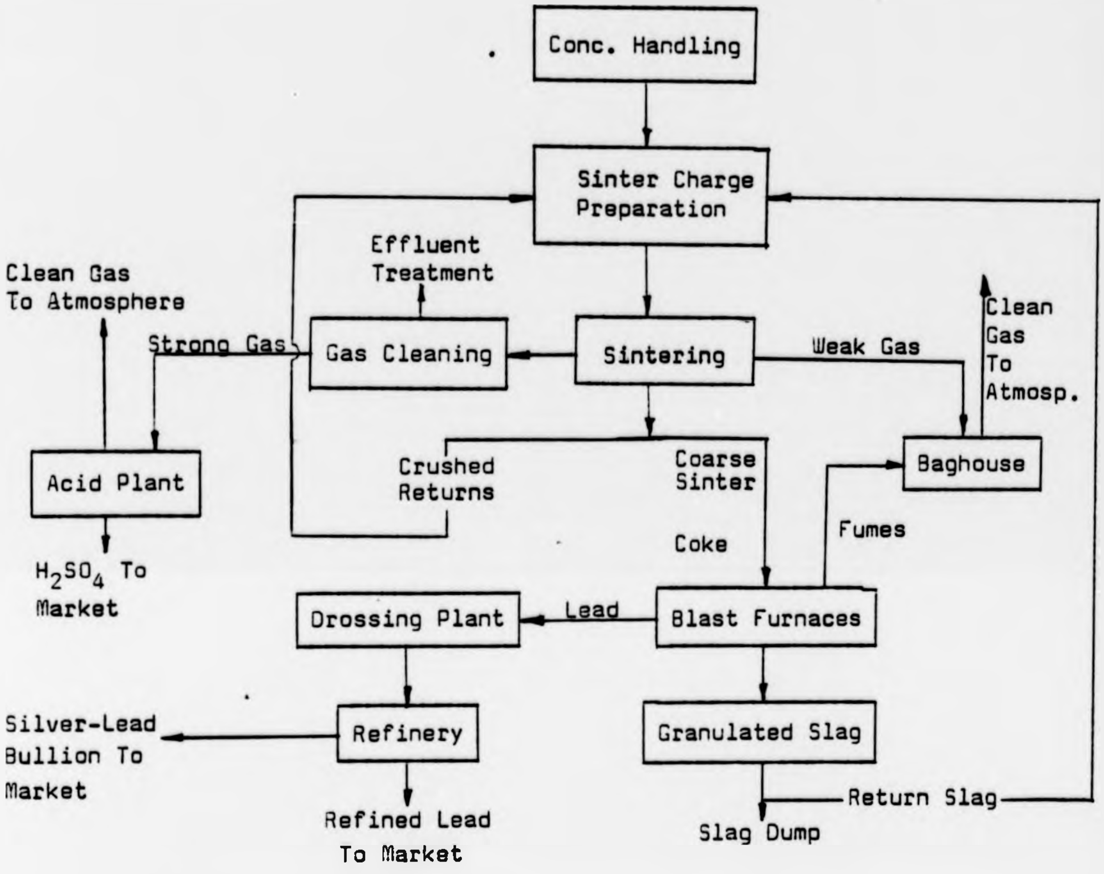


Figure 2.3 General Flowsheet Of Lead Smelter

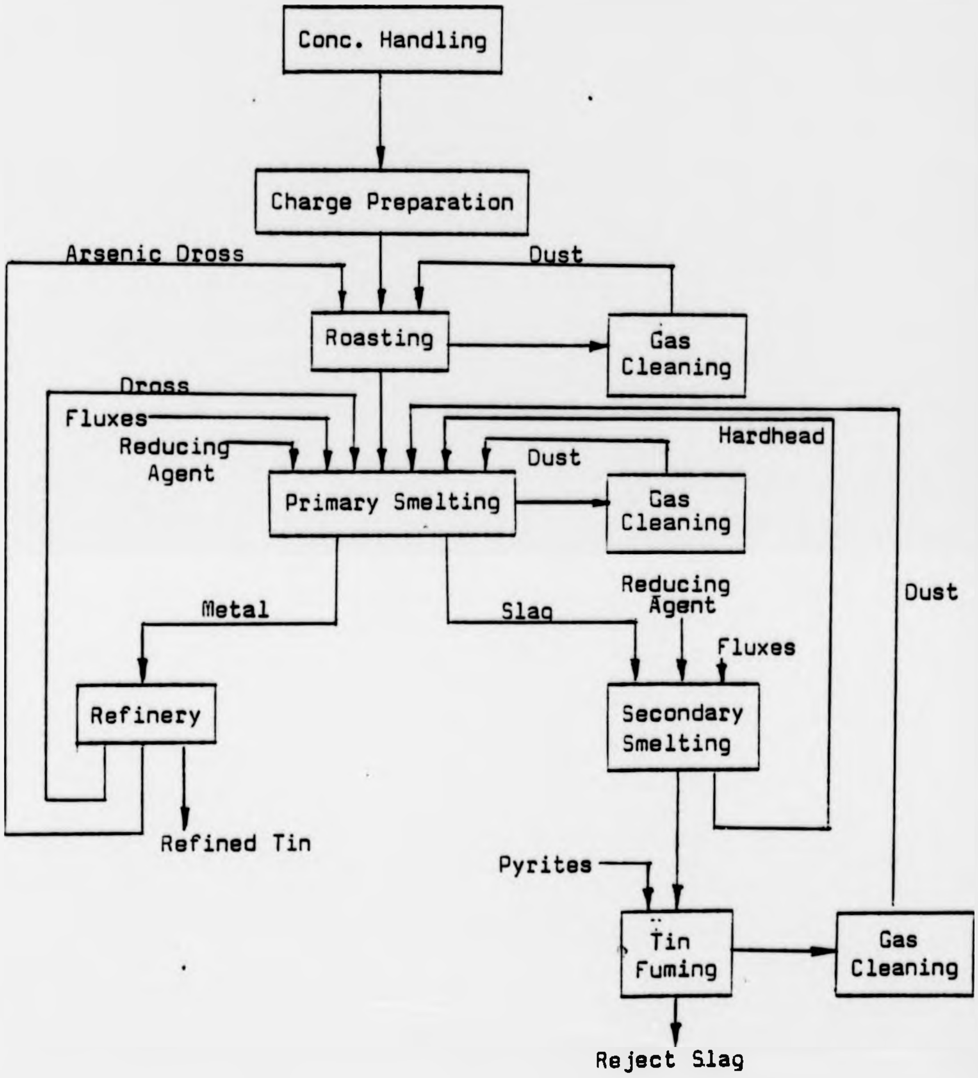


Figure 2.4 General Flowsheet Of Tin Smelter

and that some of the same steps or operations are found in the production of different metals and in different locations. Thus, for the copper flowsheet (Figure 2.1), the first few steps which involve crushing, grinding and flotation are called ore dressing, which is often practised to separate the ore mineral from the gangue or from other ore minerals near the mining area. The upgraded ore called concentrate is then transported to the smelter. After concentrate handling and charge preparation, the next step may be a roasting operation where some of the sulphur in the ore is removed. This is followed by a smelting operation where copper is enriched in a sulphide melt (matte), whereas iron and gangue minerals are discarded in a slag. The matte is then blown in a converter where the remaining iron is slagged and copper sulphide is oxidized to a crude metal (blister copper). This is refined in a refining furnace and finally refined by electrolysis to produce the commercial product. However, in some plants the roasting step is omitted, whereas sometimes slag cleaning or treatment is included. In other cases, the electrolytic refining step is omitted, whereas sometimes, the crude blister copper is cast directly into anodes for electrolytic refining.

If we look at the flowsheets for the production of zinc, lead and tin (Figures 2.2, 2.3 and 2.4), we find some of the same steps as in copper production: roasting and smelting are also used in the production of zinc, lead and tin. Thus, a large variety of flowsheets is possible by combinations of a relatively small number of different single steps. In analogy with the usage in Chemical Engineering, we call these steps "Unit Operations" or "Unit Processes". By "Unit Operation" is usually understood a step which is characterized by certain physical features. Thus, crushing, screening, proportioning, and mixing are typical unit operations. "Unit Processes" on the other hand means steps characterized by a certain chemical reaction. Roasting of a sulphide ore or gas reduction of an oxide ore could be called a unit process. In general, four major types of classification could be considered:-

1) According to phases involved
    - (a) Gas-solid. Examples: Roasting, gas reduction, cyclone, baghouse
    - (b) Gas-liquid. Examples: Bessemer blowing, distillation, scrubbers
    - (c) Liquid-liquid. Example: Slag-metal reactions
    - (d) Solid-liquid. Examples: Liquation, leaching, precipitation, flotation
2) According to equipment
    - (a) Fixed bed. Example: Sintering
    - (b) Fluidized bed. Examples: Roasting and reduction
    - (c) Rotary kiln. Examples: Drying and calcination
    - (d) Retort. Examples: Coke-oven, carbothermic zinc production
    - (e) Reverberatory furnace. Example: Matte smelting
    - (f) Electric furnace. Examples: Matte smelting and slag smelting
    - (g) Cells for aqueous electrolysis: Examples: Electrolytic reduction and refining
    - (h) Mixer. Example: Mixing of charge

3) According to chemical reactions
    (a) Oxidation. Examples: Roasting, sintering, bessemer blowing
    (b) Reduction. Examples: Carbothermic zinc production
    (c) Slag-metal reactions. Example: Matte smelting
    (d) Electrolytic refining. Examples: Refining of tin and copper
4) According to certain physical features
    (a) Crushing. Example: Reduction in size of lump ore
    (b) Drying. Example: Removing water moisture from the concentrate
    (c) Heat exchanging. Example: Transfer of heat from one medium to another
    (d) Casting. Example: Making metal into a mould

It appears that whatever system of classification is used, it will tend to emphasize certain similarities, whereas it will separate others. In order to be consistent in its application for the cost modelling, it is more appropriate to refer to the second classification, i.e. according to equipment known as modular equipment step. Subsequent to this classification, we can draw a typical list of modular equipment steps for primary production processes of non-ferrous metals as shown in Table 2.1. This table will be used for the derivation of cost models (See Chapter 5) and the definition of modular equipment step will be discussed in Section 5.2.5.

Table 2.1 Number Of Modular Equipment Steps For Primary Production Processes Of Copper, Zinc, Lead And Tin

Metallurgical Sections	Copper Process	Zinc Process	Lead Process	Tin Process
Concentrate Handling	Weighing Machines	Weighing Machines	Weighing Machines	Weighing Machines
	Sampling Equipment	Sampling Equipment	Sampling Equipment	Sampling Equipment
	Conveyors	Conveyors	Conveyors	Conveyors
Charge Preparation	Hoppers	Hoppers	Hoppers	Hoppers
	Dryers	Belt-Scale Feeders	Belt-Scale Feeders	Belt-Scale Feeders
	Crushers	Hammer Mill	Hammer Mill	Mixers
	Screens	Mixers	Mixers	Peletizers
	Belt-Scale Feeders	Conveyors	Conveyors	Conveyors
	Mixers			
	Peletizers			
	Cyclones			
	Stacks			
	Conveyors			
Roasting Or Sintering		Blowers	Blowers	Blowers
		Sintering Machines	Sintering Machines	Sintering Machines
		Sinter Breakers	Sinter Breakers	Conveyors
	-	Spike Rolls	Spike Rolls	
		Ross Rolls	Ross Rolls	
		Corrugated Rolls	Corrugated Rolls	
		Drum Coolers	Drum Coolers	
		Smooth Rolls	Smooth Rolls	
		Pug Mill	Pug Mill	
		Conveyors	Conveyors	

Smelting	Hoppers	Hoppers	Hoppers	Hoppers
	Blowers	Blowers	Blowers	Blowers
	Charging Machines	Charging Machines	Charging Machines	Charging Machines
	Smelting Furnaces	Preheaters	Blast Furnaces	Primary Smelting Furnaces
	Converting Furnaces	Shaft Furnaces	Cranes, Mobile Equipment	Secondary Smelting Furnaces
	Slag Cleaning Furnaces	Splash Condensers	Pots, Settlers, Ladlers	Slag Holding Furnaces
	Cranes, Mobile Equipment	Heated Launders		Volatilisation Furnaces
	Pots, Settlers, Ladles			Cranes, Mobile Equipment
				Pots, Settlers, Ladles
Gas Cleaning	Blowers	Blowers	Blowers	Blowers
	Waste Heat Boilers	Waste Heat Boilers	Waste Heat Boilers	Waste Heat Boilers
	Cyclones	Cyclones	Cyclones	Cyclones
	Baghouses, Cottrell, Electrostatic Precipitators	Baghouses, Electrostatic Precipitators	Baghouses, Electrostatic Precipitators	Baghouses, Electrostatic Precipitators
	Stacks	Stacks	Stacks	Stacks
Water Treatment	Pumps	Pumps	Pumps	
	Neutralizers	Neutralizers	Neutralizers	
	Clarifiers	Clarifiers	Clarifiers	
	Filters	Filters	Filters	
	Tanks	Tanks	Tanks	

Anode Casting Or Fire Refining	Holding Furnaces Anode Furnaces Casting Machines Stamping Presses Stacking Machines Mobile Equipment	Drossing Kettles Decopperization Kettles First Step Desilverization Kettles Second Step Desilverization Kettles Vacuum Dezincing Kettles Refining Kettles Casting Machines Stacking Machines Heated Launders Mobile Equipment	Fractional Distilla- Columns Liquation Furnaces Casting Machines Stacking Machines Mobile Equipment	Drossing Kettles Liquation Furnaces Casting Machines Stacking Machines Mobile Equipment
Electrolytic Refining	Pumps Cells Cranes Stripping Machines Melting Furnaces Casting Machines Stacking Machines Mobile Equipment	-	-	Pumps Cells Cranes Stripping Machines Melting Furnaces Casting Machines Stacking Machines Mobile Equipment

Acid Plant	Packed Towers	Packed Towers	Packed Towers
	Cooling Towers	Cooling Towers	Cooling Towers
	Mist Precipitators	Mist Precipitators	Mist Precipitators
	Drying Towers	Drying Towers	Drying Towers
	Blowers	Blowers	Blowers
	Converters	Converters	Converters
	Heat Exchangers	Heat Exchangers	Heat Exchangers
	Absorbing Towers	Absorbing Towers	Absorbing Towers
	Tanks	Tanks	Tanks

2.1.2 Features Of Metal Extraction

If we examine various flowsheets, we will observe certain common features, such as the circulation or return of intermediate products, slags, drosses, dusts, hardhead, to previous steps, and the recovery of byproducts. The former is done in order to recover, as completely as possible, the valuable constituents. Thus, in the flowsheet for tin (Figure 2.4), hardhear, dust and dross from the secondary smelting, baghouse (gas cleaning) and refining furnace are returned to primary smelting stage. Here the tin content of hardhear, dust and dross is recovered. And the latter is done in order to recover valuable byproducts. Thus, in Figure 2.1, sulphur is recovered as sulphuric acid in the roasting, smelting and converting steps, whereas gold and silver are recovered from the anode slimes treatment. Most other ores also contain, in addition to the major elements, smaller or larger quantities of byproduct elements. These are enriched in certain phases at certain stages in the treatment: volatile metals in the flue dust, metal with high affinity for oxygen in the refining slags, noble metals in anode mud or slimes. Also, special processes may be developed to recover valuable byproducts which do not separate out during normal refining processes. Thus, small amounts of silver usually do not harm in lead, but because of its value, special methods have been developed for desilverisation of lead.

The recovery, both of the main product and of the byproducts will always depend on economic considerations. Even though it may be technically possible to get close to 100 percent recovery, this is not necessarily the most economic solution. Sometimes, it is better to let some of the valuable elements go to the slag dumps. When extraction techniques have improved or when the market conditions have changed, these slag dumps may once again be "mined" to recover with profit those elements which earlier generations could only recover with loss.

2.2 Sources

The original source of all metals is from the earth's crust which consists of metallic deposits normally in the form of their oxides or sulphides called ores, from which metals can be extracted. In some instances, noble metals, such as gold, silver, and sometimes copper are found in native or free elemental form. Ores are seldom composed of one metallic compound but usually are made up of several, including the mineral of the desired metal and other impurity compounds referred to as gangue.

The most important zinc mineral is the sulphide sphalerite(ZnS) often referred to as zinc blends, galena(PbS), iron pyrite, and silver are commonly associated with zinc blende. Zinc deposits also occur as a mixture of zincite(ZnO) and the iron-and manganese-bearing mineral franklinite($(Fe, Mn)O$).

Lead is found in nature as the sulphide galena(PbS), which occurs in many types of deposits including sedimentary rocks, hydrothermal veins, and pegmatites. Sulphate anglesite($PbSO_4$) and carbonate cerussite($PbCO_3$) are of common occurance in the upper oxidized zones of lead deposits which contain galena.

The ores of lead usually contain, in addition to zinc blende, recoverable amount of copper, silver, gold, antimony, and bismuth. The largest producers of lead include the United States, Australia, Russia, Canada, and Mexico.

Tin is a relatively rare metal, accounting for less than 0.001wt% of the earth's crust. The most important mineral of tin is the oxide cassiterite(SnO_2). Tin oxide is often concentrated into a placer deposit as a heavy mineral. These placer deposits are found principally in Malaysia and Indonesia. In Bolivia, complex sulphide ores such as stannite($Cu_2S.FeS.SnS_2$), and franckeite($5PbS.2SnS_2.Sb_2S_3$) had had some significance in production. Cassiterite is often associated with quartz, scheelite, wolframite, tourmaline, fluorite, topaz, arsenopyrite, muscovite, molybdenite, bismuthinite, and lithium micas. In addition to cassiterite, the mined ore may contain various metal sulphides, e.g. FeS_2, $CuFeS_2$, SnS, $FeAsS$, PbS, Bi_2S_3, and Sb_2S_3.

Copper is found in nature in forms ranging from the pure metal to sulphide, oxide, and carbonates. Native copper is occasionally found, but the metal is now generally recovered from sulphide, either chalcocite(Cu_2S), chalcopyrite($CuFeS_2$), or covelite(CuS). The action of surface waters on sulphide minerals of copper leads to oxidation, and the upper portions of copper ore deposits are usually high in copper oxides including antlerite($Cu_3SO_4(CH)_4$), atacamite($3CuO.CuCl_2.3H_2O$), azurite($2CuCO_3.Cu(OH)_2$), brochantite($CuSO_4,3Cu(OH)_2$), chrysocolla($CuSiO_3.2H_2O$)^3, cuprite(Cu_2O), malachite($CuCO_3.Cu(OH)_2$)

and tenorite(CuO). Copper ores are usually low in copper content, containing less than 5% copper, but ores containing as little as ½wt% copper can usually be processed at a profit. The largest producers include Chile, Utah, United States, South America and Africa.

2.3 Industrial Smelting Processes

The first metals used by man were gold and copper, which were found in nature in metallic or native form. Around 4000 BC, man learned to produce copper and bronze by the smelting of copper and tin ores in a charcoal fire. Throughout the history of mankind, the smelting processes for metals were developed by trial and error. Nowadays, many of the new novel processes can be derived through accumulated knowledge of chemistry as well as experimental works.

In looking for a new processing plant, there is usually a reasonable choice to be made, but careful study is required to evaluate the alternatives to find that which is the most suitable. The new process that is likely to be selected will probably have been adequately tried in the laboratory and pilot plant and in commercial operation, unless risk in time and expenditure is to be accepted.

2.3.1 Copper Smelting Processes

Copper ores are usually sulphides of which chalcopyrite ($FeCuS_2$) and bornite(Cu_5FeS_4) are the most important, but also other iron-copper sulphides as well as pure copper sulphides exist. In nature, these minerals are usually associated with pyrite(FeS_2) or pyrrhotite($Fe_{1-x}S$). After mineral dressing the concentrate may be subjected to a partial roast, and is then smelted to give a matte which contains copper and iron, whereas the remaining iron is oxidized and discarded in a slag together with gangue minerals and fluxes which are added during the smelting process. Figure 2.1 shows the general flowsheet of copper smelter.

The matte may contain between 35 and 75% Cu. The grade of the matte depends on ore composition and on economic considerations, and may differ considerably from one plant to another. Thus, if a low grade matte is produced, a relatively large amount of iron will have to be removed in the subsequent converting stage (processes for converting matte to blister involve either the Pierce-Smith converter, the Hoboken horizontal siphon-type converter or the Top Blown Rotary Converter (TBRC). The iron-copper matte from the matte smelting furnace, such as conventional blast furnace, reverberatory furnace, or flash furnace is normally treated in either of these converters), with corresponding increase in operating expenses. On the other hand, for a high grade matte the copper losses in the slag will increase, and for every ore an optimum matte grade is chosen.

The matte grade may be regulated by means of the preliminary roast, the more extensive the roast, the higher will be the matte grade. If the concentrate contains more than 25% Cu, the roasting stage is often omitted; a small amount of iron will always be oxidized during the smelting process.

In most cases, the concentrate does not contain enough silica to react with iron oxide and give a suitable slag. Therefore, some quartz is always added. In some plants, lime or limestone is also added to give a slag with 10-20% CaO. This is done in order to lower the melting point and increase the fluidity of the slag, thus giving a better phase separation.

The smelting may be carried out in different types of furnace and processes. They are:-

1) Conventional blast (shaft) furnace
2) Reverberatory furnace
3) Flash furnaces including Outokumpu and Inco
4) Electric furnace
5) Kivcet process
6) The continuous smelting processes including the Mitsubishi, the Noranda and the WORCRA process

Formerly, the conventional blast furnace (Figure 2.5) was used. Since copper ores today are mostly obtained as high-grade concentrates of fine grain size, the blast furnace is in most plants replaced by the reverberatory furnace (Figure 2.6). The modern reverberatory furnace is usually about 110 ft. long and 34 ft. wide. The electric furnace (Figure 2.7) has traditionally been used for smelting copper concentrates in areas where low-cost electric energy is available. Examination of the smelting units commissioned in the 1970's (4) shows that flash furnace installations -16, dominated the decade, with electric furnaces -4, Noranda

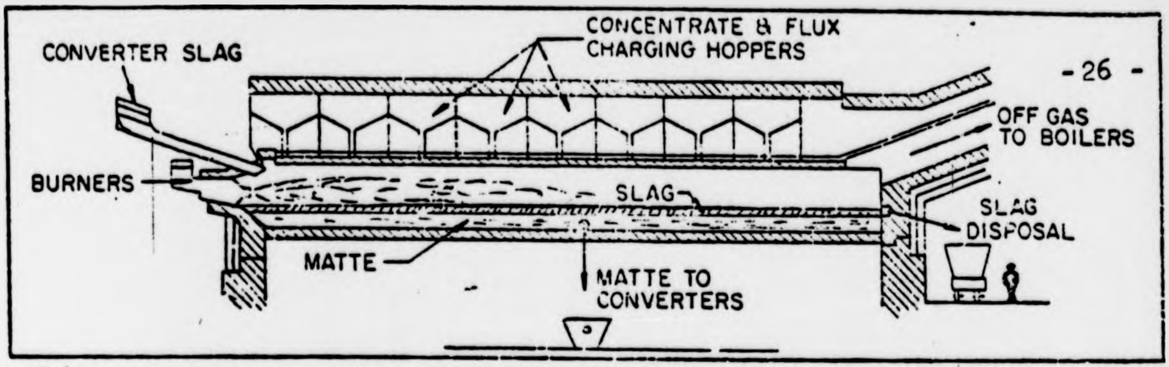


Figure 2.6 Typical Elements Of A Reverberatory Furnace Used In The US

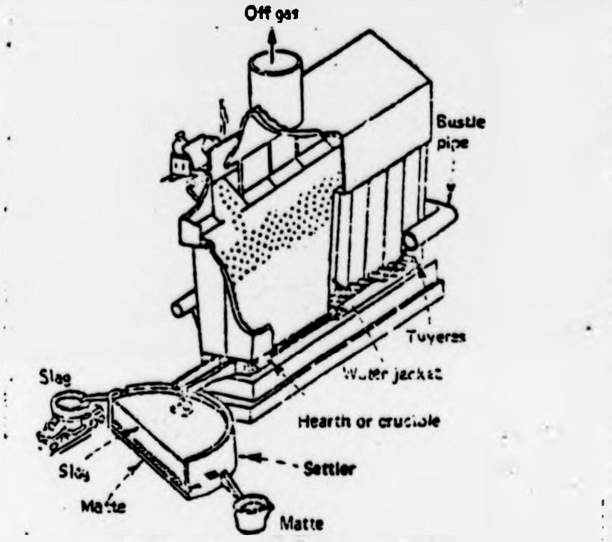


Figure 2.5 Conventional Blast Furnace Has Walls Of Water-Cooled Jackets And Is Charged By Side-Dump Cars

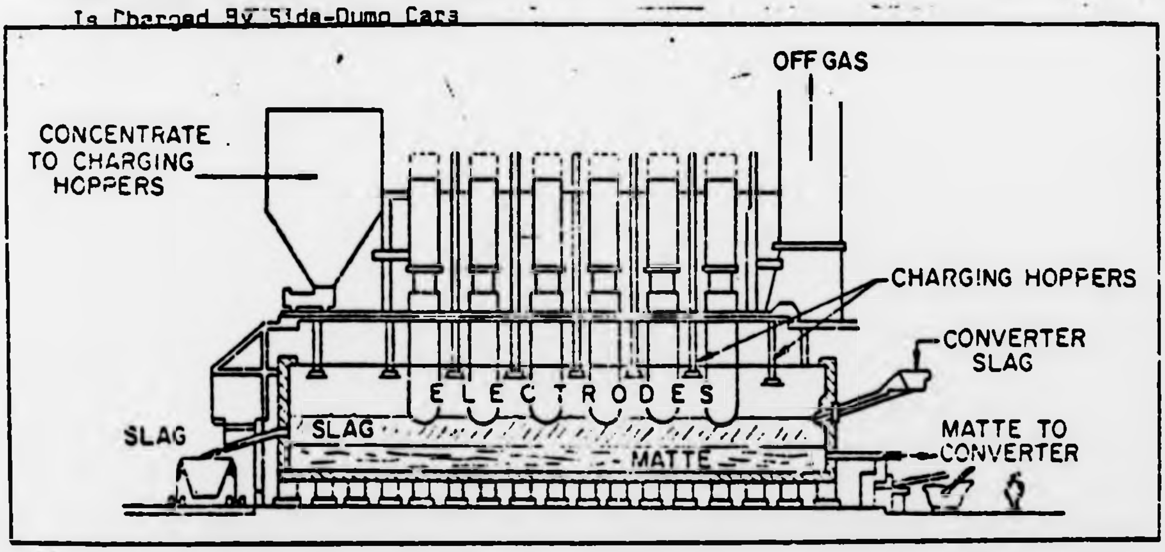


Figure 2.7 Electric Furnaces Have Been Successfully Used In Areas Where Hydro-Electric Power Is Cheap And Fuel Is Expensive

reactors -4, Top Blown Rotary Converters (TBRC's) -2, Mitsubishi systems -2, and a KIVCET unit -1, making small but significant contributions. Flash furnace smelting is now the "conventional smelting" against which all other copper-making processes should be measured. Flash furnaces for copper smelting are of two types: Outokumpu and Inco furnaces. Kivcet is a process for the smelting of complex sulphide concentrates, especially Cu-Pb-Zn concentrates which cannot be further separated by mineral processing (5). In recent years, considerable progress has been made in developing the continuous smelting processes. There are the Mitsubishi, the Noranda and the WORCRA processes (Figure 2.8, 2.9 and 2.10): the former smelts and converts continuously but in different vessels, while the latter two carry out smelting and converting reactions simultaneously in the same vessel.

2.3.2 Zinc Smelting Processes

The chief ore of zinc is sphalerite(ZnS), also known as zinc blende, which usually occurs in association with galena(PbS), iron pyrite and silver. Concentrates with more than 50% zinc are produced by flotation. From these, zinc can be obtained by various thermal reduction processes. In every case, the process must be preceded by complete roasting to convert zinc sulphide into zinc oxide and thereby make it reducible with carbon. However, zinc production presents particular difficulty because zinc has a low boiling point (906°C) and therefore occurs only in the

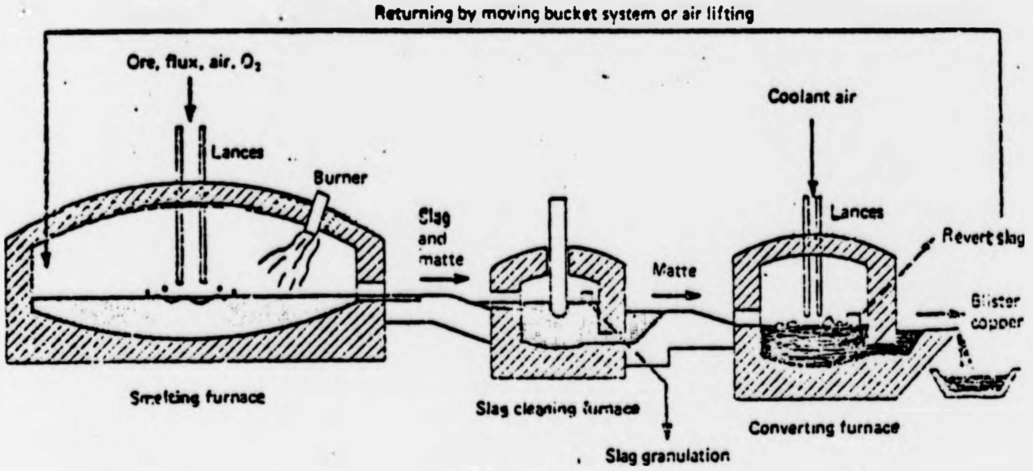


Figure 2.8 Mitsubishi Process Depends On Material Flow Between Three Vessels

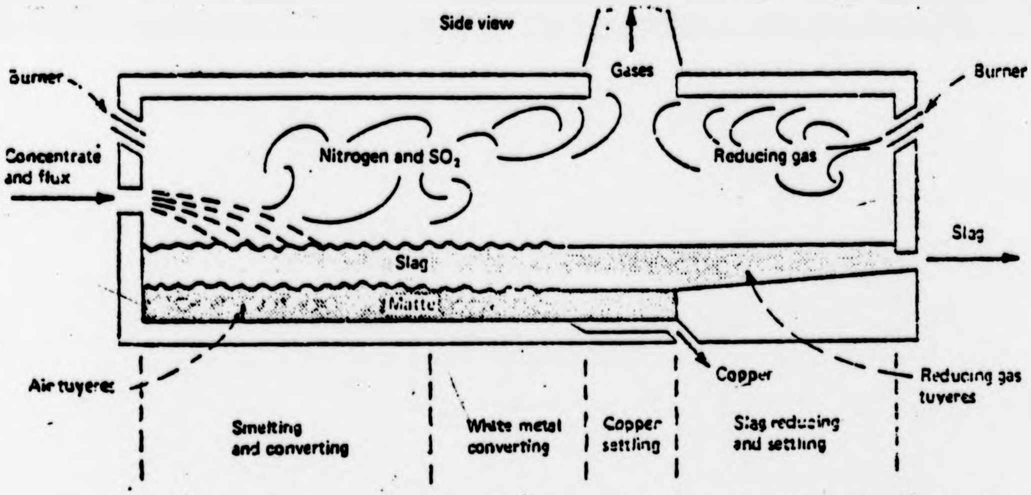
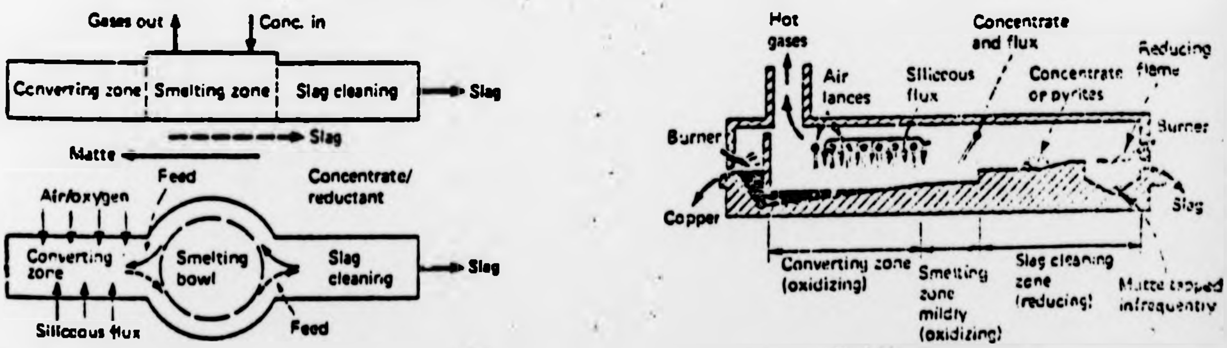


Figure 2.9 Noranda Process Produces Rich Off-Gases To Facilitate SO_2 Recovery



(a) Worca Process Schematic Shows Concept

(b) Worca Furnace Unites Three Operating Zones

Figure 2.10

gaseous form at the temperature necessary for effecting the reduction (1300°C). For this reason reduction has to be carried out in closed vessels or furnaces in which the zinc vapour can be condensed in the absence of air. Figure 2.2 shows the general flowsheet for the Zinc Smelting Process.

Production of the zinc oxide can be done by various methods. The obsolescent horizontal retort process has been in use for a very long time before the introduction of the vertical continuous retort process, which is more efficient and economical, but the main principle of both is the same. The horizontal retort having its diameter and length of about 0.3 and 1.5 metres (1 and 5 ft) is usually made of fireclay. The small cross section is essential for the heat transfer into the retort within a reasonable time. A large number of retorts in placed in a distilling furnace or furnace chamber (Figure 2.11) and they are heated by means of hot combustion gases. The retorts are charged with crushed sintered material, intermediate products containing zinc, and coke breeze (as the reducing agent). When the retorts have been charged, their mouths are provided with so-called condensers, likewise made of refractory material, and the furnace is heated up to about 1300°C, at which temperature reduction of the zinc oxide takes place according to the reaction $ZnO + C \rightarrow Zn + CO$. The zinc vapour is condensed and CO gas burns into CO_2 at the condensers' mouths. The cyclic operation of both charging and emptying the retorts and draining the condensers is manual, and therefore the process is uneconomical owing to gaseous form at the temperature necessary for effecting the reduction (1300°C). For this reason reduction has to be carried out in closed vessels or furnaces in which the zinc vapour can be condensed in the absence of air. Figure 2.2 shows the general flowsheet for the Zinc Smelting Process.

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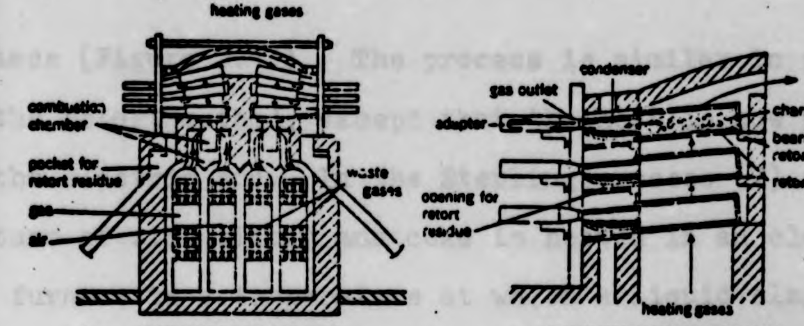
The New Jersey Zinc Co. (6) has developed the vertical retort (Figure 2.12) which is made of silicon carbide and has a rectangular shape of about 14 metres (46 ft) high, 2 metres (6.6 ft) long and 0.3 metres (1 ft) width. The advantage over the horizontal retort method is that reduction can be performed as a continuous operation. The charge consists of briquettes made of a mixture of zinc oxide material (roasted blende) and coal. The briquettes are fed automatically to the retort, the residual matter being extracted by a screw conveyor at the bottom. The mixture of carbon monoxide and zinc vapour is withdrawn near the top of the retort and passes into the condenser. This contains a pool of liquid zinc kept at a temperature of 450-500°C. By means of a rotating impeller a shower of liquid zinc is formed, on which the vapour condenses. The action of the impeller also helps to break down the films of ZnO and make the droplets coalesce. Also, to some extent, the rapid cooling helps to suppress re-oxidation. In order to remove the heat of condensation, the liquid zinc pool has to be continuously water cooled to maintain its constant temperature. After condensation of the zinc the gas which is essentially CO, is washed in a scrubber and is used as part of the fuel necessary to heat the retort.

There have been many attempts to utilize electricity for smelting of zinc. The St. Joseph Lead Co. (USA) has developed a successful method for reducing zinc in an arc



DISTILLING FURNACE WITH HORIZONTAL RETORTS (SECTION)

ARRANGEMENT OF HORIZONTAL RETORTS IN DISTILLING FURNACE

Figure 2.11

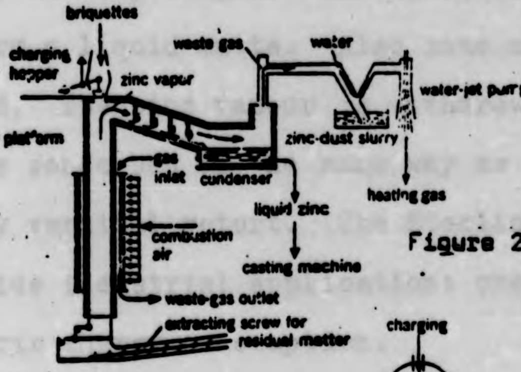


Figure 2.12 New Jersey Process

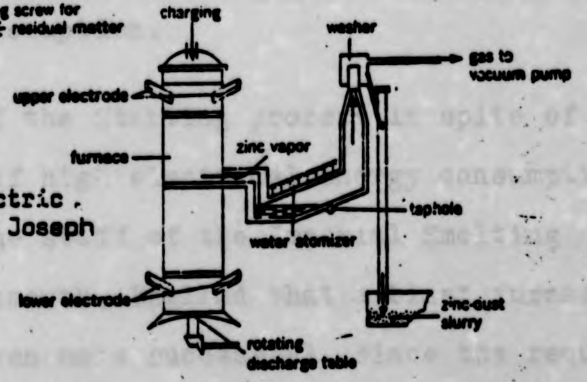


Figure 2.13 Electric Zinc Furnace (St Joseph Lead Co)

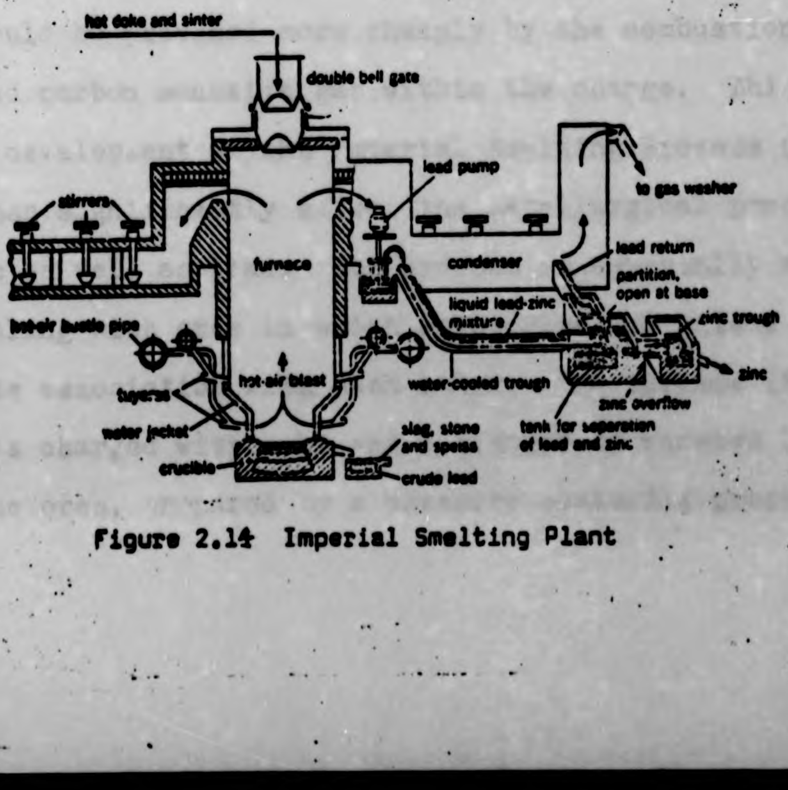


Figure 2.14 Imperial Smelting Plant

furnace (Figure 2.13). The process is similar in principle to the retort method, except that the heat is now supplied by the electric arc. In the Sterling process (7) the mixture of zinc sinter and coke is heated in an electric arc furnace to a temperature at which a liquid slag is formed. Any lead will under these conditions be reduced to liquid metal, and any sulphur will react with iron and copper to form a liquid matte. Also some metallic iron may be formed. The zinc vapour is withdrawn from the furnace and is condensed in the same way as described for the New Jersey vertical retort. The Sterling process has not found any wide industrial application: one reason may be the large electric energy consumption.

The success of the Sterling process in spite of the cost disadvantage of high electrical energy consumption has indicated to the staff of the Imperial Smelting Corporation in Avonmouth, England that a blast furnace process would be even more successful, since the required heat would be provided more cheaply by the combustion of coke and carbon monoxide gas within the charge. This led to the development of the Imperial Smelting Process (8), which has significantly affect the metallurgical processing of zinc as well as lead. The process is especially valuable for dealing with ores in which sphalerite and galena occur intimate association with each other. The furnace (Figure 2.14) is charged with coke and a mixture of roasted lead and zinc ores, prepared by a pressure sintering process.

In the furnace, which is really a form of blast furnace, the lead oxide reduced to molten metallic lead, which collects at the bottom. The zinc oxide is likewise reduced and forms zinc vapour, which is extracted at the top of the furnace along with the combustion gases. The vapour is passed to a condenser in which the cooling medium is molten lead, in which the zinc dissolves. The zinc-in-lead solution is then passed into a separator in which, on cooling, a layer of liquid zinc forms on top of the lead (this separation is due to the fact that the solubility of zinc in lead diminishes at lower temperatures). The lead is returned to the condenser, and the zinc is further processed by refining.

2.3.3 Lead Smelting Process

The lead ore most commonly mined is galena, which is the sulphide of lead(PbS). It occurs intimately mixed with other metalliferous minerals, such as sphalerite (zinc sulphide), copper pyrites and iron pyrites. The ore has to be concentrated, e.g., by flotation, in order to separate the galena from the sphalerite and other minerals that may be present. Subsequent treatment of the concentrate thus obtained consist of roasting followed by reduction in a lead blast furnace or vertical shaft furnace. Roasting is usually performed by heating the concentrate, blended with suitable fluxing minerals, on a traveling endless grate through which air is sucked.

In this way, the material is sintered-converted into lumps (called sinter) which are then smelted with coke as fuel and reducing agent in lead blast furnace. Because of the lower temperature and the higher CO_2/CO ratio in the furnace gas, the coke requirements are considerably less than in the iron blast furnace. Also preheating of the blast serves no purpose. Under the slightly reducing condition which exists in the furnace, any iron oxide present will not be reduced, but will enter the slag together with silica and other stable oxides. If the ore does not contain enough iron oxide to form a suitable slag, scrap iron may be added. In that case, iron also acts as a reducing agent, $PbO + Fe = Pb + FeO$, thus lowering the coke requirements and increasing the smelting capacity of the furnace. Figure 2.3 shows the general flowsheet of lead smelter (refer to page 14).

The lead blast furnace, usually, has a rectangular cross section with the tuyeres located along the long sides. This makes it possible to increase the size of the furnace by increasing the length of the rectangle, without increase in the distance between the tuyeres.

The products from the lead blast furnace are first of all the crude lead (lead bullion), which contains impurities such as antimony, tin, arsenic, and copper. Also any noble metals, silver or gold, would collect in the lead phase. The slag contains essentially iron silicate with some lime. If the charge contains sulphur, this will react with some of the iron to form a sulphide melt or matte. Most of the copper in the charge will enter the matte. If the charge is rich in antimony or arsenic, these may react with iron to form a separate liquid phase, the speiss, in which any cobalt or nickel will collect. The matte and the speiss have densities between those of the lead and the slag phases. When the furnace is tapped, it is therefore possible to separate as many as four liquid phases and treat them further to refine the lead and to recover valuable byproducts.

2.3.4 Tin Smelting Processes

The mined ores of tin usually upgraded into concentrates, classified as low grade (20-45% Sn), medium grade (45-60% Sn) and high grade (>60% Sn) according to the group of Gold Fields of South Africa Limited (9). Before smelting, some types of concentrates, especially in low-grade tin concentrates which contain certain impurities, require preliminary treatment by magnetic or electrostatic separation, roasting and leaching. Magnetic extraction is possible with impurities, such as iron-manganese compounds, tunsten as wolframite, and ilmenite, while the difference in conductivity between cassiterite and other minerals, such as zircon, tourmaline and monazite enables them to be removed by electrostatic techniques. In order to remove both sulphur and arsenic, a two-stage (reducing and oxidizing) roast is used. Acid leaching is performed to remove the soluble impurities, such as copper, arsenic, sulphur, antimony, bismuth, silver and some amount of iron as ferrous oxide.

Figure 2.4 shows the general flowsheet of a tin smelter (refer to page 15). Usually, tin smelting is done in two stages, i.e. primary and secondary smelting or cycle. In primary smelting, tin concentrate is mixed with limestone and coke or coal, and fed to a reduction furnace together with return drosses, dust, and hardhead (iron-tin alloy produced in the second smelting of the previous campaign), maintained at about 1200°C. Tin is reduced from the concentrate and iron is also reduced, but to a slightly lesser extent. The tapped crude tin metal is removed to the drossing kettles. In practice, the drossing kettles serve as holding kettles either for the thermal refining process or the anode casting process, in which the cast anodes are sent to electrolytic refining or both (10). The tin rich slag (15-23% Sn) which also results from the ore smelt becomes a part of the secondary smelting charge. The reduction is strictly controlled to produce the best slag for smelting in the secondary cycle.

In the secondary smelting, the furnace charge consists of primary rich slag, coal char as the reducing agent and limestone as the flux. In addition, FeO and SnO act as fluxes in the primary slag, in which the ideal operating range is from 30-40% FeO (11). The secondary smelting stage is operated at about 1350°C and the FeO and SnO are now reduced to fairly low levels. The end slag, which is either discarded or fumed for recovery, may contain from

0.5-4% Sn. No tin metal as such is tapped from the secondary smelting. Instead, hardhead is tapped and granulated and becomes part of the primary smelting charge.

The waste gases from both primary and secondary smelting are passed through a water-cooling system to a series of bag filter units, where the dust is collected. The tin oxide dust assaying around 67% Sn becomes part of the primary smelting charge after pelletizing.

The type of furnace used in smelting is governed mainly by the nature of the concentrates used and the fuel available. The blast furnace is much the older types, being in general use in the early industrial life of tin smelting. It is now only used to a limited extent, mainly because of the inefficiency of smelting, and has been largely replaced by reverberatory, rotary and electric furnaces. The reverberatory type is the most commonly used, mainly because it has the best design for draining off the tin as soon as it is reduced from the concentrates, thus offering a virtually continuous flow of molten metal during smelting, and the maximum metal recovery. Rotary and electric furnaces do, however, offer some degree of intermittent tapping. Reduction in electric furnaces is usually carried out at higher temperatures than in reverberatory furnaces and the process is more suitable for the cleaner concentrates - the iron content, for example, is not normally allowed to exceed 2%.

2.4 Refining (1,2,3)

The final stage of metal processing called refining is the removal of the impurities which originate from the ore, the fluxes or the fuel. The main purpose of refining is to produce metal as pure as possible because small amounts of the impurities would have the deleterious effects on the physical properties of product metal. In other cases, some impurities, such as silver, gold and platinum must be recovered from a base metal because of their greater economic value.

In order to remove the impurities, it is necessary to subject them to one or several refining processes. Broadly speaking, we may divide the processes into three main categories:-

1) Metal-metal,
2) Metal-slag, and
3) Metal-gas processes.

Among the metal-metal processes, we find liquation. The oxidation and slagging of less noble elements which is commonly called fire-refining is among metal-slag processes. And among metal-gas processes, we find vacuum refining. Another example is the gas bubble-liquid interactions, i.e. reactive gases, such as oxygen and chlorine are frequently used as refining agents for the removal of impurities from liquid metals.

2.4.1 Refining By Liquation

Liquation is a process where the separation of a liquid phase both by liquid immiscibility and by melting point difference is achieved. The process may be carried out by slowly cooling a melt in a kettle to permit a second phase, either liquid or solid, whereby the almost pure liquid phase drains off or the solid is skimmed off.

Processing Operations - Lead-Silver-Zinc system. Desilverization of liquid lead is today mostly done by the lead-silver melt. Zinc readily combines with silver to form a zinc-silver intermetallic compound that is highly insoluble in liquid lead, and floats on the surface of the lead as a liquid dross. In practice, a two-stage desilverization is often carried out wherein the zinc is added in two batches. The first stage of the refining process produces a fairly high-grade silver-zinc crust, whereas the second crust contains an excess of zinc and is used to recover as much silver from the lead as possible. The zinc-rich crust from the second stage is then recycled back to first-stage for reuse.

Lead-Copper System. Lead bullion from the blast furnace usually contains some copper and a first step in the refining of lead is the removal of copper. Figure 2.15 shows the lead-copper phase diagram exhibiting a low melting point eutectic in which 99.8% lead as a liquid is in equilibrium with solid pure copper. Part of the copper can be separated out effectively by slowly cooling the lead from 450-350°C. A further separation is achieved by stirring with some form solid Cu_2S. Being both Cu and Cu_2S lighter than lead, they rise and float on top of the metal to form dross and may be skimmed off.

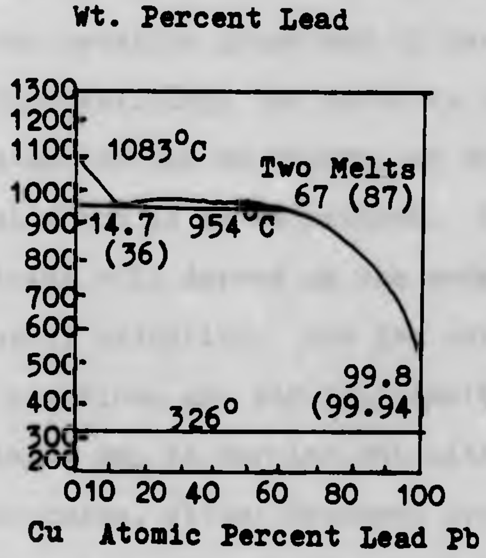


Figure 2.15

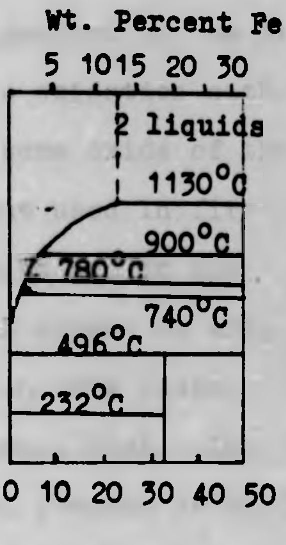


Figure 2.16

Tin-Iron System. Another example of liquation is the separation of iron from tin. Part of the iron-tin phase diagram is shown in Figure 2.16. For the removal of iron, the impure tin from the tin smelting stage is allowed to cool to above its melting point, about 300°C, when the compound $FeSn_2$ will separate out as a solid phase and give a liquid tin with less than 0.01% Fe. The process may be carried out by cooling the melt in a ladle, whereby the solid compound is allowed to settle, or impure solid tin may be heated slowly in a reverberatory furnace with a sloping hearth till above the melting point, whereby the almost pure liquid phase drains off.

2.4.2 Fire Refining

Fire-refining is based on the difference in affinity for oxygen for the different elements. However, it also depends on the chemical activities of the elements dissolved in the metallic phase and of the oxides dissolved in the slag. In fire-refining, the metal is subjected to oxidation either by means of air or oxygen, or by means of some oxide of the metal which is to be refined. The equipment used in fire-refining will depend on the metal in question and on the means of oxidation. For the oxidation with oxygen or air, the reactions are strongly exothermic and in some cases, refining may be carried out without additional fuel. In these cases, either Bessemer converter, L-D process or Kaldo process is used. On the other hand, the heat of reaction for the oxidation of impurities with metal oxides is insufficient to maintain the required temperature, and the reaction may even be endothermic. Thus, a fuel-fired reverberatory furnace is most commonly used.

In the refining of non-ferrous metals, sulphur is always present as one of the impurities, and the oxidation of sulphur can be represented by:-

$$S + 2O = SO_2(g)$$

For sulphur contents above 0.1% and low SO_2 pressures, a rather constant value of about 0.012 has been found at 1150^oC for the product $((S) \times (O)^2)/P_{SO}$ (12). For lower sulphur and correspondingly higher oxygen contents, as well as for higher SO_2 pressures, the solubility product shows an increasing trend, corresponding to oxygen decreasing the activity coefficient of dissolved sulphur. The reaction is slightly exothermic and is favoured by low temperature (13).

For oxidation of other impurities in non-ferrous metals. the less noble metals are oxidized most readily as a general rule. Thus, iron in copper is oxidized more readily than nickel. A contributing factor here is that iron in copper shows strong positive deviation from Raoult's Law, whereas the copper-nickel system is more nearly ideal. Antimony and tin in lead are removed by oxidation, whereas the more noble bismuth is not attacked. Another contributing factor is the composition of the slag. Thus, antimony and tin form acid oxides which are readily dissolved by the basic lead oxide slag. An even better slagging of these elements is obtained by the addition of alkali oxide.

Oxidation processes are nearly always exothermic and therefore, they are favoured by low temperatures. The conditions for most favourable fire-refining may be summarized:-

- The element should have a higher affinity for oxygen than the main metal
- The element should have a high activity coefficient in the metallic melt
- The oxide should have a low activity coefficent in the slag
- The temperature should be low

2.4.3 Vacuum Refining

If the impurities in a metal have a pronounced vapour pressure, they may be distilled off as in the removal of zinc from lead. Distillation may also be used if the main metal is more volatile than the impurities as in refining of zinc. Refining processes, in which gases or vapour are evolved and enhanced by decreased pressure or vacuum, are called vacuum refining processes.

Vacuum dezincing is one example in vacuum refining processes. After the desilverization of lead, which is accomplished by the addition of zinc, it is necessary to remove the residual zinc from the desilverized lead. In operation, a water-cooled hemispherical-shaped hood is placed over the kettle maintained at 595°C. The hood is connected to a vacuum pump. A vacuum is applied for several hours, distilling the zinc from the lead bath. The zinc collects in crystal form on the inside of the water-cooled hood, from where it is recovered for reuse in the desilverizing process. The dezinced lead is required for further refining.

2.5 Economic Considerations

Economic considerations of non-ferrous metal production are concerned with technical analysis which consists of the following:-

1) Raw materials consideration
2) Energy consideration

3) Materials of construction consideration
4) Environmental consideration
5) Specific capacity consideration

2.5.1 Raw Materials Consideration

In primary field, the raw materials consist of mineral ores, which have to be first sampled and analysed to obtain as accurately as possible their composition, so that physical separation of different phases can be economically planned. This phase-separating processes are called ore-dressing.

In ore-dressing the crude ore is crushed and ground to the point where each mineral grain becomes essentially free. By means of various physical methods, such as gravity separation, flotation, magnetic separation and electrostatic separation, the mineral grains are separated in various fractions, some of which contain the valuable elements, whereas others called gangue are discarded as worthless. These valuable elements called metal concentrates are then smelted with a calculated amount of fluxes to produce slag with a minimum amount of metal loss.

As economic pressure increases, the smelters have pressed the ore-dressers even further to supply them with minerals or concentrates as free from gangue as possible - because gangue leads to inevitable soluble losses of values in slag - and as free of impurities as possible - because thermal treatments and the subsequent refining operations have limited capability of discrimination between elements.

2.5.2 Energy Consideration

For a typical non-ferrous metal smelting and refining complex, e.g. copper, energy cost can account for one-third of the direct production costs (excluding raw-materials cost). It can be assumed, therefore, that one of the major opportunities for savings in direct production costs lies in improving energy utilization and selection/designing a process with a low energy consumption per unit of marketable metal.

Thus, with the rising energy costs, the metallurgists are most concerned with the pattern of energy consumption in smelting furnaces; current smelting practice begs for technological innovations that would improve the efficiency of its energy use. Thermochemical principles have made possible for the continuous smelting process which always has the advantage over conventional smelting process (usually batch process) in that:-

- A substantial amount of energy can be saved
- It generates a continuous flow of high-strength sulphur dioxide gas which is suitable for the manufacture of sulphuric acid
- Labour requirement is less

Besides in considering the selection of a smelting process, the following features must be considered:-

1) Fuel versus electrical energy
2) Recovery of waste heat
3) Use of oxygen enrichment of air

Fuel Versus Electrical Energy

One of the first choices that confront the metallurgist or designer is between the direct use of fuel and of electric power as the energy sources for a process. To understand the energy conservation aspects of the fuel-electricity choice, it must be appreciated that electricity is a secondary energy source and its production from burning fuel incure serious inefficiency due to inherent thermodynamic limitation on steam cycles employed. The average efficiency of producing electricity in the UK is 23.85% (14), which means that one KWh electrical is equivalent ot 4.19 KWh thermal. Thus, the use of electricity for heating is almost always far less efficient than the direct use of fuel. The efficiency of direct fuel heating can vary widely, from a low near 25% to a high near 90% depending on the temperature at which the combustion products leave the process, on whether waste-heat recovery is practised, and on whether oxygen-enrichment of the combustion air is employed. Table 2.2 compares the overall energy used for melting copper cathodes and that for smelting copper concentrate by competing fuel-fired and electric-arc processes.

It is well known that electricity is premium energy - clean, versatile and convenient - but a conservation ethic requires that it is used only for those purposes where direct fuel use would be less efficient or where no alternative exists. If this conservation criterion is applied to the various uses of electricity in metallurgical processing, it suggests the following cases:-

- Use of electricity for lighting, control circuits and mechanical drives is fully justified
- Use of electricity for electrolytic process is inescapable
- In countries with cheap electricity generated from water power, electric-arc furnace is preferred than fuel-fired furnace (so far, electric smelting has found its widest application in the Scandinavian countries, in Italy, Yugoslavia, Venezuela, and Japan)

Table 2.2 Comparison Of Fuel-Heated And Electrically-Heated Processes

Process	PFE*, GJ/t Cu
(a) Melting cathode copper	
Electric-arc furnace	2.8
Asarco shaft furnace (fuel-fired)	1.6
(b) Smelting copper concentrates to anode copper	
Electric-arc furnace	28
Outokumpu flash smelting with O_2 -enrichment	14

* Based on reference 15 and 16, with electrical energy evaluated at 11.07 x 10^6J/KWh. Smelting energy includes acid manufacture. Process fuel equivalent (PFE) sums the direct use of fuel and the fuel equivalent of electrical energy, supplies and reagents (oxygen), and credits waste heat recovered (17).

Recovery Of Waste Heat

Waste-heat boilers have been employed for many years to recover part of the energy from large volume flows of hot smelter gases. The importance of this practice for energy conservation may be judged from the data in Table 2.3 (18) in which the process fuel equivalents for several copper-smelting processes are compared, with and without the use of waste-heat boilers. The prevalent use of waste-heat boilers implies that they were economic even at the low fuel prices common in the past. With today's fuel prices, and even higher prices in the future, recovery of waste heat will attain greater economic urgency, and metallurgical plants will need to consider recovery of heat from even smaller volumes of hot gases and from the cooling of molten metals and slags.

Table 2.3 Effect Of Recovery Of Waste Heat On PFE For Copper Smelting* (18)

Process Type	PFE, FJ/t Cu		Saving, %
	Without heat recovery	With heat recovery	
Green-charge reverberatory	28.1	18.8	33
Outokumpu flash smelting, with O_2 enrichment	14.8	11.0	26
Noranda process to matte, with O_2 enrichment	14.4	11.2	22
Mitsubishi continuous process	17.5	12.8	27

* In each case the process includes all smelting steps necessary to convert chalcopyrite concentrate to anode copper, but excludes acid manufacture.

Use Of Oxygen Enrichment Of Air

The most significant changes in pyrometallurgy have been resulted by the use of oxygen enrichment of air. Figure 2.17 shows the effect of oxygen use on the process fuel equivalent for conversion of chalcopyrite concentrate to anode copper by flash smelting. Maximum use of oxygen (the INCO oxygen flash-smelting process) results in 38% reduction in process fuel equivalent relative to the use of no oxygen enrichment. For smelting sulphides, as in this example, the use of oxygen not only saves process energy but also lowers the capital cost of acid manufacture by reducing the volume of sulphur-bearing gas to be cleaned and converted. In addition, oxygen smelting processes have a higher specific capacity (see Table 2.4), and this reduces the capital cost of the smelting process. The capital, energy and environmental savings associated with the use of oxygen far outweigh the capital requirements and energy needed for oxygen production, in the case of copper smelting.

Application of oxygen to smelting of zinc and lead remains a fertile field. The Kivcet process (5) and the Queneau-Schuhmann (Q-S) process (19) for treatment of lead sulphide concentrate are based on oxygen smelting, but no test results are yet available. The potential of an oxygen flash-smelting process for zinc calcine has already been mentioned (18).

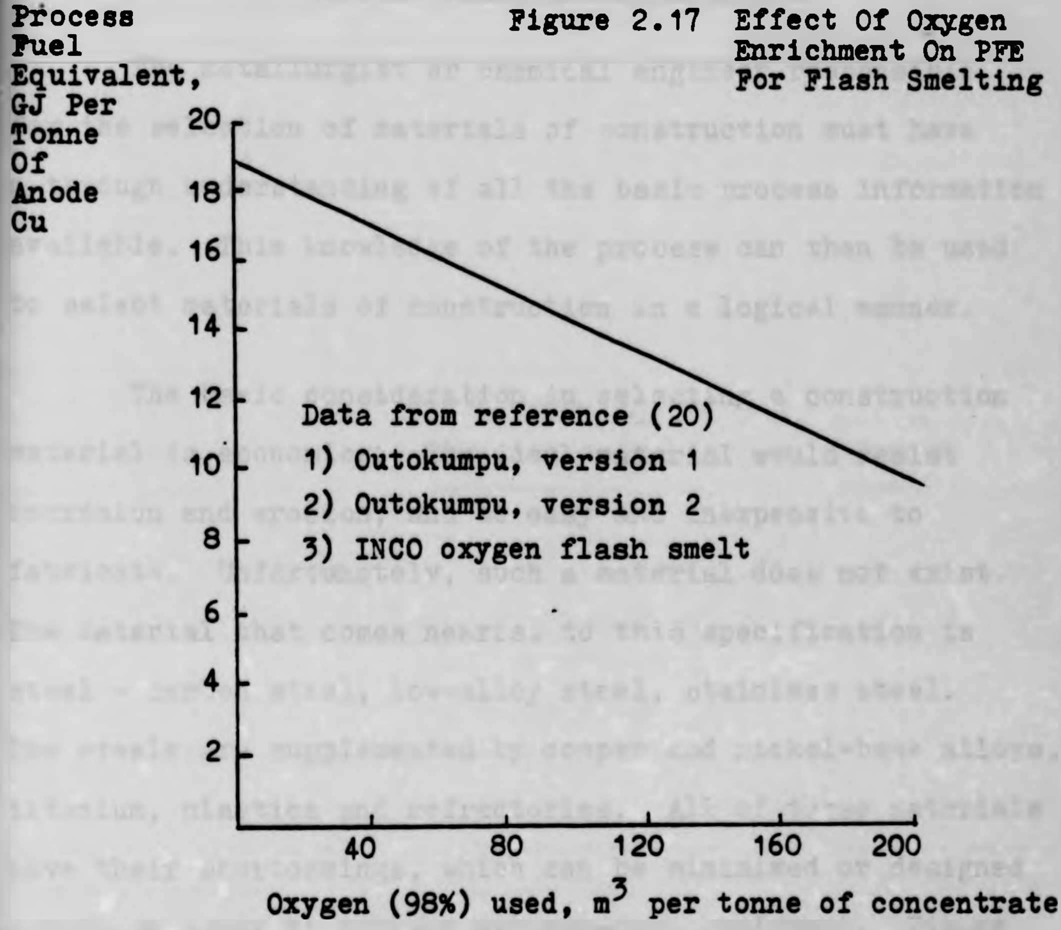


Figure 2.17 Effect Of Oxygen Enrichment On PFE For Flash Smelting

Table 2.4 Specific Capacity Comparison (15)

Process	Specific Capacity Of Furnace t/day/m^3
Reverberatory furnace (green charge)	0.24
Outokumpu flash furnace, with air	0.69
Outokumpu flash furnace, with oxygen	1.0

2.5.3 Materials Of Construction Consideration

The metallurgist or chemical engineer responsible for the selection of materials of construction must have a through understanding of all the basic process information available. This knowledge of the process can then be used to select materials of construction in a logical manner.

The basic consideration in selecting a construction material is economics. The ideal material would resist corrosion and erosion, and be easy and inexpensive to fabricate. Unfortunately, such a material does not exist. The material that comes nearest to this specification is steel - carbon steel, low-alloy steel, stainless steel. The steels are supplemented by copper and nickel-base alloys, titanium, plastics and refractories. All of these materials have their shortcomings, which can be minimised or designed around in order to produce optimum-cost equipment. Figure 2.18 summarizes the principal factors to be considered in selecting a material of construction (21). Selection of materials of construction for non-ferrous metal processes is given in Appendix B.

2.5.4 Environmental Consideration

The cost of controlling the exiting gases, liquids and soilds from a metallurgical plant has always been a substantial part of the capital and operating costs. Because there are usually a number of alternate processes that might be considered for a given situation, a rapid evaluation

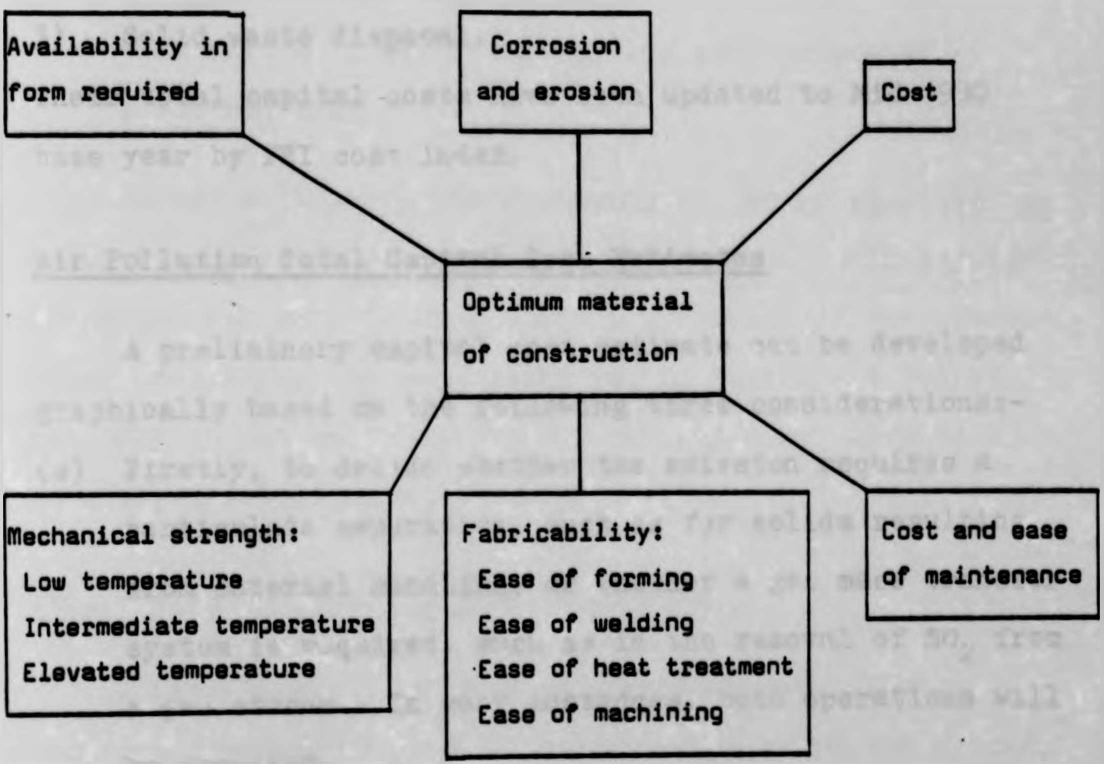


Figure 2.18 The Principle Factors To Be Considered In Selecting A Material Of Construction

technique that permits the early identification of the more attractive alternates is useful. Agarwal, Flood and Giberti (22) have developed graphical methods to estimate the total capital cost of a pollution control system including:-

1) Air pollution,
2) Water pollution, and
3) Solid waste disposal.

Their total capital costs have been updated to Mid-1980 base year by PEI cost index.

Air Pollution Total Capital Cost Estimates

A preliminary capital cost estimate can be developed graphically based on the following three considerations:-

(a) Firstly, to decide whether the emission requires a particulate separation, such as for solids resulting from material handling, or whether a gas mass transfer system is required, such as in the removal of SO_2 from a gas stream. In many instances, both operations will be required.

(b) Secondly, to calculate the actual gas volume which must be treated. Within rather broad ranges of pollutant concentrations and types, the capital cost is dependent primarily upon the gas volume. It is necessary to correct the gas volume for the volume change on cooling when the gas is scrubbed in any wet scrubbing device since wet scrubbers are sized for the volume of saturated gas. A rule-of-thumb for metallurgical processes is that the actual saturated gas volume is 65% of the actual hot gas volume.

(c) Thirdly, for particulate separations, a semi-quantitative estimate of the difficulty of removal is required, and the capital cost increases proportionately with the degree of difficulty of removal. For example, acid mists and particulates will be considerably more difficult to remove than particulates generated by solid handling.

Figure 2.19 shows the capital cost for eliminating air pollutants based on the three considerations outlined above. The graph can only be used after a flowsheet of the process under evaluation has been developed in sufficient detail, not only to determine sources of pollution but also to quantify the streams that must be treated.

Water Pollution Total Capital Estimates

A metallurgical process will produce water that requires treatment before it can be recycled to the process or discharged back to the environment. In general, water pollution comes from:-

1) Fouled process water. Examples include spent dirty reagents, such as the black acid from an electro-refining operation and solutions generated as a result of the abatement of gaseous pollutants.
2) Hot cooling water. Examples would include the heated water from process heat exchanger and condensers, from power or stream plant condensers and compressor heat

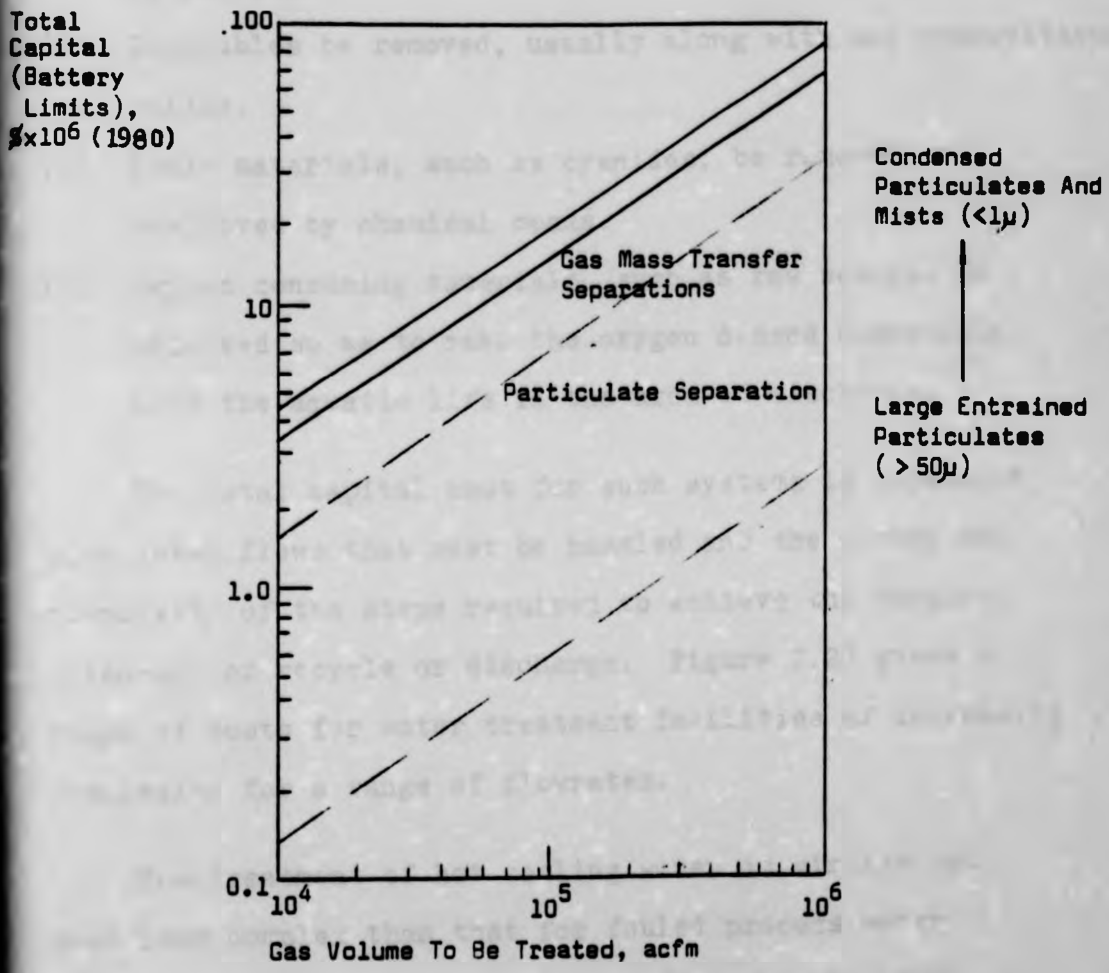


Figure 2.19 Preliminary Capital Cost Estimates For Air Pollution Abatement (22)

exchangers.

The waste water treatment system usually requires that:-

(a) Soluble materials be precipitated and removed from the system to meet specifications that permit discharge or recycle.

(b) Insolubles be removed, usually along with any precipitated solids.

(c) Toxic materials, such as cyanides, be removed or destroyed by chemical means.

(d) Oxygen consuming materials, such as raw sewage, be oxidized so as to make the oxygen demand compatible with the aquatic life in the area of discharge.

The total capital cost for such systems is dependent upon total flows that must be handled and the number and complexity of the steps required to achieve the required clean-up for recycle or discharge. Figure 2.20 gives a range of costs for water treatment facilities of increasing complexity for a range of flowrates.

The treatment of hot cooling water is similar but much less complex than that for fouled process water. Figure 2.21 gives a range of costs for water cooling facilities. From the figure, we find that an investment cost at flowrate of one millions of gallons per day will range from $\$0.2 \times 10^6$ for a simple cooling pond to $\$0.32 \times 10^6$ for a non-evaporative cooling tower. The cooling pond is an obvious choice if land area is available and if climatic

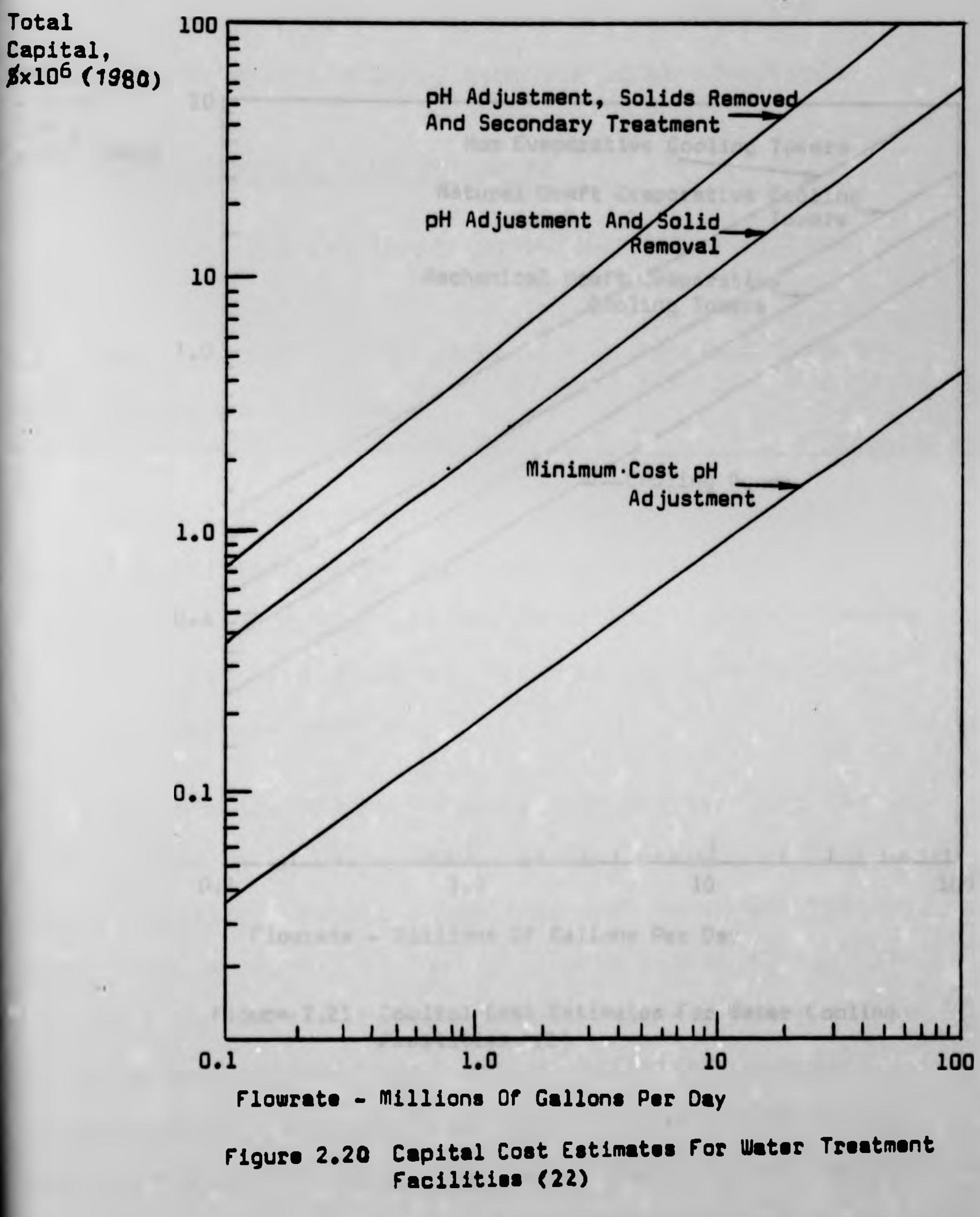


Figure 2.20 Capital Cost Estimates For Water Treatment Facilities (22)

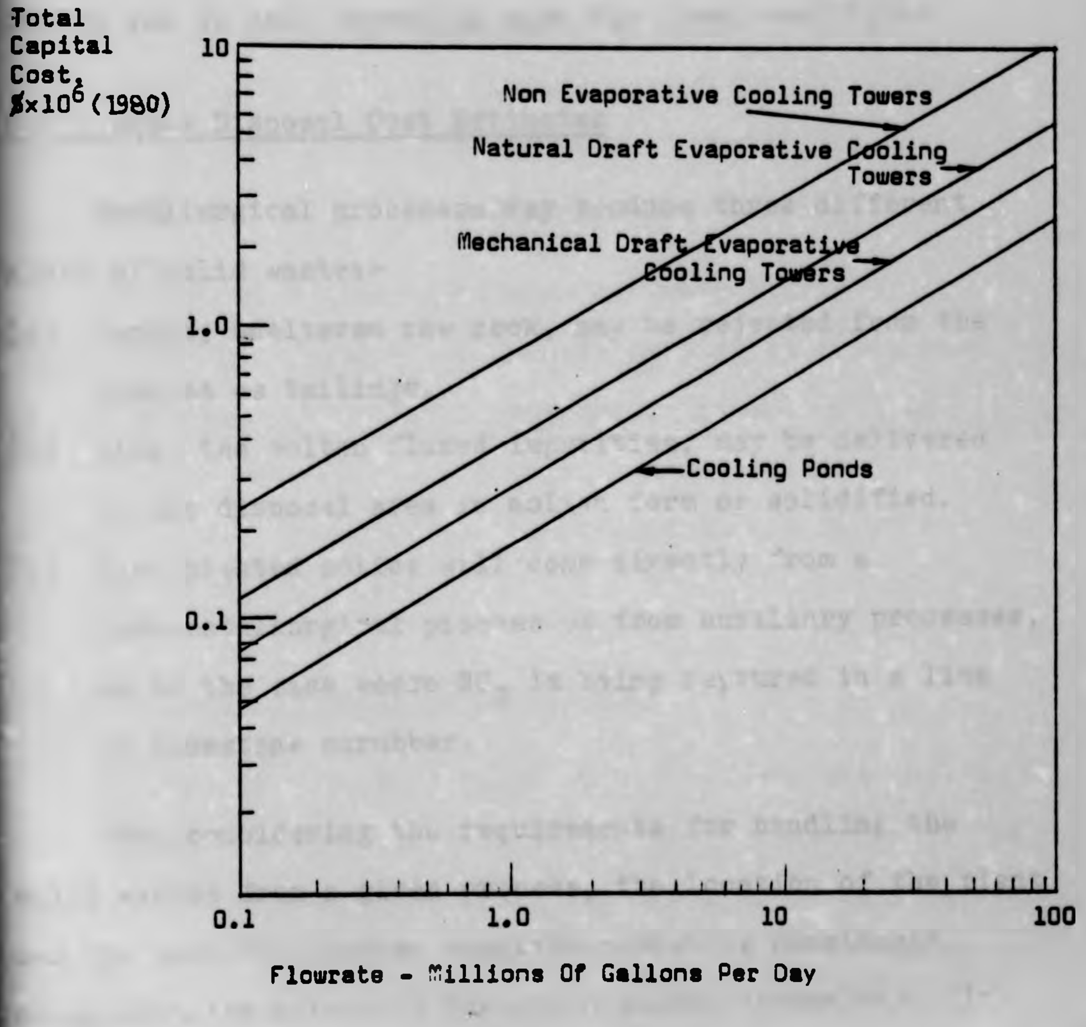


Figure 2.21 Capital Cost Estimates For Water Cooling Facilities (22)

conditions are favourable. At the other extreme, the non-evaporative cooling tower must be used if no significant loss of water can be tolerated. The evaporated cooling tower is a compromise between these two extremes. A choice can be made depending upon the local conditions.

Solid Waste Disposal Cost Estimates

Metallurgical processes may produce three different kinds of solid waste:-

(a) Gangue, unaltered raw rock, may be rejected from the process as tailings.

(b) Slag, the molten fluxed impurities, may be delivered to the disposal area in molten form or solidified.

(c) Precipitated solids will come directly from a hydrometallurgical process or from auxiliary processes, as in the case where SO_2 is being captured in a lime or limestone scrubber.

When considering the requirements for handling the solid wastes from a given process, the location of the plant and the specific whether conditions must be considered along with the nature of the solid wastes themselves. If the plant is located in a sunny arid location, evaporation losses from a tailings pond may be sufficient to avoid the problem of producing additional polluted water that must be treated. In addition, many localities now require that tailing ponds or slag dumps be restored to a useful condition that would permit development into residential, recreational or commercial uses.

Figure 2.22 shows the size of ponding area which is used in conjunction with Figure 2.23. Figure 2.23 shows a range of costs for a square solid waste pond that is equipped with earthen dikes and lined with PVC sheet. It assumes that only a minimum amount of effort will be needed to prepare the area for diking and for installing the lining. The lining must be used if wastes are toxic or if they can in any way endanger water supplies.

Slag dumps require land area but very little additional site preparation unless the slag is granulated at the furnace and pumped to the dump. If molten slag is dumped, there will be a substantial capital cost associated with railroad or trucking equipment to move the slag to dumping site.

2.5.5 Specific Capacity Consideration

There is a general relationship between the capital cost and the physical size of equipment, but mainly for the same genre of technology. However, there are many processes for the production of the same metal according to the types of furnace design, and each smelting process that deals with process streams that undergo very rapid chemical reaction inside the furnace owing to the elevated temperature has its own specific capacity (defined as tons metal produced per day per m^3 of reactor volume). Thus, for example, furnace A that has a higher specific capacity than furnace B, but with the same reactor volume, obviously, gives higher

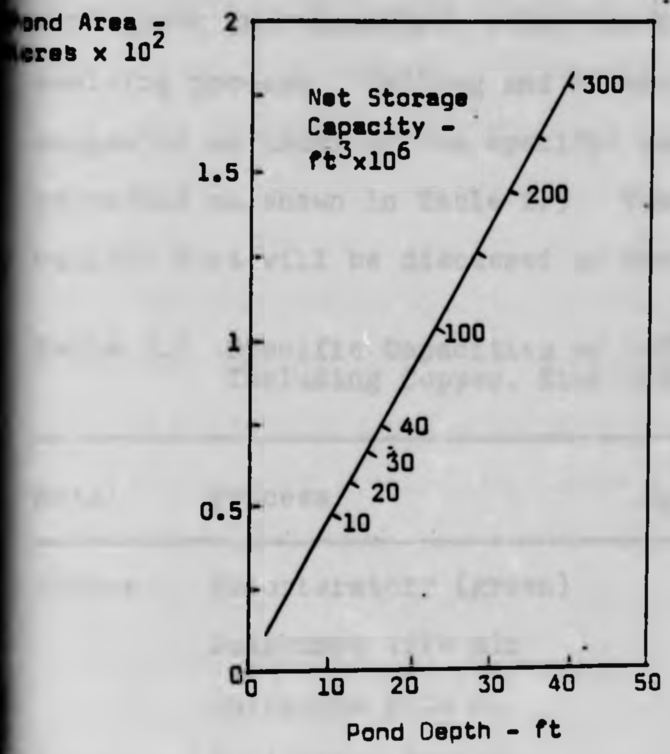


Figure 2.22 Size Of Pond Required (22)

Assumptions

(a) $\frac{\text{Pond Area }(ft^2)}{\text{Pond Depth }(ft)} = 25 \times 10^4$

(b) Square Pond

(c) Net Storage Capacity After Evaporation And Water Recycle To Process, If Any.

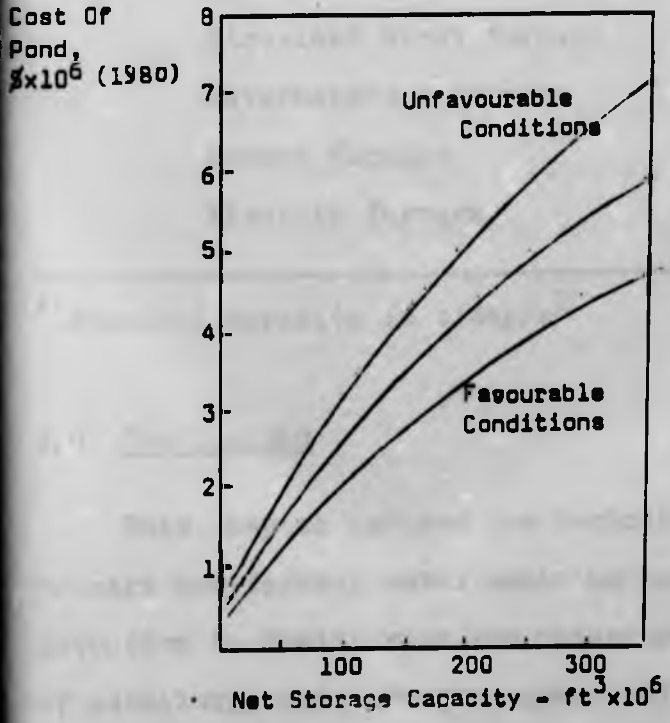


Figure 2.23 Cost Of Lined Diked Pond (22)

Assumptions

(a) $\frac{\text{Pond Area }(ft^2)}{\text{Pond Depth }(ft)} = 25 \times 10^4$

(b) Square Pond

(c) Stable Earthen Dikes, Lined With PVC, Reasonably Flat Terrain.

throughout and therefore, offer lower capital cost in the smelting process. Kellogg and Friedrich (18, 23) have suggested an index of the specific capacities of different processes as shown in Table 2.5. Their relationship with capital cost will be discussed in Section 5.3.

Table 2.5 Specific Capacities of Different Processes Including Copper, Zinc And Tin

Metal	Process	Specific Capacity, t/day/m^3
Copper	Reverberatory (green)	0.24
	Outokumpu with air	0.69
	Outokumpu with O_2	1.00
Zinc	Horizontal Retort	0.3-0.5
	Vertical Retort	1.25
	Electrothermic	1.5
	Zinc-lead blast furnace	3.4
Tin	Reverberatory furnace	1.0*
	Rotary furnace	1.36
	Electric furnace	6.6

* Specific capacity in t/day/m^2

2.6 Conclusions

This chapter reviews the technological background of primary non-ferrous metal smelting processes with the intention to familiarize the reader with the basic knowledge of metallurgy and economic aspects of the technology, at the same time, the following economic conclusions can be drawn:-

(a) Energy - Because of rising energy cost, one of the major reduction in operating cost lies in improving energy utilization or designing a process with low energy consumption. Other economical features include the use of fuel against electricity, recovery of waste heat and use of O_2 enrichment of air.

(b) Thermodynamics - Thermodynamics has made possible for the continuous smelting process which has the advantages of lower energy consumption and labour requirement. In addition, it generates a continuous flow of high-strength of SO_2 gas.

(c) Process steps - It is obvious that the more the process steps, the higher will be the capital cost. Thus, there exists a positive relationship between the number of process steps and the capital cost. Consequently, the metallurgist when designing a process will tend to reduce the number of process steps. For example, comparing the WORCRA continuous process with the conventional reverberatory-converting process, considerable savings can be obtained in the former by the elimination of roasting and handling of revert slags.

(d) Specific capacity - As there exists a general relationship between the capital cost and physical size of equipment, a furnace with the higher specific capacity will offer lower capital cost in the smelting process.

(e) Environmental consideration - Although it is required to derive a cost model for the capital investment estimation of a non-ferrous metal smelting process as a whole, graphical methods have been included here for the estimation of pollution abatement, which has always been a substantial part of the capital investment. The graphical methods can only be used after a flowsheet of the process under evaluation has been developed in sufficient detail, not only to determine sources of pollution but also to quantify the streams that must be treated.

CHAPTER THREE

SECONDARY REVOCERY OF NON-FERROUS METALS INCLUDING COPPER. ZINC. LEAD AND TIN

Concern about depletion of non-renewable mineral resources and rapidly escalating materials costs have emphasized the issue of materials conservation, which has highlighted the importance of recycling metals as a positive step towards the efficient utilization of metals in the world economy. Recovery from scrap or waste material is a resource which may be regarded as renewable and one which, in general, provides metal at lower energy and capital cost than extraction from ore, and since recovery involves orderly collection and treatment of material which would otherwise be discarded as waste, the impact on the environment is beneficial.

In the chapter, the important contribution to the economy and the technology of secondary recovery of non-ferrous metals from scrap including copper, zinc, lead and tin are reviewed. It covers secondary sources, charge preparation, current secondary smelting processes, problems in smelting secondary sources, economic benefits of secondary recovery and lastly conclusion summarizes the differences in terms of technological and economic structure between the primary and secondary industries.

3.1 Secondary Sources (1,2)

As the primary sources of non-ferrous metals become scarce, there is an increasing awareness of the need for a large recycling industry to supply the world's demand for raw materials. The available supplies of non-metallic waste products depend on consumption patterns for the generation of old scrap (scrap or waste material from used manufactured articles) and, in addition, on manufacturing processes for the generation of new scrap (scrap or waste including drosses, residues, ashes, drippings, cuttings, etc).

Storage battery scraps contribute the larger share of secondary lead. Batteries which have been been growing in line with a growing car and truck population, are a growing source of scrap, in contrast to other major sources, such as sheathing power transmission cable, sheet and pipe lead and type metal, which are of decreasing importance because of substitution by alternative materials. Other sources of scrap include solders and "tinny lead", babbit (lead based bearing metal) and lead drosses; except for lead drosses, all these sources are classified as old scrap. New scrap in the form of clippings and cuttings can generally be remelted, but lead drosses must be smelted and refined to recover lead for further use.

Many of zinc's uses are essentially dispersive and thus, their recovery are mostly uneconomical. For example, zinc galvanizing cannot be economically recovered from scrap steel fed to steel furnaces, zinc die-cast components of products, such as motor vehicles, washing machines and refrigerators, have not been extensively recovered to date and there is no economic method currently available for the recycling of rubber tyres for zinc oxide recovery. Die-castings comprise the greater part of recycled old zinc-base scrap, with lesser amounts of rolled zinc and engravers' plates. However, the largest source of secondary zinc is new scrap arising out of galvanizing and die-casting operations. Drosses, ashes and skimmings are generated in galvanizing baths and in the melting of zinc alloy for die-casting; clipping and trimmings form new die-castings also provide a significant source of new scrap. Brass contributes a very important sector of the secondary zinc industry and average zinc content in brass is 35%.

The variety of copper scrap is heterogeneous but can be generally classified according to the routes by which they are normally processed (3):-

(a) The first group called No. 1 scrap consists of untinned wire, clean turnings, scrap tubing, and copper refinery castings that failed to pass inspection due to physical defects. It is simply remelted and turned into first-quality copper with a minimum of refining.

(b) The next class of material called No. 2 scrap nominally contains 80-95% Cu and is normally refined in furnaces of the reverberatory or rotary type whence it is cast either into saleable copper ingots of "fire-refined" grade or into anodes for further treatment in an electrolytic tankhouse. It includes tinned wire and heavier forms of dirty copper, such as old copper hot-water boilers.

(c) Clean and graded copper-base alloy scrap forms an important source of all secondary materials; most of this returns to the market in the form of specification ingots of brass, bronze, gun-metal and aluminium bronze.

(d) Mixed copper and alloy scrap containing from 40-75% Cu is smelted, together with rich drosses and skimmings, and refined into anode copper as under (b).

(e) Lower-grade skimmings, ashes, residues, copper-clad steel, mixed radiators, and terrible-looking junk of telephone, electrical and electronics scrap form another group called smelter-grade scrap. This contains 15-30% Cu and is natural feedstock for the blast furnace which yields a black copper suitable for further refining.

The main secondary sources of tin are from new tin plate scrap and old tin cans which contain about 0.06% Sn. The other important scrap includes tinned wire, alloys (white metal, gun metal, bronze) and tin residues, such as drosses and fume from the secondary lead and copper industries, as well as residues from solder users.

3.2 Charge Preparation (4)

Scrap usually arises in many forms and shapes and often in conjunction with several other materials, not necessarily metallic. Such materials have to be separated prior to smelting either because they are deterimental to furnace performance or for their own inherent value.

Most of the scrap collected are usually reclaimed with minimum possible amount of refining: Refining operations are expensive and rarely result in 100 percent separation of the constituents, and in the process of removal of impurities, significant proportions of metal values are usually lost to the slags or as fume, hence, the desirability of keeping refining operations to a minimum. On the other hand, the attainment of standard alloy specifications depend tightly on impurities by good scrap selection. This highlights the necessity for scrap segregation at source as a preliminary stage of charge preparation. Methods of scrap identification are manual as well as scientific. In the former, reliance has to be placed mainly on the experience and skill of scrap sorters, who can identify scrap through the appearance of the metal and through simple fracture tests and drilling tests. In the latter, chemical analysis requires elaborate instruments, such as optical spectographs or X-ray fluorescence spectrometers, and their samples need careful preparation in a standard way.

In copper reclamation, the most common scrap consists of wire and cable with organic insulation, and according to Tauben (5) there are 40,000 different types of insulated wire and cable constructions. Because of the deterimental effect to furnace performance, the organic insulation is not allowed to enter the smelting furnace. Several recovery methods are available: In the burning process, the polymeric material covered conductors are simply burnt to remove the covering - this is especially undesirable in view of the fact that the polymeric insulation is not recovered and that the copper portion is substantially contaminated, additional energy is required in refining; many mechanical means have been devised, in which the preceding disadvantages are overcome, for stripping a polymeric coating from a conductor, such as chopping, grinding and hot pressing (6); and promising techniques based upon treating the polymeric insulator with a swelling agent and then milling to remove the softened insulator and recovering perfectly clean copper wire have been patented (7).. Future techniques might employ distillation of the insulation by pyrolysis, or even the application of cryogenic technology.

Charge preparation has also been used to remove low melting-point metals which would otherwise contaminate a melt, by "sweating". Traditionally, this technique has been used for treatment of lead-sheathed cable, radiators and the like, for recovery of babbit, lead and solder. In its simplest form, a sweating furnace consists of a sloping hearth charged at its highest point. The low-melting point constituents liquefy and flow to the lower end of the hearths where they can be collected. Besides, small scrap can be sweated efficiently in a rotary kiln, but this is not suitable for heavy scrap due to excessive wear on the furnace.

Development of liquation technique has been successful in separating lead, zinc, aluminium and copper from each other. Coreco metal separator furnace (8) which incorporates this principle, consists of inclined rotary furnace indirectly heated with well controlled temperature. With accurate temperature control, the combination of mechanical action and indirect heating can effect complete recovery of zinc from unsorted scrap, then by varying the temperature, excellent recoveries of lead and aluminium can be made. Liquation techniques have also been employed for the treatment of the non-ferrous fraction from automobile scrap. In one method, scrap was heated under a midly reducing atmosphere to recover zinc-based alloys at 600°C, aluminium-based alloys at 800°C and a brass product at 1100°C.

A more refined approach to the liquation technique (9) involves the use of molten salt baths to treat the non-ferrous fraction of the scrap. The best ratio of calcium and sodium chloride mixture being 68:32, is stable over a wide range of temperature to allow melting out of zinc, aluminium and copper-based alloys using the same bath. In another study (10), a similar technique for recovering copper and steel from metallic scrap by preferential melting in a bath of molten barium chloride or calcium chloride at 1150-1250°C has been reported. Excellent separations (0.01% Cu remaining in steel) were achieved by pre-treatment with sodium sulphate or silicate which coated the steel surface to inhibit brazing or alloying with copper.

A final technique for charge preparation finds application at EMI Refiner Ltd., where high zinc residues are treated in a Waelz rotary kiln at 1000°C to remove zinc prior to smelting. At this temperature zinc fumes off and the vapour is oxidized in the pressence of carbon dioxide.

3.3 Current Secondary Smelting Processes

Today, we are not only concerned with primary smelting but also with secondary smelting. The main difference between them is that the former involves mineral ores whereas the latter, a great variety of scrap. The current secondary smelting processes including copper, zinc, lead and tin are described below. Table 3.1 summarizes the modular equipment steps for secondary recovery of non-ferrous metals including copper, zinc, lead and tin.

Table 3.1 Number Of Modular Equipment Steps For Secondary Recovery Of Copper, Zinc, Lead And Tin

Type Of Scrap Metallurgical Section	Copper Bearing Residues	Ingot Galvanizer's Dross	Battery Scrap	Soft Lead Cable-Covering Scrap	Solder, Babbit Type Metal Bronze
Scrap Handling	Weighing Machines	Weighing Machines	Weighing Machines	-	Weighing Machines
	Sampling Equipment	Sampling Equipment	Sampling Equipment	-	Sampling Equipment
	Cranes	Cranes	Cranes		Cranes

Charge Preparation	Hoppers Mixers Peletizers Conveyors	-	Crushes Separators Conveyors	-	-
Smelting	Hoppers Blowers Blast Furnaces Converting Furnaces Cranes, Mobile Equipment Pots, Settlers, Ladles	Hoppers Blowers Horizontal Retort Cranes, Mobile Equipment Pots, Settlers Ladles	Hoppers Blowers First Stage Smelting Furnaces Second Stage Smelting Furnaces Cranes, Mobile Equipment Pots, Settlers, Ladles	-	Hoppers Blowers First Stage Smelting Furnaces Second Stage Smelting Furnaces Cranes, Mobile Equipment Pots, Settlers, Ladles
Gas Cleaning	Blowers Coolers Baghouses Stacks	Blowers Coolers Baghouses Stacks	Blowers After-burners Coolers Baghouses Stacks	-	Blowers Coolers Baghouses Stacks
Effluent Treatment	-	-	Pumps Neutralizers Clarifies Filters	-	-
Refining	Pumps Cells Cranes	-	Drossing Kettles Decopperization Detinning Kettles	Melting Furnaces Drossing Kettles Decopperization Kettles	Sulphur Drossing Kettles Antimony Removal Kettles

	Stripping Machines Melting Furnace Casting Machines Stacking Machines Mobile Equipment	-	Caustic Drossing Kettles Casting Machines Stacking Machines Mobile Equipment	Caustic Drossing Kettles Casting Machines Stacking Machines Mobile Equipment	Drossing Kettles Casting Machines Stacking Machines Mobile Equipment
Product	Refined Copper	Zinc Dust/ Zinc Oxide	Refined Lead (to battery manufacture)	Refined Lead/ Cable Alloy	Solder

3.3.1 Copper

There is no primary copper production in the UK, but the secondary industry currently produces approximately 254,000 tons/annum, equivalent to about 38% of total UK consumption, from scrap (2). Normally, high-grade scrap is directly remelted in reverberatory or rotary furnace whereas the lower grades of copper-bearing material are treated in a blast furnace and then in a converter, following which it is electro-refined.

The flowsheet is shown in Figure 3.1. The blast furnace is the cornerstone of the secondary smelter due to its ability to produce a remarkable consistent product from a very wide range of charge material. Unlike primary copper operations, a regular and consistent size of feed material is impossible to obtain. Therefore, the use of pelletizing

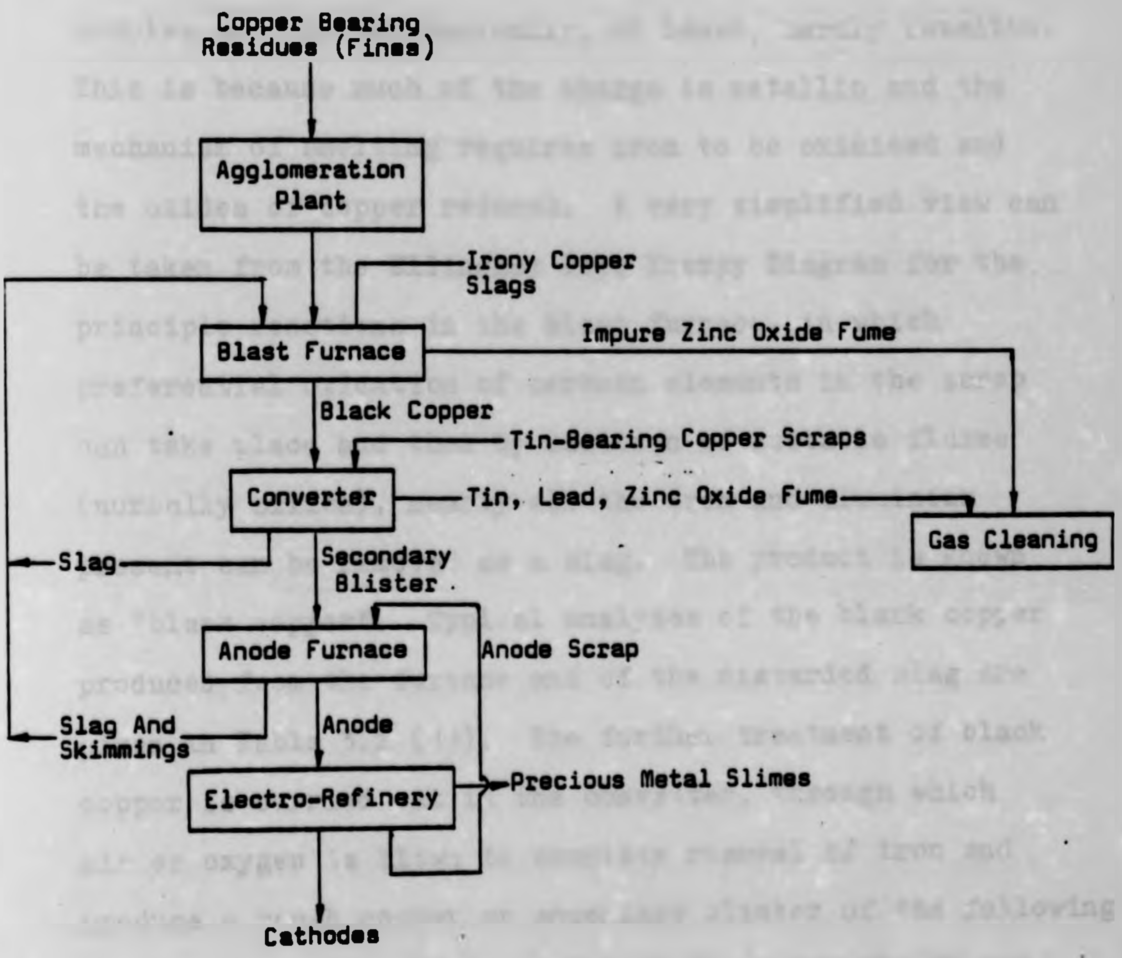


Figure 3.1 Secondary-Copper Smelting And Refining

or briquetting as an agglomeration process is frequently employed. The basic metallurgy of the blast furnace is complex and thermodynamically, at least, hardly feasible. This is because much of the charge is metallic and the mechanism of smelting requires iron to be oxidized and the oxides of copper reduced. A very simplified view can be taken from the Ellingham Free Energy Diagram for the principle reactions in the blast furnace, in which preferential oxidation of certain elements in the scrap can take place and then by addition of suitable fluxes (normally silica), nearly all the iron and aluminium present can be removed as a slag. The product is known as "black copper". Typical analyses of the black copper produced from the furnace and of the discarded slag are given in Table 3.2 (11). The further treatment of black copper is carried out in the converter, through which air or oxygen is blown to complete removal of iron and produce a rough copper or secondary blister of the following compositions: 96-97% Cu; 0.3-0.4% Sn; 0.2-0.25% Pb and 0.5-1.0% Ni. Further refining is undertaken in an anode furnace to remove remaining tin and lead by fire-refining. Thereafter, anode casting and electrolytic refining are very much in line with the standard practice employed by the primary industry. Valuable byproducts of the process are oxide fumes of zinc, lead and tin collected by baghouse associated with the converter; a tin-rich slag containing most of the remaining tin from the converter; and nickel and precious metals from the tank-house slimes.

Table 3.2 Typical Metallic Contents Of Black Copper And Discard Slag

Element	Black Copper (%)	Discard Slag (%)
Copper	70-85	0.8-1.5
Tin	1-3	0.1-0.5
Lead	1-4	0.1-0.5
Zinc	2-6	1.0-5.0
Iron	3-5	35-40
Nickel	0.1-3.0	0.1-0.6

3.3.2 Zinc (2)

As many of zinc's uses are dispersive and their recovery is required for a minimum purity of 98.5% zinc, their recoveries are mostly uneconomical. However, there are some zinc chemical, such as zinc dust and zinc oxide that can be manufactured through pyrometallurgical routes from scrap and residues (zinc sulphate can also be made from zinc residues through a hydrometallurgical route). The manufactures of zinc dust and zinc oxide are described below.

Zinc Dust

Zinc dust is produced by distillation at 1000°C in horizontal retorts purged with nitrogen. The zinc vapour is led into large vessels where it condenses as dust. Particle size is controlled by the rate of distillation and condensation and the condenser geometry, rapid distillation with slow condensation giving coarser particles than slow distillation with rapid condensation.

Zinc Oxide

There are three different methods of producing zinc oxide. The indirect (French) process, the direct (American) process and the wet route. In the indirect process, the metallic zinc scrap, such as ingot and galvanizer's dross is melted in a horizontal retort and vapourized. On contact with air, the zinc vapour burns into zinc oxide, which is collected in a bag filter. The product purity depends on the degree of scrap segregation. In the direct process, galvanizer's ash and other oxidic residues are reduced with coke in a slowly rotating inclined kiln, such as a Waelz kiln. An oxidizing atmosphere is maintained at the lower end and the charge is fed at the higher end and thus moves counter-current to the hot gases. As the charge moves towards the hot zone, oxidized zinc is reduced by the carbon and zinc vapour and carbon monoxide formed. The zinc burns to oxide which is collected in a baghouse. In the wet route, impure zinc oxide is dissolved in acid and the solution purified before precipitating the carbonate, which is then calcined.

3.3.3 Lead (2)

Lead is produced in the UK from imported bullion (approximately 137,000 tons/annum) and from imported concentrates (approximately 30,000 tons/annum). Production from scrap amounts to nearly 200,000 tons/annum; the high-grade scrap ($>$ 95% Pb) is remelted and refined whereas the lower-grade, such as battery scrap is smelted and refined.

High-Grade Scrap

High-grade scrap, such as soft lead and cable-covering scrap can be refined by similar processes used by primary industry. A typical refining flowsheet showing the process steps for high-grade lead scrap is shown in Figure 3.2. The scrap lead is first melted in a kettle and drosses removed. Initially, a light sulphur drossing at 400°C is used for removal of zinc, bismuth and cadmium if present. Otherwise, the first stage involves cooling the molten metal to just above freesing point - the process is termed "cooling back", which produces a copper rich dross. Final traces of copper can be further reduced to 0.008% Cu by stirring sulphur into bullion at 330°C. The Harris process, which involves preferential oxidation, removes tin, arsenic and antimony by forming the double sodium salts with flux mixtures containing caustic soda and sodium nitrate at about 500°C. Refining continues until 99.97% Pb (soft lead) is obtained and this may be alloyed to produce different types of cable alloy.

Battery Scrap

Starter batteries, which represent the largest source of scrap, are first drained of acid and then crushed either

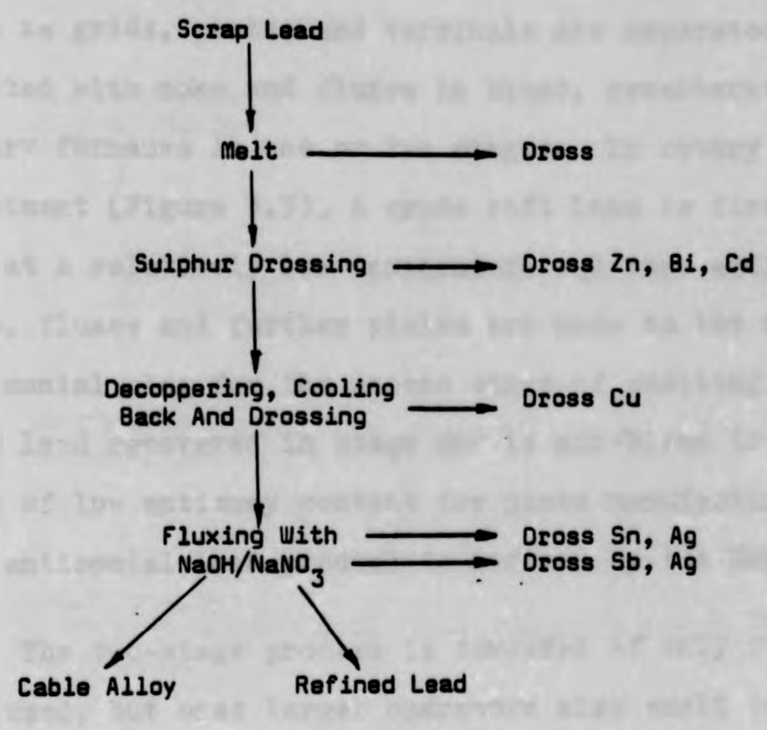


Figure 3.2 Refining Of High-Grade Scrap (Showing The Process Steps)

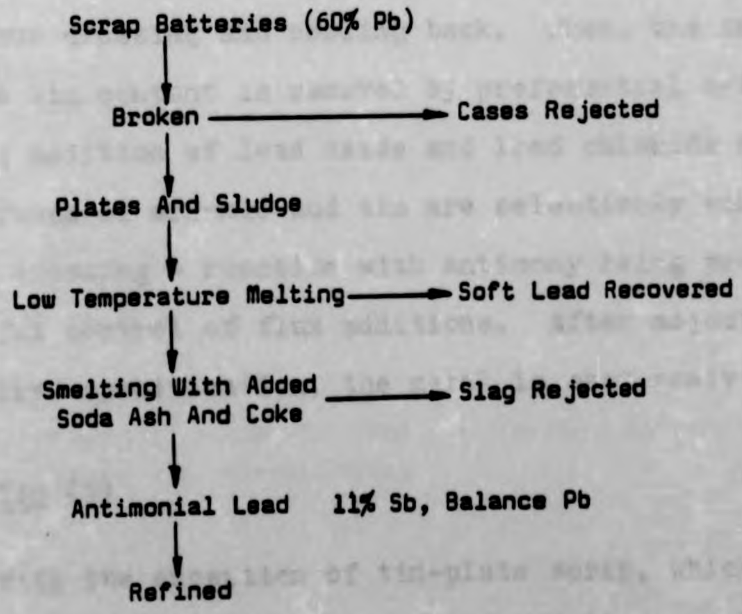


Figure 3.3 Two-Stage Rotary Furnace Operation For Lead (Showing The Process Steps)

manually or mechanically into pieces, where valuable scrap, such as grids, pastes and terminals are separated and then smelted with coke and fluxes in blast, reverberatory or rotary furnaces in one or two stages. In rotary furnace treatment (Figure 3.3), a crude soft lead is first melted out at a relatively low temperature and then additions of coke, fluxes and further plates are made to the residual antimonial slag for the second stage of smelting. The soft lead recovered in stage one is air-blown to produce lead of low antimony content for paste manufacture, while the antimonial lead product is refined by the Harris process.

The two-stage process is favoured if only rotary furnaces are used, but most larger operators also smelt in blast furnaces or reverberatory furnaces in a single stage operation. The product is a antimonial lead, which requires further refining as shown in Figure 3.4. Copper is first removed by sulphur drossing and cooling back. Then, the small but valuable tin content is removed by preferential oxidation by using addition of lead oxide and lead chloride or chlorine. Final traces of arsenic and tin are selectively removed by caustic drossing - reaction with antimony being prevented by careful control of flux additions. After adjusting to the desired specification, the metal is cast ready for use.

3.3.4 Tin (2)

With the exception of tin-plate scrap, which can be recovered by methods, such as Chlorine Detinning, "Vacuum"

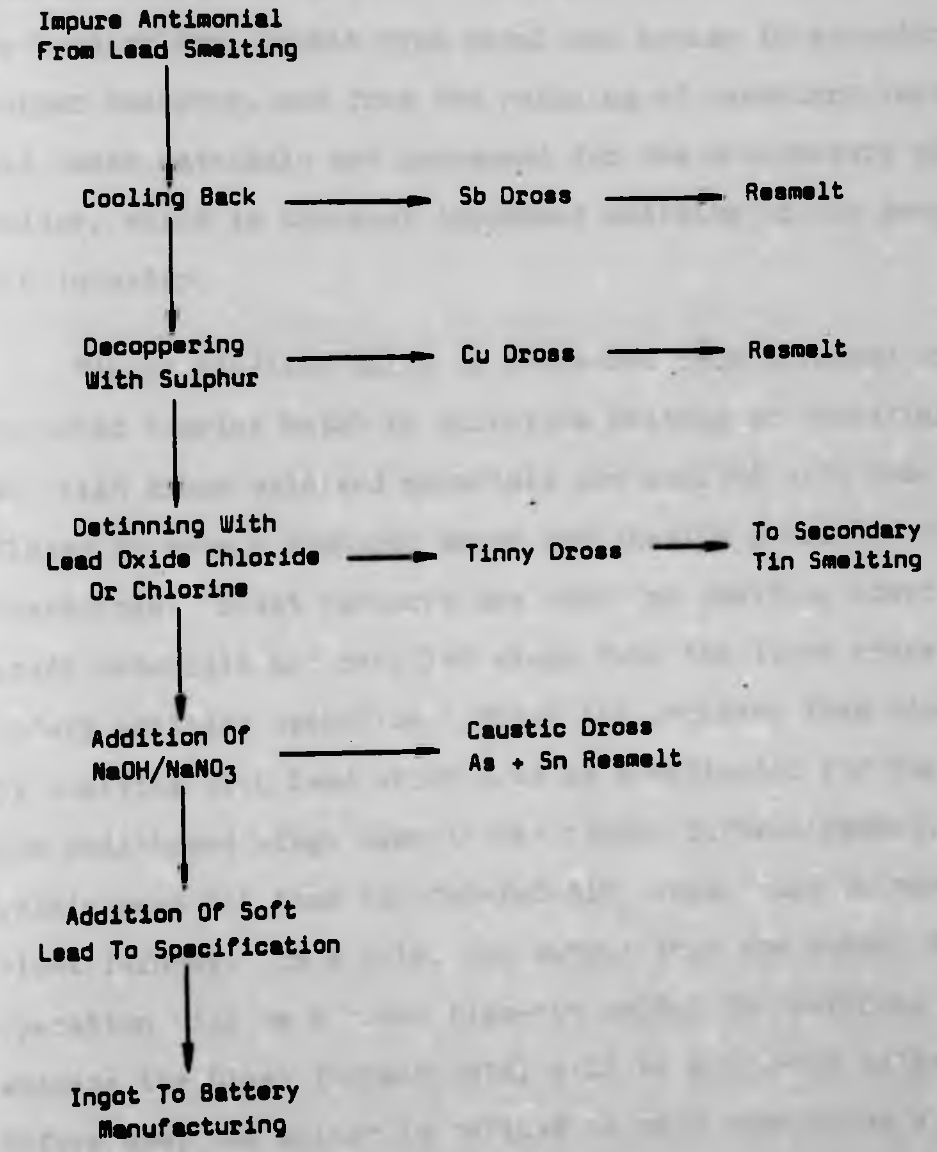


Figure 3.4 Refining Of Antimonial Lead From Smelting Battery Scrap (Showing The Process Steps)

Detinning and Alkaline Leaching, the rest of scrap tend to follow the smelting route. Secondary tin smelting is mainly concerned with the residues arising from remelting of alloys, such as solder, babbit type metal and bronze in secondary copper industry, and from the refining of secondary lead. All these materials are processed for the manufacture of solder, which is the most important activity of the secondary tin industry.

Tin or tin/lead alloy is recovered from scrapped or rejected bearing metal by selective melting or "sweating". All high grade oxidized materials are smelted with coke and fluxes in rotary furnaces which are ideally suited to these operations. Blast furnaces are used for smelting lower grade materials and recycled slags from the first stage rotary smelting operation. Final tin recovery from slags is by smelting with lead which acts as a collector for the tin. The soda-based slags used in the rotary furnace operation retain more tin than the $CaO-FeO-SiO_2$ slags used in the blast furnace. As a rule, the output from the rotary furnace operation will be a crude high-tin solder for refining whereas the blast furnace metal will be a low-tin solder. Before use, the solder is refined to meet specifications.

Crude solder from secondary feedstocks usually contains excess antimony, copper and zinc. The latter two are removed by drossing with sulphur and cooling back as described for lead refining. Antimony removal presents a more difficult problem. Scrap aluminium is used above its melting point to remove any excess as the intermetallic compound Al-Sb or Al-Sb-Sn. The dross can react with moisture to form arsine and extreme care is required in this particular operation. Sodium metal is a safer but less effective reagent for antimony removal. Any residual aluminium can be removed by a light drossing with sulphur, and then it is only necessary to make any final composition adjustments before casting.

3.4 Problems In Smelting Secondary Sources (12)

Secondary smelting industry encounters a lot of problems that are not arised in the primary field; these accrue largely from differences in physical form and chemical composition of the feed material, especially in copper bearing material. Obviously, problems concerned with all aspects of non-ferrous secondary metal recycle and reclamation cannot be made fully. Thus, the problems concerned with smelting certain grades of copper scrap, treating starter batteries, and treating the resulting impure zinc oxide fumes are only mentioned.

In copper reclamation, the basic problem is how to handle the organic insulation. Many mechanical means have been devised for stripping a plastic coating from a simple conductor, such as chopping, grinding or hot pressing to separate the plastic from the copper conductor. These procedures become less and less effective as a cable becomes more complex or if a simple conductor is a part of a scrapped electrical or electronic apparatus. Use of organic solvents have been proposed but finding an inexpensive, universal solvent for the many types of rubber and plastic involved has been elusive. Burning the insulation to remove it is the method preferred by most processors. The problems to be solved are how to burn completely and how to scrub the products of combustion to free them of pollutants, such as hydrochloric and hydrofluoric acids.

The "irony bearing" secondaries present a different problem. This is a mixture of many different types of consumer-generated scrap including iron backed bearings, motors, generators, fuse boxes and similar electrical components. The electrical gear all have insulation as well as a high percentage of steel. Various chemical processes have been suggested and evaluated in which the copper is selectively leached away from the iron. The problem is to expose the copper by finding some means of removing the organic coatings. Burning off the organics presents the same pollution problems as with insulated wire.

The fumes which come off of the blast furnaces and converters treating the smelter grade copper scraps are essentially zinc oxides contaminated with large quantities of lead, tin, iron, chlorides and fluorides. A similar type of impure zinc oxide fume is resulting from smelting of galvanized steel scrap. Both of these byproducts are too impure to be acceptable feed for conventional zinc smelters either because of impurities, such as chlorides and iron or because other valuable impurities, such as tin, copper, and precious metals are not recoverable. Furthermore, because of their fine particle size, they are difficult to transport without special packaging.

As lead scrap mainly consists of starter batteries, they cause the most problems. As concerns the processing of starter batteries, particular attention is to be given to the inherent ecological problems. Each case of starter battery consists of filling compound low in antimony, antimonial lead with 3-5% Sb and waste products low in lead, such as box material, separators and iron handles. If the whole case is treated as such in melting furnaces, the antimony content of the lead extracted will be diluted by the fines. Furthermore, the chlorine content of the separators, which actually often consist of PVC, causes problems.

3.5 Economic Benefits Of Secondary Recovery

Secondary recovery or recycling of non-ferrous metals will occur only when economic conditions justify it. In recycling, as in any other industry, the profit is a prime factor, and at the same time it serves social objectives. These objectives are the conservation of resources - by saving raw materials and reducing metallurgical processing requirements and energy expenditures - and the protection of the environment from the pollution of primary production.

Scrap recycle reduces the drain on ore deposits and decreases the demand for mining and smelting operations. It also saves the indirect materials required by primary production processes. For instance, the primary production of copper consumes large amounts of coke which are needed in the processing of secondary copper. Scrap recycle provides the only indigenous sources of metals in industrialized countries that lack ore deposits. In addition to the increased supplies of materials, it benefits the balance of payments of resource-poor countries.

Secondary sources are usually more concentrated and purer than primary sources. They are already in the metallic state and generally need only refining, and in the most favourable cases, only melting. Therefore, the recovery of secondary metals can be carried out with fewer and simpler processing operations and usually with less pollution than primary production, which result in fixed capital investment saving. The operating costs of secondary production are also generally lower although some secondary operations are labour-intensive. Some of the savings of metallurgical processing costs, however, are presumably expended on collection and physically processing. Little information is availble on the comparative costs of secondary and primary production.

The energies required for the metallurgical processing of primary metals are always higher than for secondary recovery, mainly because they involve heavy expenditure of energy in mining, concentration of low-grade ores and smelting of upgraded concentrates. The energy requirements (unit weight basis) for production of primary metals from ore and for production of secondary metals from scrap are shown in Table 3.3.

Table 3.3 Unit Energy For Production Of Primary And Secondary Metal (13)

Metal	KWh Per Ton		Energy Saving Per Ton By Recycling (KWh Per Ton)
	Primary From Ore	Secondary From Scrap	
Copper	13,532	1,726	11,805
Zinc	5,770	2,300	3,470
Lead	2,550	1,615	1,615
Tin	-	-	-

Very little is known about energy consumed by collection, transportation, physical separation, mechanical processing of secondary metals. The nature and location of old scrap determine the amount of energy expended in collection and transport. The energy consumed in mechanical processing of scrap metals can be evaluated, but this has not yet been done or published. The energy and labour that must be expended on the recovery of scrap increases with the degree of its dispersion.

Finally, secondary recovery avoids much of the air and water pollution often caused by primary production. Also, the recovery of non-ferrous metals from scrap does not involve the disposal of mineral waste associated with production from ores (14). It does not incur the need for the extensive pollution abatement measures required increasingly for the smelting of ores, particularly sulphide ores.

3.6 Conclusions

Although secondary recovery operations are largely based on processes developed in primary field for metal extraction from mineral concentrates, the differences in terms of technological and economic structure between them can arise:-

(a) The primary smelter, who handles constant supply of primary concentrates of even chemical composition, will usually operate on a large enough scale to allow him to make each process step an efficient link in a pre-planned sequence of events with attendent benefits in mechanical, thermal and metallurgical efficiency. On the other hand, the secondary smelter, who handles a great variety of scrap, operates on a small scale and not as efficiently as the primary smelter.

(b) The secondary smelter differs from the primary smelter in that it rarely handles sulphidic materials; most of its feed contains metal in the metallic or oxidized form and roasting prior to smelting is, therefore, not usually practised.

(c) The cost of controlling the exiting gases, liquids and solids has always been a substantial part of the capital and operating costs in the primary field, but it does not incur in the secondary field.

(d) The energies required for the metallurgical processing of primary metals are always higher than for secondary recovery, mainly because they involve heavy expenditure of energy in mining and concentration of low-grade ores, and smelting of upgraded concentrates.

(e) Finally, the secondary industry has developed a sophisticated technology of its own to overcome problems, especially in the charge preparation, not encountered in the primary field.

CHAPTER FOUR

ELEMENTS OF CAPITAL COST ESTIMATION

4.1 Introduction

Capital cost estimates are required for a process right from its initial conception, through its development stages of metallurgical and detailed mechanical engineering design, to its final construction and start-up, in order that it may constantly be monitored and evaluated. Before manufacturing organisations commit themselves to build the plant, however, they need cost estimates capable of screening alternative process routes in order to seclect their optimum production unit. In addition, it is desirable for them to complete this screening study as early as possible, certainly before detailed process design is required, in order that valuable time, money and engineering manhours are not wasted. This assessment can be performed through special techniques which already exist in the chemical and petrochemical industries. Generally, they are based on breaking a process down into basic equipment items, functional units or process steps and obtaining reference costs by analogy with other processes in the same type of industry. A cost model is then constructed of the new process under consideration, bringing in factors for such parameters as operating conditions (pressure and temperature), scale of operation, special materials of construction and the physical state of materials being processed.

A similar approach has not yet been developed for non-ferrous metal production processes. These differ in several important features from chemical and petrochemical processes from a cost modelling point of view, for example, high temperature and densities, frequent batch stages, material transfer not usually in pipes, all affect the basic cost structure. Thus, Chapter Four examines the elements of capital cost estimation. This covers the definition of capital investment; discussion of various types of capital cost estimates according to different accurancies and purposes, and their limitations in use; review of cost indices showing how the historical data can be updated for the cost estimating purposes, what they consist of and limitations of their use; breakdown of fixed-capital-investment items for a non-ferrous metal production process giving an insight of the essential cost structure of the plant; and conclusion summarizing the essential points for the development of capital cost model for the non-ferrous metal smelting industry.

4.2 Capital Investment

Before a project can generate any earnings, a large sum of money must be spent to install the necessary machinery and equipment in a suitable site. In addition, further expense is necessary for the plant operation. All these expenses are made up of:-

1) Fixed capital investment and
2) Working capital investment

4.2.1 Fixed Capital Investment

Fixed capital investment can be further subdivided into direct and indirect costs: Direct costs represent the investment in production and auxiliary facilities, such as purchased equipment, equipment installation, instrumentation and controls, electrical and materials, material handling and storage, piping and process gas handling, building, yard improvements, service facilities and land, whereas indirect costs consist of components, such as engineering and supervision, construction expenses, contractor's fee, contingency, interest during construction and startup expense. A check list of items (1) for a non-ferrous metal production process in Table 4.1 is an invaluable aid in making a complete estimation of the fixed capital investment, i.e. each item could be checked, especially for detailed estimates (see sub-section 4.3.6).

Table 4.1 Check List Of Fixed-Investment Cost Items

Direct Costs

1) Purchased equipment
    - (a) All equipment listed on a complete flowsheet
    - (b) Spare parts and non-installed equipment spares
    - (c) Surplus equipment, supplies and equipment allowance
    - (d) Inflation cost allowance
    - (e) Freight charges
    - (f) Taxes, insurances and duties
    - (g) Allowance for modifications during start-up

2) Purchased equipment installation
   - (a) Installation of all equipment listed on complete flowsheet
   - (b) Foundation, structural supports, insulation, paint

3) Instrumentation and controls
   - (a) Purchase, installation, calibration

4) Electrical equipment and materials
   - (a) Electrical equipment - switches, motors, conduit, wire, fittings, feeders, grounding, instrument and control wiring, lighting, panels
   - (b) Electrical materials and labour

5) Materials handling and storage
   - (a) Conveyor belt system, screw type conveyor, bucket system, pneumatic system, jib hoist, launder
   - (b) Mobile Equipment - Locomotive, front-end loader, fork truck, straddler carrier, slag car
   - (c) Settler, ladle, holding bath, bin, hopper

6) Piping and process gas handling
   - (a) Process piping - carbon steel, alloy, cast iron, lead, lined aluminium, copper, asbestos-cement, ceramic, plastic, rubber, reinforced concrete
   - (b) Pipe hangers, fitting, valves, water-cooled hoods
   - (c) Insulation, installation labour

7) Buildings (including services)
   - (a) Process buildings - substructures, superstructures, platforms, supports, stairways, ladders, accessways
   - (b) Auxiliary buildings - administration, medical or dispensary, cafeteria, garage, product warehouse, parts warehouse, guard and safety, fire station, change house, personnel building, shipping offices and platform, research laboratory, control laboratory

(c) Maintenance shops - electrical, piping, sheet metal, machine, welding, carpentry, instrument

(d) Building services - plumbing, heating, ventilation, dust collection, air conditioning, building lighting, elevators, escalators, telephones, intercommunication systems, painting, sprinkler systems, fire alarms

8) Yard improvements

(a) Site development - site clearing, grading, roads, walkways, railroads, fences, parking areas, wharves and piers, recreational facilities, landscaping

9) Service facilities

(a) Utilities - steam, water, electricity, oxygen, compressed air, fuel, chemical

(b) Facilities - boiler plant incinerator, wells, river intake, water treatment, cooling towers, water storage, electric substation, oxygen plant, air plant, fuel storage, waste disposal plant

(c) Nonprocess equipment - office furniture and equipment, cafeteria equipment, safety and medical equipment, shop equipment, laboratory equipment, garage equipment, housekeeping equipment, fire extinguishers, hoses, fire engines, loading stations

(d) Distribution and packaging - raw-material and product storage and handling equipment

10) Land

(a) Surveys and fees

(b) Property cost

Indirect Costs

1) Engineering and supervision

(a) Engineering costs - administrative, process, design and general engineering, drafting, cost engineering, procuring, expenditing, reproduction

(b) Engineering supervision and inspection

2) Construction expenses

(a) Construction, operation and maintenance of temporary facilities, offices, roads, parking lots, railroads, electrical, piping, communications, fencing

(b) Construction tools and equipment

(c) Construction supervision, accounting, timekeeping, purchasing, expediting

(d) Warehouse personnel and expense, guards

(e) Safety, medical, fringe benefits

(f) Permits, field tests, special licenses

(g) Taxes, insurance, interest

3) Contractor's fee

4) Contingency

5) Interest during construction

6) Start-up expense

4.2.2 Working Capital Investment

Much of the literature on working capital can be categorized in terms of balance sheet of the firm. Table 4.2 represents a typical balance sheet. Using this representation, working capital is defined as current assets, in which we are concerned with.

Table 4.2 Typical Balance Sheet

Current assets, $a = \Sigma a_i$	Current liabilities, $l = \Sigma l_i$
Fixed assets, $A = \Sigma A_i$	Long-term debt, $L = \Sigma L_i$
	Equity, $E = \Sigma E_i$
Total assets $= a + A$	Total source $= l + L + E$

Working capital refers to the funds tied up for the normal conduct of business. It is estimated from the following items:-

(a) Raw-materials inventory (estimated as 30 days of daily raw-materials and utilities costs).

(b) Product and in-process inventory (estimated as 30 days of daily total product cost less depreciation).

(c) Account receivable, i.e. unpaid accounts against products already delivered to customers and allowable 30 days payment period (estimated as 30 days of daily total product cost less depreciation).

(d) Cash available (estimated as 30 days of daily total product cost less depreciation less raw-materials cost).

4.3 Estimation Of Fixed Capital Investment

One of the objectives of the research is to establish a novel capital cost model for the non-ferrous metal smelting industry, so that the costs of any particular smelting concept, either existing or hypothetical, can be estimated at the preliminary process design stage. In order to do that, it is therefore necessary to attain a complete knowledge and understanding of existing techniques of cost estimation through literature survey. Also, types of capital cost estimates are identified and classified, so that each group is examined in detail.

4.3.1 Estimate Classifications

There are numerous types of fixed capital cost estimates, which are generally classified according to their accuracies. Classification by accuracy is by far the most suitable as it is intended to include a wide range of cost models of varying sophistication and accuracy, which can be applied throughout process development to accomodate the existing variety of situations. Various authors (2,3,4,5) have proposed their estimation classifications as in Table 4.3.

It was found that the estimation classification proposed by the American Association of Cost Engineers in 1958 (5) is most complete among them. It is considered to be a logical, definitive and comprehensive system and it is as follows:-

Type Of Estimate	Other Names	Usual Basis	Probable Error %*
(a) Order of magnitude	Ratio estimate	Previous similar cost information	> ± 30
(b) Study	Factored estimate	Knowledge of Flowsheet and major equipment	± 30

Table 4.3 Estimate Classifications According To Their Accuracies

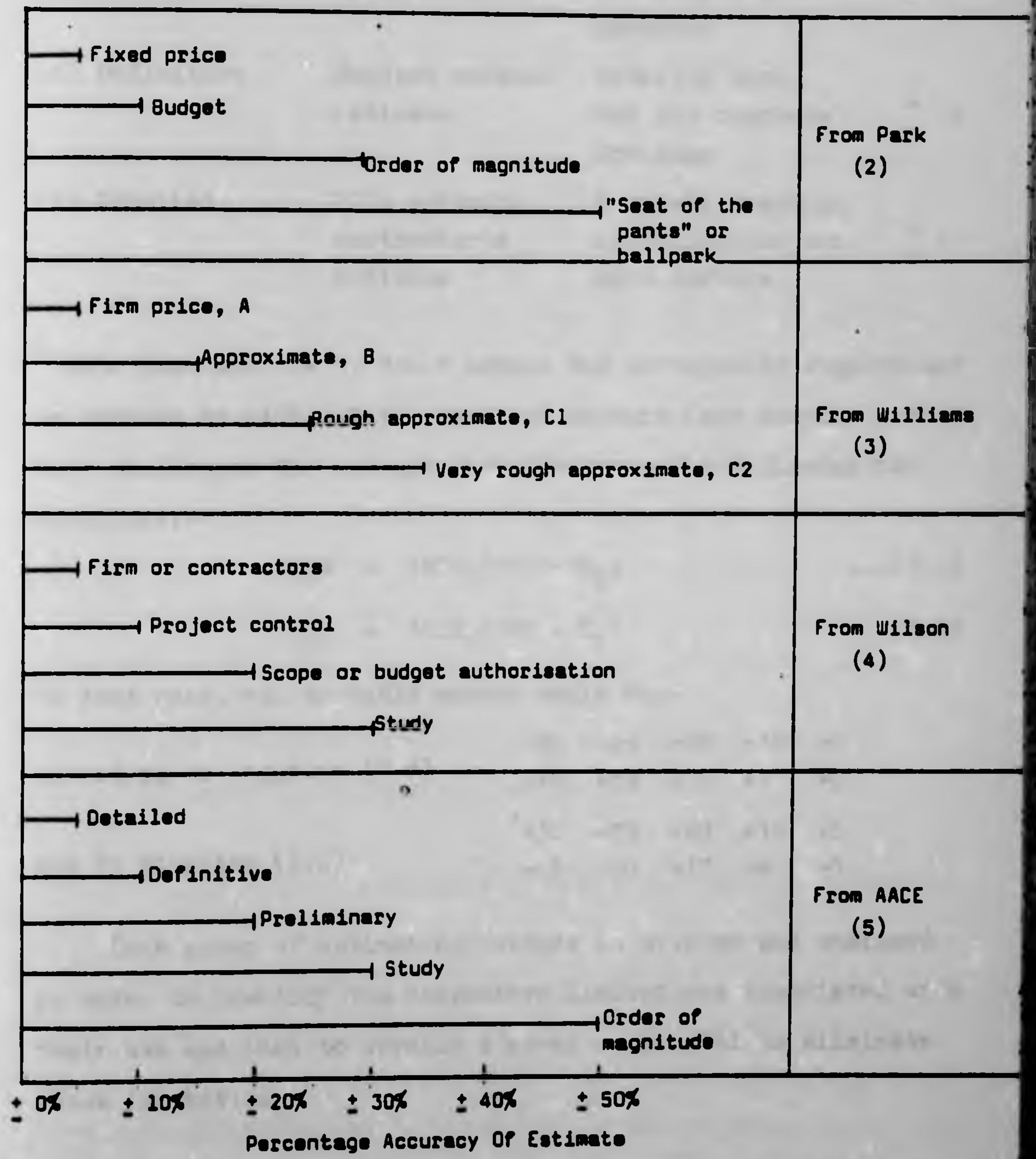
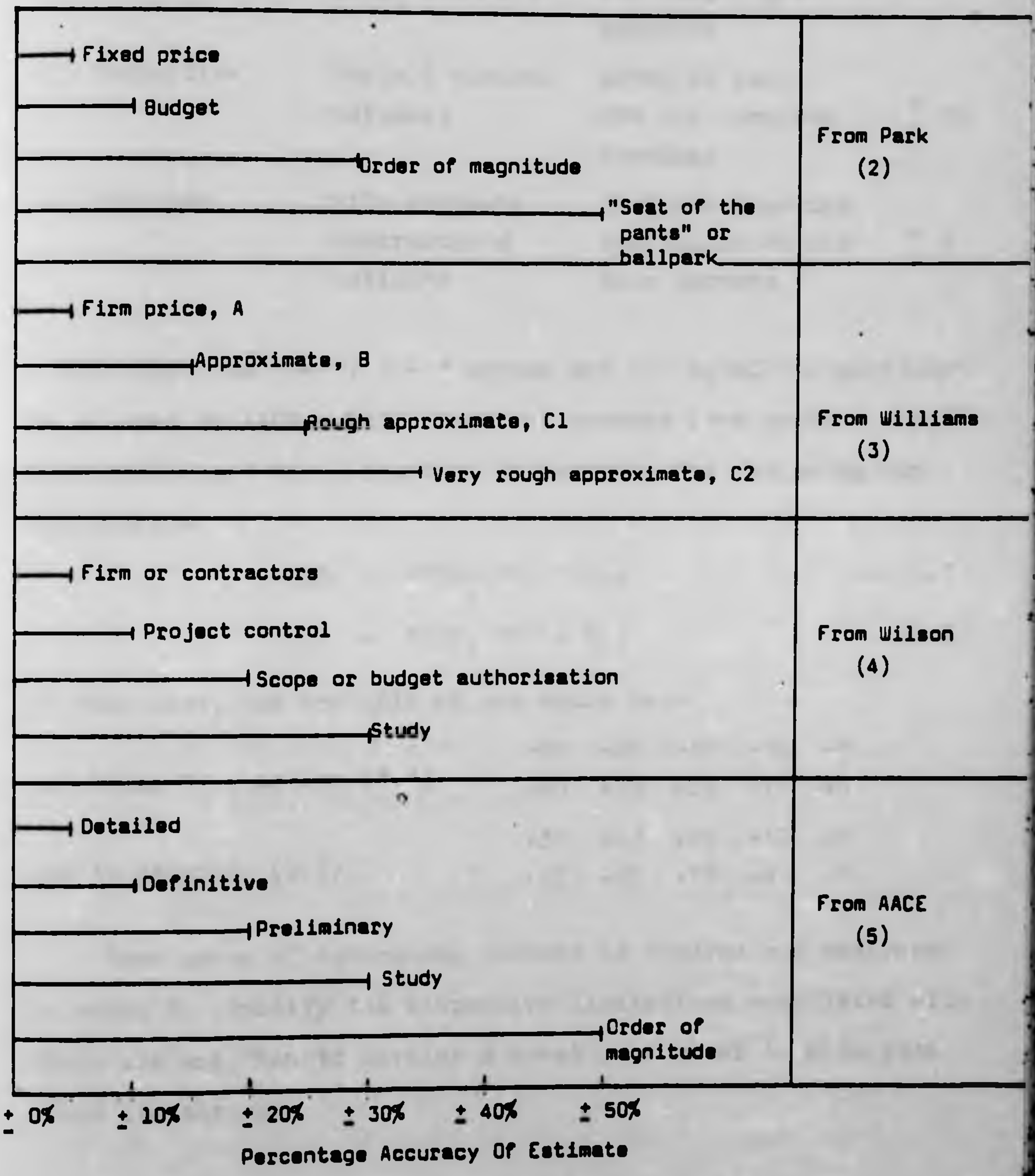


Table 4.3 Estimate Classifications According To Their Accuracies



Type Of Estimate	Other Names	Usual Basis	Probable Error %*
(c) Preliminary	Initial budget, Scope estimate	Sufficient data for budget preparation	± 20
(d) Definitive	Project control estimate	Detailed data, but not complete drawings	± 10
(e) Detailed	Film estimate contractor's estimate	Complete drawings specification and site surveys	± 5

* Note that the " + ", " - " errors are not equally significant as assumed by AACE. Later research workers (see section 5.1.1) have challenged the assumption by deriving the following two equations:-

$$+ X_1\% = 100X_2(100 - X_2) \qquad \ldots(3.1)$$

$$- X_2\% = 100X_1(100 + X_1) \qquad \ldots(3.2)$$

In that case, the probable errors would be:-

according to equation (3.1) -	-30 +40	-25 +33	-20 +25	-10 +11	-5 +5
and to equation (3.2) -	+30 -25	+25 -20	+20 -17	+10 -9	+5 -5

Each group of estimating methods is studied and analysed in order to identify the respective limitations associated with their use and then to develop a novel cost model to eliminate those limitations.

4.3.2 Order Of Magnitude Estimates

In deciding on new industry ventures, quite often it is undesirable to prepare a definitive or detailed capital cost estimate because of the considerable amount of time, money and effort required. Thus, several extremely useful shortcut estimating techniques have been developed and classified as order of magnitude estimates. Such estimates usually give probable errors of over ± 30%, and they are often referred to as ratio methods because they are mostly derived from historical ratios between cost and plant capacity. One distinctive limitation on their use is of course the requirement of historical cost data and therefore, it is not applicable for novel projects. However, these methods are not based on flowsheets or equipment lists and they give a very quick estimate of capital cost. They are categorized as follows:-

1) Unit cost method (or investment cost per unit capacity method)
2) Capital ratio or turnover ratio method
3) Cost capacity exponential method

4.3.2.1 Unit Cost Method (Or Investment Cost Per Unit Capacity Method)

This is a simple rule of thumb method in which the annual plant capacity is multiplied by a unit cost to give the fixed capital investment. The unit cost is typically expressed as investment cost per ton of annual production, based on historical data. Many sources in the literature (6,7,8) gave the fixed capital investment required for various processes per unit of annual production capacity.

The most common error associated with this method is by assuming a particular unit cost essentially constant over a range of plant capacities. This is not the case as is illustrated by the graph shown in Figure 4.1, which shows the significant variation in unit cost, i.e. decreases as plant capacity increases. Another pitfall is that unit cost figures from historical data for identical plants will differ depending on local cost factors, and the extent to which infrastructure is included. In addition, the effect of technological innovation will render the historical data out of date.

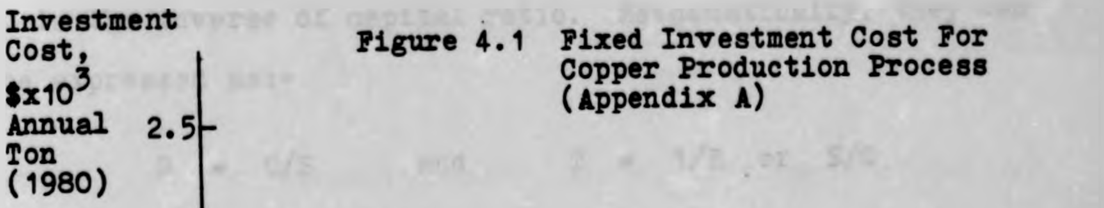


Figure 4.1 **Fixed Investment Cost For Copper Production Process (Appendix A)**

Generally, the method is considered to be the least accurate among the order of magnitude methods. Nevertheless, the concept of unit costs has been exploited and developed into a more sophisticated method in which a unit cost is applied to unit operations and processes, and even to individual equipment items (see. sub-section 4.3.5).

4.3.2.2 Capital Ratio Method (Or Turnover Ratio Method)

Capital ratio, R is defined as the ratio of fixed capital investment, C to annual sales volume, S, both expressed in the same monetary units. And turnover ratio, T is the inverse of capital ratio. Mathematically, they can be expressed as:-

$$R = C/S \quad \text{and} \quad T = 1/R \text{ or } S/C$$

The ratio method is a useful tool in obtaining a rough estimate of the fixed capital investment, provided the average selling price of the product is known. The ratios are usually derived from the estimators' files or from the published sources, of which Kidoo (9) gave ratios for specific chemical processes; Wessel (10), and Aries and Newton (11) for a number of different chemicals; and Lynn (12) for different types of industry.

The method is more advantageous than the unit cost method in that the fixed capital investment is self-adjusting according to the selling price of the product and therefore, it is inflation as well as technological change proof.

However, a limitation thus arises from the accurate forecast of sales volume and price. These are sensitive areas and subject to fluctuation in the economic environment.

4.3.2.3 Cost-Capacity Exponential Method (13)

This is a classical method long known to industry. This method relates the fixed capital investment of a new process plant to the fixed capital investment of a similar previously constructed plant by a capacity exponential power ratio. Mathematically, the method can be expressed as follows:-

$$C_n = C_o\left(\frac{Q_n}{Q_o}\right)^b$$

where C_n = estimated fixed capital investment of the new process plant

C_o = previous fixed-capital investment

Q_n = new process plant capacity

Q_o = previous process plant capacity

b = capacity exponential (scale) factor

A closer approximation for this relationship which involves the direct and indirect plant costs has already been proposed (14):-

$$C = f(D\left(\frac{Q_n}{Q_o}\right)^b + I)$$

where f = lumped cost index factor relative to the original installation cost. (This factor is the product of a geographical labour cost index, the corresponding area labour productivity index and a material and equipment cost index)

D = direct cost

I = total indirect cost for the previously installed facility of a similar unit on an equivalent site

An account of its history and development is given by Estrup (15). The earlier applications of the method were mostly based on the capacity exponential factor ranged between 0.6 and 0.7 for most types of processes. However, subsequent cost investigations (16,17,18) have revealed that the capacity exponential factor may range from 0.3 and 1.0 from process to process. It should also be noted that there can be a significant variation in the capacity exponential factor within different areas in a process plant. Miller and his collegues (19) have in fact studied the cost pattern of the four different areas and obtained the capacity exponential factor of 0.7 for the battery limit, 0.6 for the utilities, 0.5 for the storage and handling and 0.4 for the service in a process plant.

The limitations associated with the use of cost-capacity exponential method are:-

(a) It is essential to know the fixed capital investment of a similar previously constructed plant at a given capacity and with the correct scale factor.

(b) The scale factors used in the method are only applicable over a certain capacity range and can vary for each process as a function of process size. A typical graph of log capital cost versus log process size is shown in Figure 4.2. In general, scale up or scale down should be within roughly five fold range of capacity for good results (20).

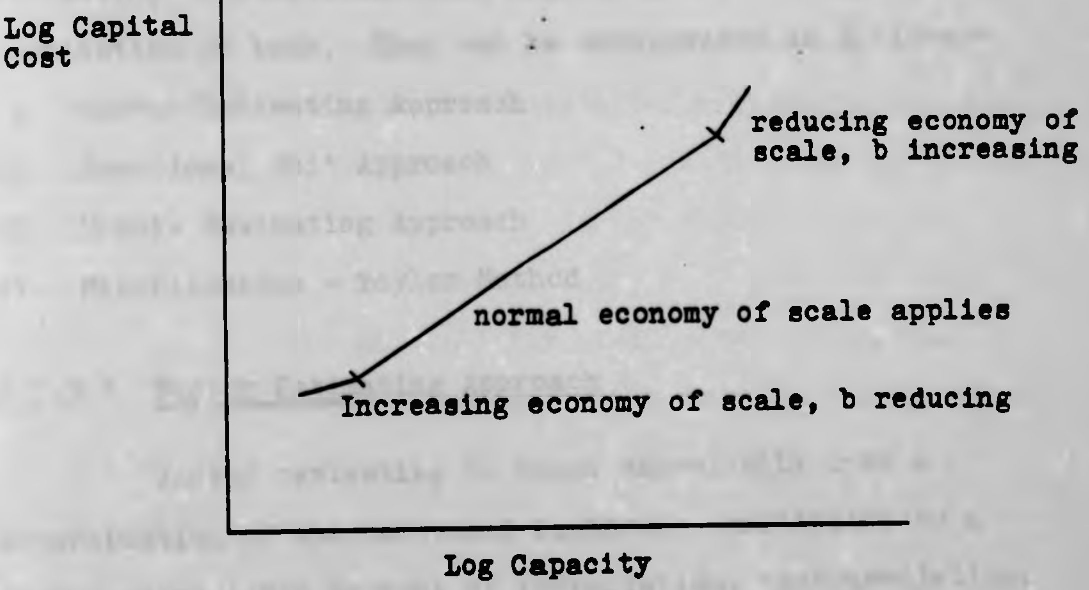


Figure 4.2

4.3.3 Study Estimates

Study estimates of capital cost are usually prepared from limited amount of process information and flowsheet. They are mostly used at pre-design cost estimating situations for screening process design alternatives and for making initial assessments of project profitability. These estimates produce an error range of ± 30% or less depending on the varying quantity as well as quality of information. The techniques employed in study estimates range from factor estimating to functional unit approach, and including combination of both. They can be categorized as follows:-

1) Factor Estimating Approach
2) Functional Unit Approach
3) Module Estimating Approach
4) Miscellaneous - Taylor Method

4.3.3.1 Factor Estimating Approach

Factor estimating is based essentially upon a determination of the delivered equipment, multiplied by a factor which takes account of installation, instrumentation, buildings, piping, service facilities, electrical and indirect costs, so that fixed capital investment is arrived at. The factor employed may lie between three and six depending upon the type of process involved. These range all the way from the traditional Lang factor method (21,22,23), with an overall factor depending on whether solid, solid-fluid, or fluid process phase system are being handled to a rather detailed factoring system for each type of equipment, such as was described by Waddel (24) (see sub-section 4.3.4.2).

Lang, based on his analysis of historical cost data, first presented this idea of using factors to obtain total estimated plant cost:-

Delivered or Purchased Equipment Cost	x	3.10 for solid phase processes 3.63 for solid-fluid phase processes 4.74 for fluid phase processes	= Total Estimated Plant Cost (Fixed Capital Investment)

Peter and Timmerhaus (13) gave a table showing the derivation of factors for each capital-investment item (e.g. piping, electrical, buildings, etc) for estimating the fixed capital investment. The overall factor values given are slightly different from those of Lang, i.e. 3.87 for solid. 4.13 for solid-fluid and 4.83 for fluid phase processes. The reason for their differences in the overall factor values may either due to time, technology advancements or changes in standards.

Later workers have modified Lang factor methods by using a number of factors or detailed factoring to achieve greater accuracy of capital cost. Thus, Hand (25) compiled a series of factors for specific equipment types related to the petrochemical industry. The factors shown in Table 4.5 apply mainly to carbon steel. However, Clerk (26) published a more general approach which allows for differences in materials of construction.

Table 4.5 Hand's Factors For Specific Equipment Types

Factionating column	4
Pressure vessels	4
Feed exchangers	3.5
Fixed heater	2
Pumps	4
Compressors	2.5
Instruments	4
Miscellaneous	2.5

Another approach is to use separate factors for erection of equipment, foundations, utilities, piping, etc. or even to break up each item of cost into material and labour factors. With this approach, each factor has a range of values and experience is required to decide for each case, whether to use a high, average or low figures. Gilmore (27), Bach (28), Haselbarth and Berk (29), and Hackney (30) have published tables depicting various ranges of values for these factors. Table 4.6 shows an example given by Haselbarth and Berk.

Since tables are not convenient for computer calculations, Hirsch and Glazier (31) developed an equation for the estimation of fixed capital investment:-

$$C_n = f_I(E(I + F_f + F_p + F_m) + E_i + A)$$

where C_n = fixed capital investment

Table 4.6 Plant Cost Breakdown, Percent Of Total Plant Investment (29)

	Solids Processing						Solid-Fluid Processing						Fluid Processing					
	Small Installation			Large Installation			Small Installation			Large Installation			Small Installation			Large Installation		
	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H
Direct Process Costs																		
Total principal items (TPI)	20	30	40	20	30	40	20	27	33	20	26	33	15	21	30	15	21	30
Installation of TPI (includes painting & insulation...	8	12	16	8	12	16	8	10	13	8	10	13	6	9	12	6	9	12
Process piping (installed)	2	4	8	2	5	9	9	10	15	8	12	16	8	15	20	8	16	25
Instruments (installed)	1	2	5	1	3	6	1	2	5	2	3	6	2	4	8	2	4	8
Electrical (installed)	1	2	5	1	2	5	1	2	4	1	2	4	1	2	3	1	2	3
Process buildings	.5	1	5	.5	2	6	1	2	8	1	2	10	1	2	15	1	2	15
Average Total Process Costs	51			54			53			55			53			54		
Other Direct Costs																		
Utilities (installed)*	3	5	10	3	7	12	6	9	15	3	13	20	5	8	12	3	12	20
General services**	4	7	10	3	5	8	1	3	4	.5	3	6	1	2	3	1	3	6
Buildings, general+	8	9	12	6	8	12	4	7	12	3	6	10	2	3	10	2	3	14
Receiving, shipping & storage (installed)	2	6	10	3	6	10	3	6	10	2	6	12	2	4	10	2	5	12
Average Total Direct Costs	78			80			78			83			70			77		

cont'd

Indirect Costs						
Engineering, overhead, etc.	8 10 12	8 9 10	8 10 12	6 8 9	12 13 16	8 10 12
Contigencies	10 12 14	9 11 13	9 12 14	7 9 12	15 17 22	12 13 18
Grand Total Costs	100	100	100	100	100	100

* Includes plant power; steam; cooling towers, all electrical costs other than process wiring, starters, panels, etc; utilities piping and buildings.

** Includes plant site improvements, fire protection, waste disposal, fences, drainage, etc.

\+ Includes offices, warehouses, shops, garages, etc.

Note: L = Low
A = Average
H = High

f_I = indirect cost factor representing engineering, supervision, contractors overhead and profit, and contingencies

E = purchased-equipment cost on f.o.b. basis

E_i = installed equipment cost

A = incremental cost of alloy materials

F_f = cost factor for field labour

F_p = cost factor for piping materials

F_m = cost factor for miscellaneous items, including the materials cost for insulation, instruments, foundations, structural steel, building, wiring, painting and the cost of freight and field supervision

The installation cost factors are further defined by:-

$$\text{Log } F_f = 0.635 - 0.154 \log 0.001E - 0.99\frac{e}{E} + 0.506\frac{f_v}{E}$$

$$\text{Log } F_p = -0.266 - 0.014 \log 0.001E - 0.156\frac{e}{E} + 0.556\frac{P}{E}$$

$$\text{Log } F_m = 0.344 + 0.033 \log 0.001E + 1.194\frac{t}{E}$$

where e = total heat exchanger cost

f_v = total cost of field fabricated vessels

p = total pump plus driver cost

t = total cost of tower shells

Hence, it can be seen that Lang's original concept of factor estimating has been subsequently well developed since its introduction. The methods described are well established and used widely in the process industries. However, they require detailed flowsheet and equipment specifications which in many cases, make them unsuitable in situations of minimum process information and so limit their use in the early stages of process development. Also, considerable experience is needed in selectting detailed component factors for a given situation. Owing largely to these limited constraints, the functional unit approach comes to be derived and achieves prominence in the filed of rapid pre-design capital cost estimation.

4.3.3.2 Functional Unit Approach

Generally, the techniques employed in functional unit approach primarily place upon all the characteristics of a functional unit or process step which would contribute towards investment cost, and as the information is limited, an average cost is attributed to each process step at a given scale of operation for a given process phase system. In addition, its approach provides the basis of a cost modelling which is able to account for investment changes with physical changes in the process system, such as changes in operating conditions (pressure and temperature) and process materials of construction. As such, the techniques within the capital cost classification are of particular interest to this research study. The functional unit approach includes the following methods:-

1) Zevnik and Buchanan's Method
2) Gore's Method
3) Stallworthy's Method
4) Bridgwater's Method

4.4.3.2.1 Zevnik And Buchanan's Method

An implicit form of functional unit approach is identifiable in the work of Zevnik and Buchanan (32). A functional unit approach was proposed in which a unit operation or a unit process is to be a functional unit (defined as all the equipment necessary to carry out a single significant process function). With a small number of basic sets of published process and cost data for fluid-type chemical plants, a generalized correlation was obtained taking account of the capacity of the proposed process plant, number of functional units (obtained from a conceptual flowsheet) and construction cost index. And Zevnik and Buchanan use graphical technique to provide further assessment of process complexity, which include operating temperature and pressure, and materials of construction. The correlation, which has been developed and based on the traditional "6/10 factor" over most of the investment-capacity correlation range, with the exception in the range below ten million lb/yr. where capacity exponential factor of 0.5 is more representive, can be summarized as follows:-

$$C = 1.33 \times N \times IFU \times ENR/300$$

where C = fixed capital investment

N = number of functional units

IFU = direct investment per functional unit

ENR = Engineering News Record construction cost index (base 100 in 1939)

1.33 = constant factor allowed for utilities and allocated facilities

The following is the procedure to be followed in obtaining an estimate of fixed capital investment for a new process:-

1) Estimate maximum temperature to be encountered. Read temperature factor, F_t from Figure 4.3.
2) Estimate maximum pressure to be encountered. Read pressure factor, F_p from Figure 4.4.
3) Consider materials of construction requirements. Select alloy factor, F_a from Table 4.7.
4) Calculate complexity factor, CF from the equation below:-

$$CF = 2 \times 10^{(F_t + F_p + F_a)}$$

5) Read cost/functional unit, CPF from Figure 4.5.
6) Calculate fixed capital investment from the cost equation.

Table 4.7 Alloy Factors For Various Materials Of Construction (33)

F_a	Materials Of Construction
0	Cast iron, carbon steel, wood
0.1	Aluminium, copper, brass, stainless steel (400 series)
0.2	Monel, nickel, inconel, stainless steel (300 series)
0.3	Hastelloy, etc.
0.4	Precious metals

Their method, which involves a comparatively small amount of work and requires relatively little process information, is quick and easy to use. However, a number of limitations have been noted in applying Zevnik and Buchanan's

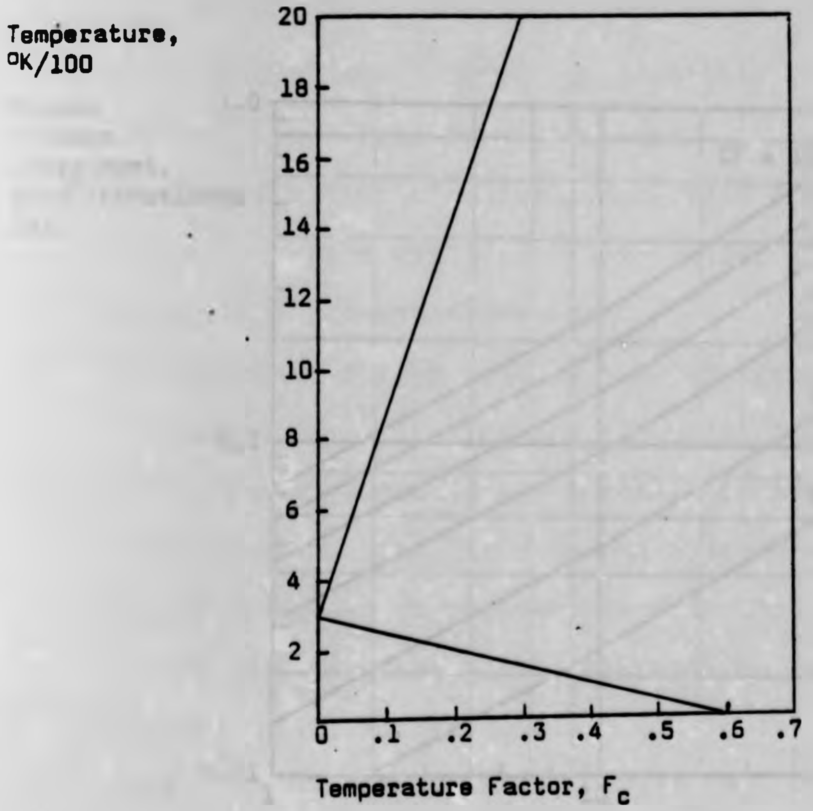


Figure 4.3 Temperature Factor Curve

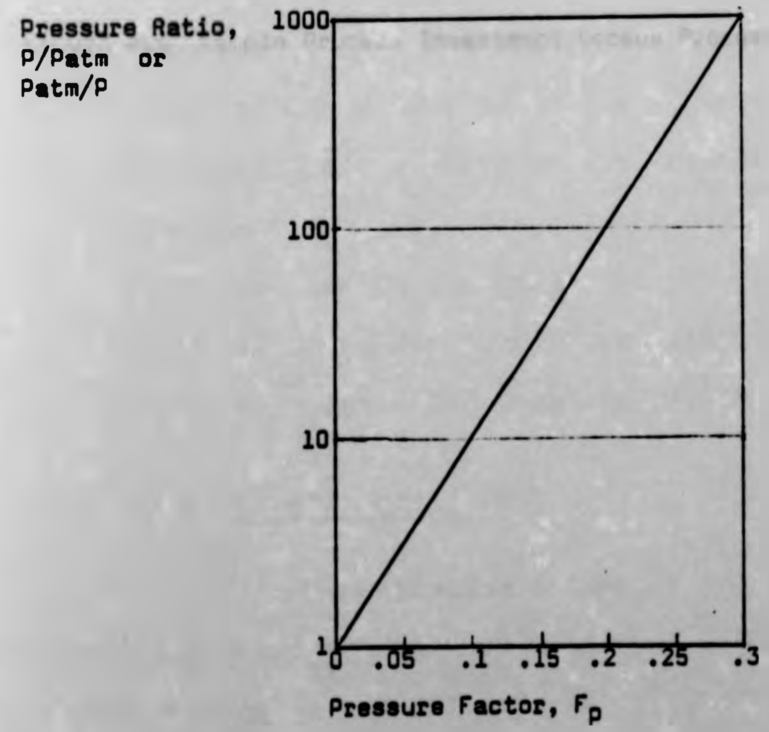


Figure 4.4 Pressure Factor Curve

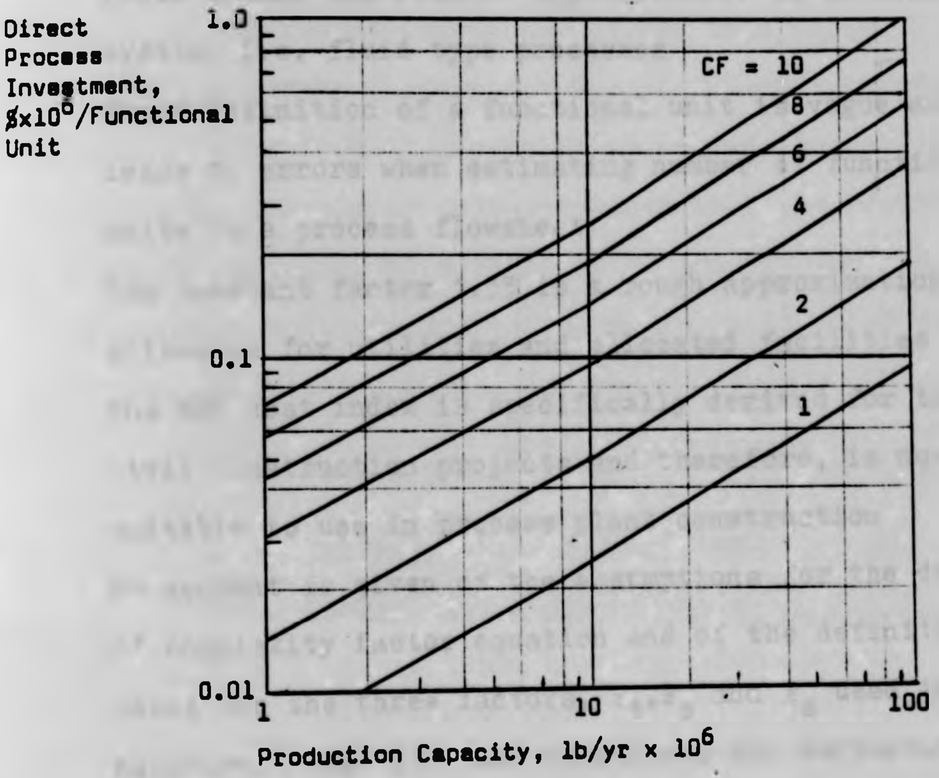


Figure 4.5 Simple Process Investment Versus Process Capacity Correlation

method:-

- Their method has limited applicability in process phase system, i.e. fluid type processes
- Their definition of a functional unit is vague and thus leads to errors when estimating number of functional units in a process flowsheet
- The constant factor 1.33 is a rough approximation allowance for utilities and allocated facilities
- The ENR cost index is specifically derived for the civil construction projects and therefore, is not suitable to use in process plant construction
- No account is given of the assumptions for the derivation of complexity factor equation and of the definition of bases for the three factors, F_t,F_p and F_a used in the equation. Page (33) has questioned the derivation of the complexity factor when he discovered a notable discrepency in the calculation of CF where the minimum value of CF $= 2 \times 10^{0+0+0} = 2$, instead of CF = 1 as indicated in the graph by the authors. The only logical explanation is that the authors might have drawn a parallel line on the graph for factor value of 1 by speculation rather than by calculation. Thus, this leads to suspect the validity of the graph as a whole.

4.3.3.2.2 Gore's Method (40)

From examination of Zevnik and Buchanan's paper, Gore (34) set about the collection of a broad range of gas-solid process investment data in order to derive realistic cost estimation correlations. In addition, he was most concerned with the definition of functional unit (see Table 4.8) and use of throughput rather than capacity on a volumetric rather than weight basis. Based on approximately 65 sets of data from 11 gas solid processes, he carried through the analysis by computer-based multiple regression procedures according to a range of alternative models related to physical conditions and consequently, arrived at the following correlation giving agreement within ± 20% :-

$$C = 4680 \times N \times Q^{0.62} \times T^{x} \times P^{0.395} \times F_m \times ENR/400$$

where C = battery limits capital cost

N = number of functional units

Q = average throughput (million lb moles per year), which was obtained by multiplying the process capacity by a "recycle factor" which was derived empirically

T = temperature factor = $(T_{max}\,^{o}K - 300)/300$

P = pressure factor = P_{max} in atm

F_m = materials of construction factor, taken as 1.0 as there did not appear to be any significant difference in the plants considered

x = 1.07 approximately, but is a function of $Q/x = (Q^{0.206})/2.52$

ENR = Engineering News Record cost construction index (base 100 in 1939)

Table 4.8 Definition Of Functional Unit According To Gregory And Gore (34,35)

(a) A functional unit is that equipment which is necessary to achieve a chemical or physical transformation of the major process stream, and is consistent with the equation:-

Output = f(input)

(b) A functional unit is a significant piece of plant which carries out an operation on the main process stream. It is usually represented by an individual block in an initial flow diagram. Examples including a distillation column and rotary vacuum filter, but exclude pumps, heat exchangers, reboilers, and hoppers which are subsidiary to a unit operation or unit process. Also, the actual size or number of units (as in a multi-effect evaporator) are neglected. Storage tanks and hoppers are excluded. Pieces of equipment that carry out mechanical separation only count as a functional unit if they constitute substantial systems in their own right, and cannot reasonably be built into a unit operation or unit processes. Such equipment would include crushers, centrifuges, and rotary vacuum filters but not cyclones or simple gravity settlers without mechanical gear. Mechanical items for feeding and discharging complete systems count as a functional unit, as do heating or cooling main process streams where the heat load is excessive or substantial or the media employed is unusual. Heat transfer equipment which is dependent on local economics is excluded, but waste heat boilers, quench towers and chequer systems are included.

The following limitations stated by Gore when using his correlation are as follows:-

(a) The correlation is valid for the following constraints:

- Throughput - $10 < Q < 500$ million lb moles per annum
- Maximum temperature - $450 < T_{max} < 1250^{\circ}C$
- Maximum pressure - $1.5 < P_{max} < 300$ atm

(b) The estimate should be treated with caution when the number of functional units, N is less than 4.

(c) The correlation is only valid for well established gas-phase processes.

(d) A learning allowance has to be made for novel processes, but this is not necessary when comparing alternatives.

However, difficulties have been noted when applying his correlation:-

- Though Gore's definition of a functional unit is more refined than that of Zevnik and Buchanan's, it is difficult to interpret and thus leads to possible errors
- Like Zevnik and Buchanan, Gore uses ENR cost index to update costs, which is not suitable for process plant cost escalation
- Throughput calculation poses problems as there is no clear definition of recycle factor or procedure for its calculation

Although Gore's method requires a little more information and considerably more care in its use, it is considered to provide a more accurate result than Zevnik and Buchanan's. In addition, his correlation study did provide few interesting information, such as the throughput term apparently agrees with the accepted "six-tenths" or "two-thirds" power law, and the temperature and pressure effects are significant as might be expected for gaseous phase processes, and seem to affect the capital cost more than is suggested by Zevnik and Buchanan's proposal.

4.3.3.2.3 Stallworthy's Method

Stallworthy has developed a quick method of estimating for use within his own company (36). His method, which was intended to be used within his company's plant, was derived from an analysis of his company's cost data as well as a wide range of published cost data obtained by Gore. The plants he considered were mainly fluid based processes in the petrochemical field. And his method was the most sophisticated development of the functional unit approach. Instead of considering the process as a simple sequence of units with an average capacity or throughput, he developed a correlation based on a study of each stream - main stream, recycle streams and side streams. This overcomes the assumption that the material flow is constant throughput the process, but means that a detailed mass balance is required. Stallworthy's correlation is :-

$$C = 0.00075/A \sum_{i=1}^{S} (N \times F_t \times F_p \times F_m \times R)_i$$

where C = battery limits capital cost in £ Sterling

N = number of significant process steps in the main, recycle and side streams

S = number of main, recycle and side streams

R = ratio of the stream to the main stream

F_t = factor for design temperature

F_p = factor for design pressure

F_m = factor for the specific materials of construction

A = size factor for the capacity of the plant required (A is derived graphically or mathematically, as : $A = 7.30 \times 10^{-7} \times Q^{0.66}$ where Q = plant capacity)

Of the several elements or factors in this correlation, F_t may vary between 1.0 and 1.5, F_p between 1.0 and 1.3, and F_m between 1.0 and 2.0 where the base case being 1.0 for a "mild steel" plant operating at normal temperature (100°C) and pressure (100 lb psi). Later research workers Page (33) and Wilson (37), after a private communication with Stallworthy, have respectively attributed a graphical method for obtaining temperature and pressure factors. Nevertheless the graphs derived by Page (Figure 4.6 and 4.7) are of similar in form with Wilson's. Also, Page and Wilson have provided F_m values as shown in Table 4.9.

The assessment of the factors S and N remains the major problem according to Stallworthy. He carefully avoided the definition of functional unit and also explained that his method was being further developed at that time. His refined approach giving an accuracy of ± 15% of the detailed estimates made for the same process was claimed. However, later workers (33,38) have indicated that Stallworthy's method gives an accuracy of around ± 25%. Though his method generally gives good investment results it should be pointed out that a detailed information is required, which make it unsuitable

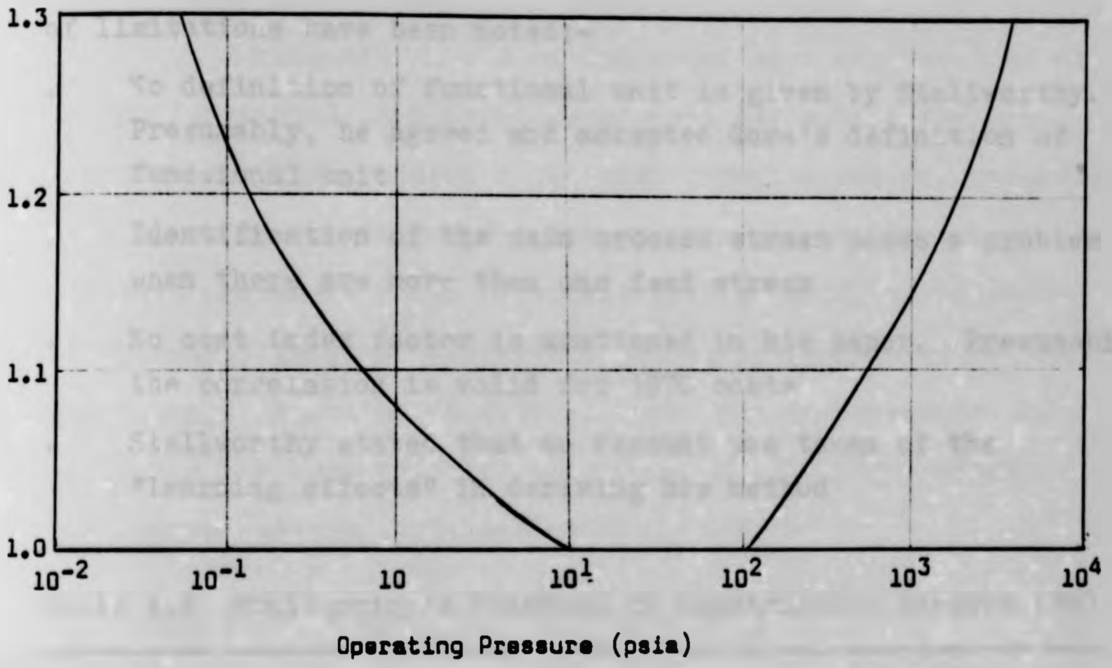


Figure 4.6 Pressure Factor

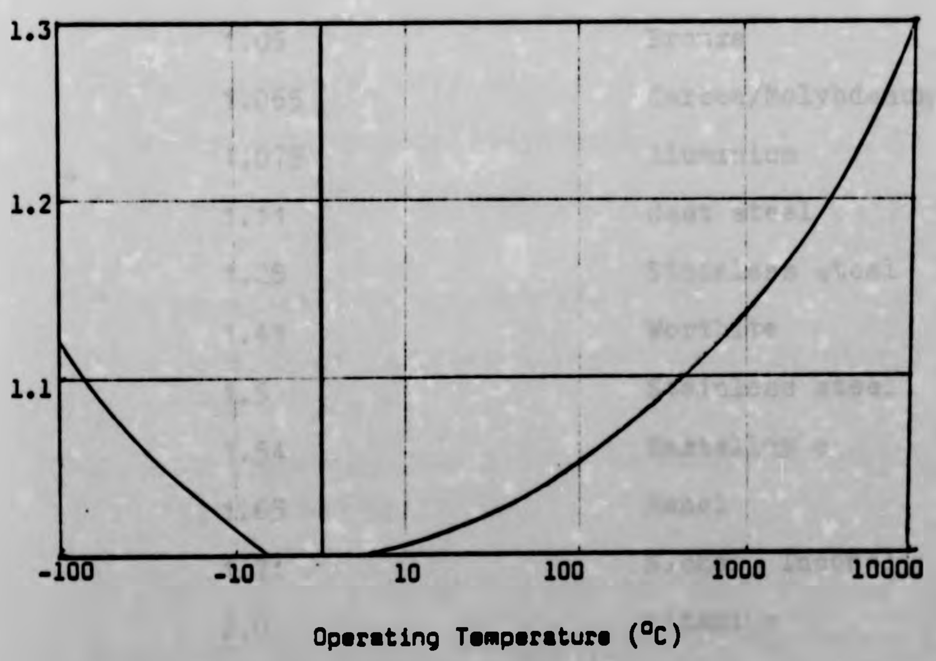


Figure 4.7 Temperature Factor

for use in pre-design cost estimating. Besides, a number of limitations have been noted:-

- No definition of functional unit is given by Stallworthy. Presumably, he agreed and accepted Gore's definition of functional unit
- Identification of the main process stream poses a problem when there are more than one feed stream
- No cost index factor is mentioned in his paper. Presumably, the correlation is valid for 1970 costs
- Stallworthy stated that no account was taken of the "learning effects" in deriving his method

Table 4.9 Stallworthy's Material Of Construction Factors (36)

Factor For Material Of Construction, F_m	Material
1.0	Carbon steel
1.05	Bronze
1.065	Carbon/Molybdenum
1.075	Aluminium
1.11	Cast steel
1.28	Stainless steel
1.41	Worthite
1.5	Stainless steel
1.54	Hastelloy c
1.65	Manel
1.71	Nickel, Inconel
2.0	Titanium

4.3.3.2.4 Bridgwater's Method (39,40)

Bridgwater has been concerned with the development of the functional unit approach of cost estimating for many years and he has produced a few cost correlations for processes, such as refuse sorting and treating, and non-biological effluent processes (20). But, his initial study was directed at hydrometallurgical extraction processes (solid-liquid phase processes). Based on 24 sets of data from 16 processes and employing the same principles as Gore, a cost correlation was derived giving agreement within ± 20% :-

$$C = 50.26 \times N \times (Q/S^{0.5})^{0.85} \times (T \times n/N)^{-0.17} \times (P \times n'/N)^{0.14} \times F_m \times ENR/1300$$

where C = fixed capital investment in £ Sterling

N = number of functional units

Q = plant capacity (tons/annum)

S = "conversion" factor

T = maximum process temperature (°C)

n = number of functional units operating at greater than T/2°C

P = maximum process pressure (atm)

n' = number of functional units operating at greater than P/2 atm

ENR = Engineering News Record construction cost index (base 100 in 1913)

The estimating procedure is given below:-

1) Determine the number of functional units, N (the same definition as quoted by Gore, but it further includes

side stream, particularly recycle streams and offsite).

2) Calculate throughput as a function of plant (process) capacity, Q and "conversion" factor on mass basis:-

$$\text{Throughput} = Q/S^{0.5}$$

where Q = plant capacity, expressed in tons/annum (Bridgwater concluded that mass is more suitable than volumetric measurement, which would cause considerable difficult when considering complex minerals of unknown or indeterminate molecular weight)

S = "conversion" factor is defined as:-

$$\frac{\text{Weight of desired reactor product}}{\text{Total weight of reactor input}}$$

3) Calculate the temperature effect via weighting approach, i.e. $(T \times n/N)^{-0.17}$ (as he considered maximum temperature was two crude for the correlation).

4) Calculate the pressure effect by using the same approach as above, except $(P \times n'/N)^{0.14}$ is used.

5) A materials of construction factor, F_m is not evaluated due to the similarity of process conditions of all the processes, but the results suggested later that non-acid processes would cost about 20% less.

6) Model constant value - he concluded that the model constant does vary with plant capacity. The following constant values were proposed:-

(a) for low capacity processes, $Q < 1000$ tpa, $K = 400$

(b) for medium sized processes, $1000 < Q < 10{,}000$ tpa, $K = 140$

(c) for large scale processes, $Q > 10{,}000$ tpa, $K = 50.26$

According to Bridgwater, the correlation is only valid for liquid and solid-liquid processes, operating at above ambient temperature and pressure, and with a capacity greater than 10,000 tons/annum. He also stated that the method probably gives greenfield site costs, but this is difficult to ascertain due to problems with the data.

Apart from the stated constraints, others are, however, noted:-

- As he makes use of Gore's definition of functional units, same problem arises
- As mass balance data is required, difficulties can arise when using the "conversion" factor, S to calculate throughput
- Like Zevnik and Buchanan, Bridgwater initially used the unsuitable ENR cost index to update costs. However, later methods (20) recognised this limitation and Engineering Process Economics, EPE cost index was used instead
- The negative exponential factor of -0.17 of temperature effect seems suspicious. It could be postulated that increasing temperature increases reaction rate and so reduces cost. Nevertheless, on increasing temperature, costs are expected to increase due to:-
  - (a) Possible change in materials of construction,
  - (b) Increased control for safety reasons,
  - (c) Increased insulation requirement, and
  - (d) Increase in numbers of ancilliary heat transfer equipment.

4.3.3.3 Module Estimation Approach

The term module estimating (or unit cost estimation) is used to differentiate between factor estimating as described in sub-section 4.3.3.1 in that it goes a step further by applying factors to individual equipment items. In other words, the cost of each unit (major piece of equipment) is multiplied by a factor to determine its constribution to total plant cost. The product is termed a module, and the sum of the modules is the total plant cost.

Generally, there are two levels of module estimating:-

(a) Simple module estimating, one where the capital cost is a function of the average cost of each unit. This includes Allen and Page, Wilson and Miller methods (33,37,38,41). However, Miller method will be described under preliminary estimate category as it gives estimating accuracy of ± 15% for the reason of estimating classification (see sub-section 4.3.4).

(b) Complex module estimating, one where each unit is treated individually. This will be described under definitive estimate category as it gives estimating accuracy of ± 10% (see sub-section 4.3.5).

4.3.3.3.1 Wilson's Method (37)

The object of Wilson's study was presumably to combine the advantages of functional unit estimating and factor estimating approach, and the following equation is proposed for the capital investment required for a process plant:-

$$C = f \times N \times (AUC) \times F_m \times F_p \times F_t$$

where C = capital cost of plant in 1971 £ Sterling

f = an investment factor

N = the number of main plant equipment items

AUC = the average unit cost of main plant equipment items

F_m = factor for specific materials of construction

F_p = factor for design pressure

F_t = factor for design temperature

The estimating procedure is given below:-

1) Determine the number of main plant items, such as reaction vessels, columns, exchangers, unit operations equipment, compressors blowers, etc. (Perhaps, ten pumps are equivalent to one main plant item) from the flowsheet.

2) Calculate the average throughput, V (tons/annum) of the main plant items and then obtain their average unit cost, AUC of main plant items from the Figure 4.8. Wilson obtained this graph by fixing all the parameters of the model, except f and AUC for any plant, and determining the relationship between AUC and V from the known total investment. This process was repeated for all the plants until linearity was achieved on a log-log plot of AUC versus V. The equation of the line shown in Figure 4.8 is:-

$$AUC = 21 \times V^{0.675}$$

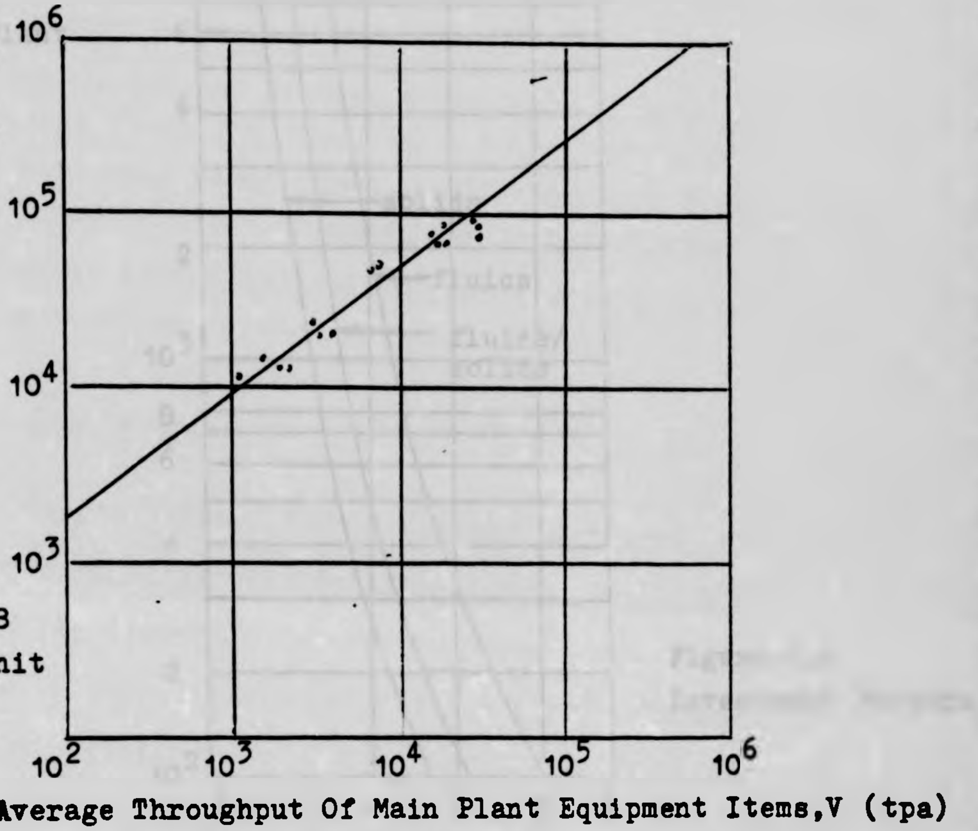


Figure 4.8

Average Unit Cost

3) Obtain the investment factor from the graph of factor values versus the average unit cost as shown in Figure 4.9. Wilson derived this graph by combining the Lang factor categorization (i.e. fluid, fluid-solid, solid) and Miller's factor as a function of average unit cost (41), so making the investment factor a function of the dominant phase.

4) Determine F_m, F_p and F_t from Table 4.9, Figure 4.6 and 4.7 respectively. In all cases, a number-weighted mean value of F , F and F may be used.

5) Estimate capital cost from the cost equation.

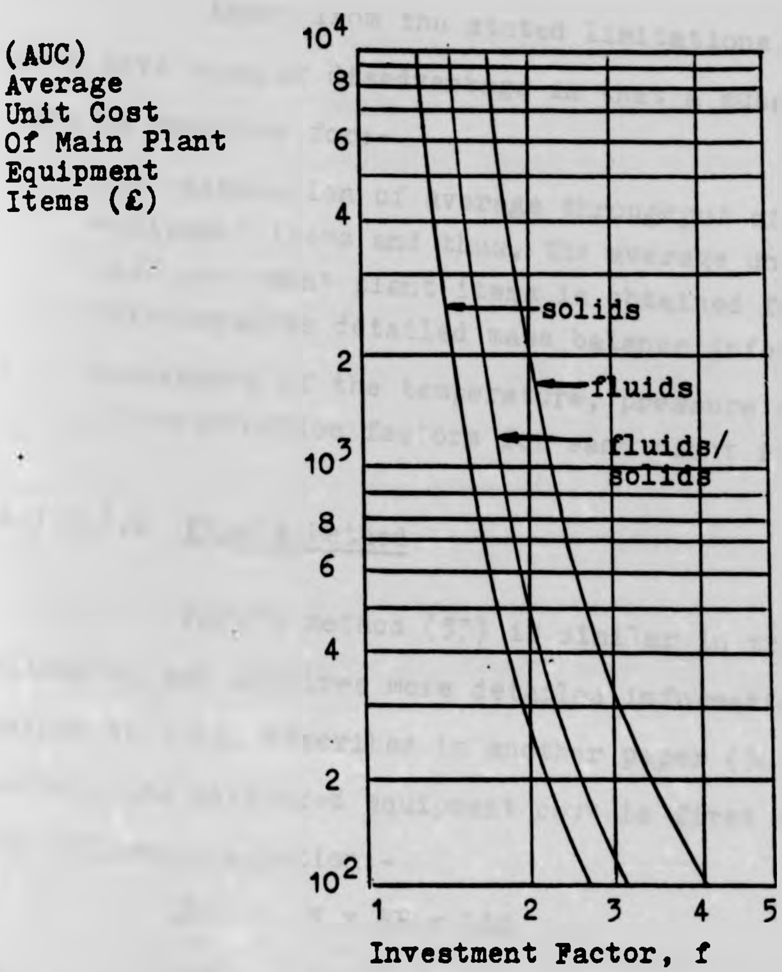


Figure 4.9
Investment Factors

Wilson considered sixteen plants in arriving at his correlation, of which thirteen plants gave estimating accuracies within ± 30%. As only sixteen data sets were used to derive the method, it means that the method should be treated with caution. In fact, Page (33) had tested the method and stated that inconsistent results were obtained. Wilson stated that the troughput range is valid from 10^4-10^6 tons/annum, that his method is restricted to battery-limits estimates, and that no account of learning effect was considered in the method.

Apart from the stated limitations, the method does have a major disadvantage in that a substantial process data is required for:-

- The calculation of average throughput of main plant equipment items and thus, the average unit cost of main equipment plant items is obtained from Figure 4.8. This requires detailed mass balance information
- Assessment of the temperature, pressure and materials of construction factors for each plant item

4.3.3.3.2 Page's Method

Page's method (33) is similar in principle as Wilson's, but requires more detailed information. His method is fully described in another paper (38). In his method, the delivered equipment cost is first estimated by the following equation:-

$$DEC = N \times SF \times BIC$$

where DEC = delivered equipment cost

N = number of main plant items including pumps shown on the process flowsheet

SF = state factor

BIC = basic item cost

The state factor, SF, which takes into account of operating temperature and pressure, and materials of construction, is defined as:-

$$SF = F_{tmax} \times F_{pmax} \times F_{mmean}$$

where F_t = temperature factor

F_p = pressure factor

F_m = materials of construction factor

As used by Wilson and developed by Stallworthy, similar temperature, pressure and materials of construction factors are employed (see Figure 4.3 and 4.4 and Table 4.7). The F_t and F_p factors were taken at the most extreme conditions as it was found that any advantage in calculating or assuming values for all main-plant items in order to derive a number-weighted mean value did not justify the effort involved. However, a number-weighted mean value for F_m was thought to be better.

The term BIC, basic item cost is obtained graphically and is a function of a throughput variable, TP defined as:-

$$TP = CAP \times FF \times PF$$

where CAP = total plant feed in lb moles/annum (volumetric basis is preferred as the physical size of a plant is more related to volumetric than mass throughput, especially for gaseous stream)

FF = flow factor, which accounts for all process streams in order to avoid mass-balance information, is defined as:-

$$FF = \sum_{1}^{N} \frac{\text{(number of input and output process streams of each main plant item)}}{\text{Number of main plant items, N}}$$

PF = phase factor, which accounts for the phase of operation of the individual equipment items and thus, equipment size and cost, is a function of the proportion of volume items, VI in a plant:-

$$PF = 0.0075 + (VI/N)$$

where the constant 0.0075 represents the ratio of densities of a typical hydrocarbon stream in the gas and liquid phases.

Having defined and calculated the throughput term, investment cost data from eight fluid-type petrochemical plants were required to obtain eight straight lines on the BIC-TP correlation, where a point of convergence (i.e. TP = 2.5×10^6 lb moles/annum, BIC = $7000) was obtained with gradients of:-

$$EXP = \sum_{i=1}^{N} (c_i e_i) / \sum_{i=1}^{N} (c_i)$$

where c_i is the base cost of main plant item, i, and e_i, the exponent of main plant item. Both are obtainable from Guthrie's equipment exponent data (42).

A method is therefore available for determining DEC for petrochemical plant, which can then be converted into total plant investment (fixed capital investment) by a percentage factor to account for other direct and indirect costs. Over twenty references giving the breakdown of total plant investment into its various component costs were found, from which each delivered equipment cost was determined as a percentage of the fixed capital investment and an average value of 21% was obtained for grass roots investments (it can vary between 15 and 30%). Since the method was based on 1972 data, the Marshall and Stevens, M & S cost index with 1972 reference values of 331 is required to update the total plant investment. An accuracy of +25% to -20% was claimed in the method.

The following limitations were imposed in the method:-

(a) The processes employed in deriving the method were all petrochemical processes. Therefore, the method is only applicable to petrochemical processes.

(b) The method is restricted by the range of throughput used in its development, i.e.

$$15 \times 10^6 < \text{Throughput} < 340 \times 10^6 \text{ lb moles/annum}$$

(c) As the graphs used to calculate F_t and F_p were obtained by extrapolation, their accuracy at extreme values of range limits is suspect.

(d) F_m is only known for a limited range of materials.

Apart from the stated limitations, other limitations or disadvantages are noted:-

- Detailed process information, such as the number of main plant items, flow configuration and process feed (calculated in lb moles/annum, which may be difficult or impossible for complex feed mixtures of unknown molecular weight) is required, which limits its use in the early stages of process development
- It is noted from the description that the method is complex and time consuming and thus, it is not suitable for use as a quick screening estimating method by process engineers
- The method is derived from the correlation of only eight processes and thus, the degree of confidence attached to this method is suspect

4.3.3.4 Miscellaneous - Taylor's Method (43,44)

Basically, Taylor's method is a different type of approach from the others and his method is a continuation of Le Page's work at ICI Ltd (45). He refers to his technique as the "Process Step Scoring" method, which he claimed an accuracy of +36% to -26% within 95% confidence limits (standard deviation of 15%), based on an analysis of 45 ICI UK projects.

The method was based on a system in which a complexity score accounting for such factors as throughput, corrosion problems, reaction time, storage time, operating conditions, number of streams and special conditions, such as (i) explosion, odour, dust or toxicity problems, (ii) fractionation of materials of similar boiling points, (iii) reactions in fluid beds, (iv) film evaporation and (v) tight specification, is estimated for each process step and these are summed up to give an overall "costliness index":-

$$I = \sum_{1}^{N} (1.3)^s$$

where N is the number of "significant process steps" and s is a complexity score. The capital cost is then derived from a relationship between this index and process capacity:-

$$C = 42 \times Q^{0.39} \times I$$

where C = battery limits capital cost in £ Sterling

Q = process capacity in 1000 tons/annum

The estimating procedure is given below:-

1) Define the process parameters (factors) from the proposed flowscheme, which should show the main process steps, relative throughputs (ton/ton product), temperatures, pressures, materials of construction, reaction times, multi-streaming and any special conditions, such as

explosion hazards.

2) Identify the significant process steps from the process flowscheme. Table 4.10 shows a list of unit operation/ unit processes, which are regarded as significant process steps.

3) Score each significant process step on throughput, materials of construction, temperature, pressure, multi-streaming, reaction or storage time any special conditions according to Table 4.11.

4) Convert the total score for each significant process step into costliness index using the conversion table (at foot of Table 4.11). For a single process step, the costliness index is given by 1.3^s.

5) Sum the costliness indicies for each process step to give the costliness index, I for the whole process:-

$$I = \sum_{1}^{N} (1.3)^s$$

6) Estimate the battery limits capital cost using the following relationship:-

$$C = 42 \times Q^{0.39} \times I$$

7) Make allowances, where necessary, to cover:-

   (a) Inflation: Inflation from January 1977 should be added using EPE PLANT cost index

   (b) Off-sites and site development: Add 0-50% or more to the capital, but it is suggested that an average allowance of 30% should be added to cover off-sites and site development

   (c) Use of existing structure: This would reduce the capital by 25-50%

   (d) Plants overseas: Published location indicies should be used

Table 4.10 Taylor's List Of Process Steps

- Chemical reactions
- Neutralization/Acidification
- Storage/handling of a raw material, product, byproduct, intermediate, or recycle stream. Also effluents when these are not assumed to be discharged directly to outside battery limits
- Filter, screen or centrifuge
- Distil, evaporate, fractionate or strip
- Crystalise or precipitate
- Formulate
- Compress
- Vaporise
- Dry or spray dry
- Mill or grind
- Scrub or absorb
- Packing into special containers
- Quench
- Phase separation of a reaction mixture but not when part of a still or an extraction system
- Extract or leach
- Condense when used to separate a component from a gaseous stream containing inerts
- Dissolve, mix, slurry or blend when required as a specific pre or post treatment

---

Table 4.11 Scoring For Complexity Of Significant Process Steps

	Score												
	-3	-2	-1	0	1	2	3	4	5	6	7	8	9
Relative throughput (t/t product)	0.2	0.35	0.6	1	1.7	3	5	8	14	23	40	67	110
Reaction time in h (reaction, crystallisation, etc)				3	5	9	14	35	42	69	120		
Storage time in weeks				1	2	3	5	8					
Temperature extreme (^{o}C)Min				20	-25	-75	-125						
Temperature extreme (^{o}C)Max					500	1100	1700	2300					
Pressure extreme (atm)Min				1	0.1	0.01							
Pressure extreme (atm)Max					10^{a}	50^{a}	200	700	1500				
Materials of construction				MS^{b}	SS^{c}, Keebush RLMS^{d}, EbLMS^{e}, PVC	EIMS^{f} Inconel Nickel Monel PbIMS^{g}	Titanium Hastelloy	Precious metals Tantallum					
Multistreaming. No. of streams				1	2	3	5	7	11				

cont'd

Special conditions:

(a) Explosion, dust odour or toxicity problems. Score 1 if a major problem.

(b) Reactions in fluid beds. Score 1.

(c) Distilling materials of similar b.pt. Score 1 if b.pt. difference $<5^{\circ}C$ and Score 2 if $< 1^{\circ}C$.

(d) Tight specification eg. Score 1 if distillation is to reduce "key" component to 10 ppm level.

(e) Film evaporation eg. in Luwa. Score 1.

<u>Conversion of score to costliness index</u>

Score (S)	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Costliness index (I)	0.4	0.6	0.8	1	1.3	1.7	2.2	2.8	3.7	4.8	6.3	8.1	10.6	14	18	23	30	39	51	66

Note: a - for liquid reactions only. All others score = 0

b - MS = Mild Steel

c - SS = Stainless Steel

d - RLMS = Rubber lined mild steel

e - EbLMS = Ebonite lined mild steel

f - ELMS = Enamel lined mild steel

g - PbLMS = Lead lined mild steel

Taylor's method can be used for complete new plants of capacities ranging from 300 to 250,000 tons/annum. However, he stated that the method is unsuitable for estimating of the following:-

(a) Very simple plant involving less than about five process steps.

(b) Modification or extension of existing plants.

(c) Fully batch operated plants of abnormally high capacity (500 tons/annum or more).

(d) Fully continuous plants of abnormally low capacity (500 tons/annum or less).

(e) Plants involving appreciable solids handling on the large scale (500+ tons/annum)

(f) Plants involving special operations, such as electrolysis, fibre spinning, extrusion, when these are likely to represent a substantial proportion of the cost.

Apart from the stated limitations, other disadvantages can be identified:-

- Detailed process information is required, which limits its use in the early stages of process development
- Taylor's "process step scoring" method is surely a novel and interesting one, which relates capital cost directly to the chemistry involved in the process without considering engineering aspects of the type of equipment required. Thus, it differs from the functional unit approach in this respect. However, it is assumed that Taylor has possessed sound data from which to develop his method, otherwise it is too much to ask the user to assume that the method is capable of producing realistic cost estimates by the means stated

4.3.4 Preliminary Estimates

Preliminary estimates, sometimes called budget authorisation estimates, are prepared from well-designed process flowsheets, detailed equipment lists, and good site and structure information. Their usual range of accuracy is ± 20%, which is good enough for initial budget approval of capital funds. Some study estimating methods can often be applied to preliminary estimates depending on how confident the estimator is.

All the methods reviewed from preliminary estimates onwards (to detailed estimates) are sophisticated, and developed to a high accuracies. They all require considerable detailed information and thus, not suitable for pre-design cost estimating. However, they are reviewed here in order that the techniques of detailed estimating and accuracy-information relationship which exist, may be understood to assist in the research.

4.3.4.1 Miller's Method

Miller (41) published a method which may be described as simple module estimating technique. Basically, the method is based on Lang factor technique, which is further refined, such that it makes allowance for variation in size but takes advantage of the effects of overall averaging to give a wide coverage of different types of plants. In addition to the nature of the process (i.e. solid, solid-liquid or liquid), the method also takes care of the effect of the size of the equipment, materials of construction and operating pressures. The cost equation is as follows:-

Total Capital Cost = Overall Factor x Delivered Equipment Cost

Miller postulated that the overall factor becomes smaller if the size of the equipment gets larger, the equipment is made from more expensive materials or the operating pressures increase and that to a considerable degree, all these items can be taken into account by one number, the "average unit cost" of the process equipment which he defined as:-

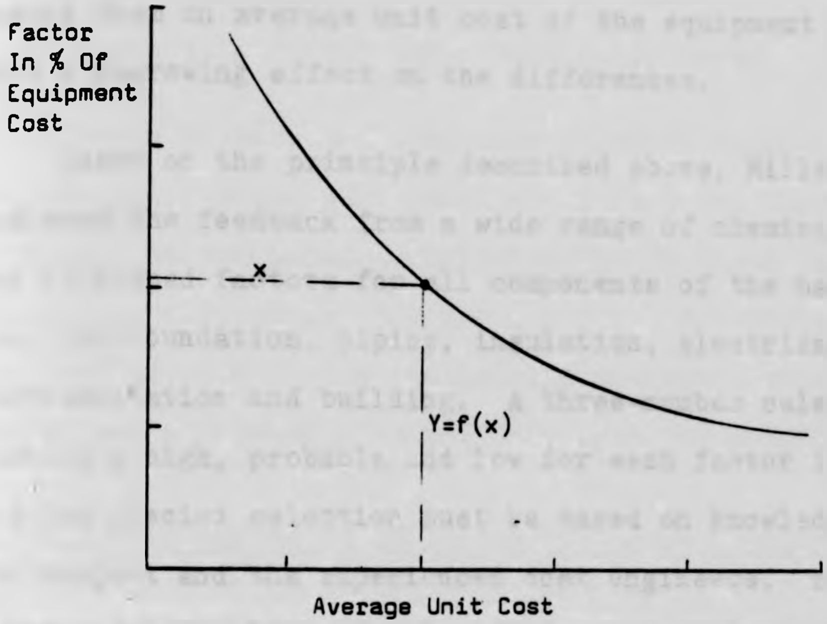
$$\frac{\text{Total Cost Of Process Equipment}}{\text{Number Of Equipment Items}}$$

He presented two graphs (Figure 4.10) which illustrates how this relationship can be used as follows:-

(a) If the size of a plant is increased, the equipment becomes larger and the average cost per item increases. Thus, the point on the curve will move further to the right, and the corresponding factor will be lower.

(b) Alternatively, if the equipment has been carbon steel and is changed to stainless steel, the average cost of each item will increase, and again the point on the curve will move further to the right and the factor will be reduced.

(c) Similarly, if the operating pressure is increased from atmospheric to a high-pressure operation, the average cost per item will again increase and the resulting factor will go down.



In practice, the above becomes a band

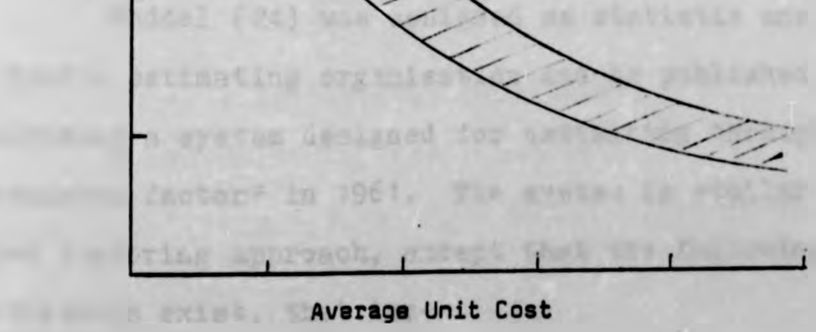


Figure 4.10 Miller Curves (41)

It follows that regardless of what issues which are causing variations in the factors, the principle of basing them on average unit cost of the equipment will have a narrowing effect on the differences.

Based on the principle described above, Miller had analyzed the feedback from a wide range of chemical plants and developed factors for all components of the battery limit, i.e. for foundation, piping, insulation, electrical, instrumentation and building. A three-number selection picking a high, probable and low for each factor is used and the precise selection must be based on knowledge of the project and the experienced cost engineers. This is a major disadvantage of the method since it is only applicable to experienced cost engineers.

Miller claimed an estimating accuracy of ± 15% on battery limits estimates while on equipment ± 10%. The method considered greenfield site costs, battery limit costs and plant extension costs.

4.3.4.2 Waddel's Method

Waddel (24) was assigned as statistic analyst in Du Pont's estimating organisation and he published a paper describing a system designed for estimating through use of "expansion factor" in 1961. The system is similar to other factoring approach, except that the following basic differences exist, that is:-

- Accurate to within ± 10%
- Applicable for any arrangement of four or more differing types of equipment
- Statistically rather than empirically based

As the factors and equations on which expansion estimating is based were peculiar to Du Pont, they were not given in the paper. Therefore, it is impossible to verify the estimating accuracy claimed. Nevertheless, it has been grouped in the preliminary estimate category as the method was based on sound data from the company.

4.3.4.3 Percentage Of Delivered Equipment Cost Method

This method for estimating the fixed capital investment requires determination of the delivered equipment cost. The other items included in the total direct plant cost are then estimated as percentages of the delivered equipment cost. The remaining items which go to make up the fixed capital investment are based on average percentages of the total direct and indirect plant costs. This method (13) can be summarized mathematically as follows:-

$$C = (\Sigma E + \sum_{i=1}^{i=n}(f_i E)(1 + f_I)$$

where C = fixed capital investment
E = delivered equipment cost
f_i = $f_1, f_2, \ldots f_n$ = multiplying factors for instrumentation, piping, electrical, etc.
f_I = indirect cost factor

The percentages used in making a preliminary class estimate are determined on the basis of the type of process involved, design complexity, materials of construction, plant location, past experience, and other relevant items. Average values of the various percentages have been published for typical chemical plants by numerous authors (13,25,26, 46,47). Ratio factors have been analyzed and average values have been determined for non-ferrous metal production processes as shown in Table 4.12. The average ratio factors will be incorporated into the cost model as a constant factor which will be described in Chapter Five.

Table 4.12 Ratio Factors For Estimating Fixed-Investment Cost Items Based On Delivered-Equipment Cost (13,29,48)

Item	Percent Of Delivered Equipment (Ratio Factor)	Percent Of Fixed Capital Investment
Direct Costs		
Purchased equipment-delivered (including equipment and process machinery)	100	22.5
Purchased-equipment installation	32 (.32)	7.2
Instrumentation and controls (installed)	7 (.08)	1.6
Electrical equipment and materials (installed)	10 (.10)	2.2(5)
Material handling and storage (installed)	0	0

cont'd

Item	Percent Of Delivered Equipment (Ratio Factor)	Percent Of Fixed Capital Investment
Piping and process gas handling (installed)	10 (.10)	22
Building (including services	30 (.30)	6.7
Yard improvements	11 (.11)	2.5
Service facilities	49 (.49)	11.0
Land	5 (.05)	1.1
Total direct plant cost, D	254 (2.54)	57.0
Indirect Costs		
Engineering and supervision	33 (.33)	7.4
Construction expenses	39 (.39)	8.8
Total direct and indirect plant costs, (D + I)	326 (3.26)	73.2
Contractor's fee(about 5% of D+I)	16 (1.6)	3.6
Contingency (about 10% of D+I)	33 (.33)	7.4
Interest during construction (about 12% of D+I)	39 (.39)	8.8
Startup expenses	31 (.31)	7.0
Fixed Capital Investment	445 (4.45)	100.0

These preliminary estimating methods yield most accurate results when applied to processing plants similar in configuration to recently constructed plants. However, a few limitations will emerge when in use and they are summarized as follows:-

- Detailed information of flowsheet, equipment cost and specification and materials of construction are required
- Considerable experience is required to determine detailed component percentage factors for a given process
- Technology change - since the factors were first promoted, considerable advances in technology have occurred, which will affect the significance of each component in Table 4.12, and there is little information available on the extent of the change

4.3.5 Definitive Estimates

The definitive estimating techniques involve the preparation of process flowsheets and the basic design of equipment, together with reasonably complete site and auxilliary facilities information. These estimates have an error range of ± 10% and are in sufficient detail to be the basis for project cost control. These techniques are generally based on the factorial concept of estimating developed by experience and well-informed company cost engineers and exist in various forms of sophistication and refinement.

4.3.5.1 Unit-Cost Estimate

The most advanced form of factorial estimating in definitive estimates is the unit-cost technique. This technique requires the costing of all items of equipment, either from vendor quotation or updated cost records. Equipment installation labour is estimated as a fraction of delivered equipment cost. Costs for concrete, steel, piping, material transportation and storage, electrics, insulation, instrumentation and painting are obtained by take-offs from drawings, and applying unit costs to the material and labour requirements. A unit cost is also applied to engineering man-hours, number of drawings, and specifications. Field expense, contractors' fees and contingency are estimated by applying factors obtained from past projects. Bauman (1) summarizes the method with the following equation:-

$$C = \left((E + E_L) + (f_x M_x + f_y M_L) + f_e H_e + f_d d \right) (1 + f_F)$$

where C = fixed capital investment
E = purchased-equipment cost
E_L = purchased-equipment labour cost
f_x = specific material unit cost
M_x = specific material quantity
f_y = specific material labour unit cost per man-hour
M_L = labour man-hours for specific material
f_e = unit cost for engineering

H_e = engineering man-hours
f_d = unit cost per drawing or specification
d = number of drawings or specifications
f_F = construction or field expense factor

The major limitations are the availability of data and the time involved in calculations of detailed factoring. However, the latter disadvantage was overcome with the advent of computers, which inherently possess the benefits of calculation speed, easy data storage and retrieval.

4.3.6 Detailed Estimates

Of course, the most accurate evaluation of investment requirements for a new process is that which is ultimately developed by a detailed estimate, such as made by an engineering and construction firm for the purpose of submitting a bid; it is normally prepared for lump sum proposals in which the contractor is required to carry the main risk. Such an estimate usually gives probable errors of up to ±5%.

4.3.6.1 Detailed-Item Estimates

A checklist of items shown in Table 4.1 is an invaluable aid in making a detailed-item estimate. Process equipment and material requirements are obtained from detailed design documents, such as process flowsheets, electrical on-line diagram, instrument diagrams, design specifications, equipment drawings and data sheets, piping and conveying, plot plans and bulk material take-offs. They are priced either from reliable current cost data or preferably from firm delivered quotations. Estimates of installation costs are derived from accurate labour rates as well as productivity. Accurate estimates of engineering, drafting, field supervision man-hours and field expenses are also necessary. Complete site surveys and soil investigation data must be available for the site development and construction cost estimates. In fact, quotations from vendors and suppliers are obtained whenever possible in this type of estimate.

4.4 Review Of Cost Indices

Most cost data which are available for immediate use in a preliminary or pre-design estimate are based on accumulated past data. Because prices are changing rapidly with time, a method must be derived to compensate this change. As a result, cost indices come into existence.

A cost index is, essentially, a numerical interpretation of the incremental cost changes which have been recorded for a cost element over a period of time, and through its use, one can convert the price in 1975 to the price in 1980, for example, by means of a simple formula:-

$$\frac{\text{Cost in 1980}}{\text{Cost in 1975}} = \frac{\text{Index for 1980}}{\text{Index for 1975}}$$

The above formula permits fairly accurate estimates if the time period involved is less than 10 years. This is due to oil crisis in 1973, when the prices of commodity went up very steeply.

Many different types of cost indices are published regularly and a few articles (49,50,51) have given a very good description of derivation of cost index. The most common of these indices in USA and UK are summarized in Table 4.13.

4.4.1 Engineering New-Record Construction Cost Index (52)

This index is mainly applicable to civil engineering work as it is based entirely on labour rates and materials costs for industrial construction. So, it is relevant only for the construction components of process plants. It employs the following components:-

(a) 2500 lb structural steel

(b) 1088 fbm lumber (where fbm = ft board measure)

(c) 6 bbl cement (where bbl = barrel)

(d) 200 mh common labour (where mh = man-hours)

4.4.2 Nelson Refinery Construction Cost Index (53)

This index is totally based on construction costs in the petroleum industry. The total index percentages are weighted as follows:-

Table 4.13 Cost Indices - Process Plant And Equipment (Base: 1970 = 100)

Year	Engng. News-Record Constr. (ENR) Index	Nelson Refinery (NR) Constr, Index	M & S Installed-Equipment Index	Chem. Eng. (CE) Plant Constr. Cost Index	Process Engng. (PE) Plant Cost Index	Process Econ. Int. (PEI) Plant Cost Index	
						UK	USA
1965	71	72	81	83	77		
1966	74	75	83	85	82		
1967	79	78	87	87	83		
1968	84	83	90	90	88		
1969	93	91	94	95	93		
1970	100	100	100	100	100	100	100
1971	115	111	106	105	109	109	106
1972	129	122	109	109	119	119	110
1973	140	129	113	115	130	131	115
1974	151	144	131	132	158	160	133
1975	162	158	146	145	210	206	140
1976	174	162	156	153	248	247	148
1977	196		167	162	282	265	162
1978			180	174	306	303	177
1979			198	190	343	338	196
1980			217	208	406	385	219

40% Of Material		60% Of Labour	
Iron & Steel	60%	Common	50%
Building Material	20%	Skilled	50%
Miscellaneous Equipment	20%		
	100%		100%

4.4.3 Marshall And Swift Equipment Cost Indexes (54)

They consist of the all-industry equipment index and the process-industry equipment index. The former represents the arithmetic average of the indices for 47 different types of industrial, commercial, and housing equipment, and the latter is just a weighted average of eight of these, with the weighting based on the total product value of the various process industries. Percentages used for the weighting in a typical year are:-

Industry	Percentage
Cement	2
Chemical	48
Clay product	2
Glass	3
Paint	5
Paper	10
Petroleum	22
Rubber	8
	100

4.4.4 Chemical Engineering Plant Construction Cost Index (49,55)

Construction costs for chemical plants form the basis of the Chemical Engineering plant construction cost index. The four major components of this index, with the percentage weighting respectively, are:-

(a)	Equipment, machinery and supports	61%
(b)	Erection and installation labour	22%
(c)	Buildings, materials and labour	7%
(d)	Engineering and supervision manpower	10%
		100%

As equipment, machinery and supports occupy the largest weight percentage, it is further split into the following sub-components with their respective weighting:-

(a)	Fabricated equipment	37%
(b)	Process machinery	14%
(c)	Pipe, valves and fittings	20%
(d)	Process, instruments and controls	7%
(e)	Pumps and compressors	7%
(f)	Electrical equipment and materials	5%
(g)	Structural supports, insulation and paint	10%
		100%

4.4.5 Process Engineering Plant Cost Index

The Chemical and Process Engineering Journal (now Process Engineering) introduced the index initially in 1964. The weighting of the various factors was changed

(56) in 1973 and the present formula is:-

$$I = (0.37)M + (6.08)E + (0.10)C + (0.19)S + (0.26)O$$

where I = PE Plant Cost Index

M = Mechanical Engineering

E = Electrical Engineering

C = Civil Engineering

S = Site Engineering

O = Overheads

The respective indices for M,E,C,S, and O are published monthly as well as annually by the Official Agency, Central Statistical Office, in UK.

4.4.6 Process Economics International Plant Cost Indices

Bluck (57) has reported that a cost index based on a simple weighting:-

$$I = (0.60)(\text{Labour Index}) + (0.40)(\text{Material Index})$$

This formula has, in fact, been adopted for the EPE cost indices published by a recent journal, Engineering and Process Economics, (58) started in 1976. These indices are based on a labour : steel weighting of 70:30 and being published for 15 countries. But, these indices have recently been transferred to more recent journal, i.e. Process Economics International (59) started in 1979, and are now known as PEI cost indices, which are being published for 33 countries; only UK and USA PEI cost indices are given respectively in Table 4.13. Obviously, these indices are advantageous in offering an international comparison on a uniform basis.

4.4.7 Indices Comparison

Table 4.13 gives comparative data on various indices described above with base year taken as 1970 for the sake of comparison. If UK indices are excluded for a moment, it becomes obvious that ENR cost index rises faster than the rest. It is because its basis is for civil engineering work only, which rises very rapidly in the cost of construction. For USA conditions, in general, labour wages are rising much faster than material cost and further, the construction labour wage is rising faster than the shop labour wage. The CE Cost Index agrees fairly closely with M & S Cost Index as both based on industrial equipments to certain extents. NR Cost Index is somewhat higher than the CE and M & S Cost Indices. This may be due to the fact that refineries have a higher field construction element and field costs are rising faster than shop costs.

It is interesting to note that the UK indices have been rising much faster, particularly lately, than the USA indices regardless of various components basis. In view of this, the British manufacturers face the problems such as market forces, delivery commitments, the decline in the value of Sterling, etc., which have caused the equipment and plant costs to rise at a substantially higher rate.

4.4.8 Suggested Cost Index For Pyrometallurgical Industry

Notice in Table 4.13 that the PEI cost index for USA is in close agreement with the CE Cost Index and also, the PEI cost index for UK has remarkably close agreement with the PE Cost Index although they have a very simple labour:steel weighting of 70:30. If this is the case, then the more complicated weighting in PE and CE Cost indices may have no advantage. Thus, there is much merit to adopt PEI Cost Index for pyrometallurgical industry.

In conclusion, all the indices described above are based on an assumption of splitting up of the process plant and represents a weighted index using official cost indices of various components. Hence, they completely ignore the magnitude and effect of market forces, e.g. supply and demand. No index can reflect a technological change or breakthrough. Also, it normally cannot and does not account for learning curve, improvement in construction technique and major productivity change. Nevertheless, they do give fairly accurate cost escalation for capital forecasting.

4.5 Breakdown Of Fixed-Capital-Investment Items For A Non-Ferrous Metal Production Process

As mentioned in the preceding section a check list of items (Table 4.1) is an invaluable aid in making a complete estimation of the fixed capital investment. Therefore, each cost item is discussed in order to understand their significance as well as contribution towards fixed-capital-investment cost. They are presented in the order as shown in Table 4.1.

4.5.1 Purchased Equipment

The cost of the purchased equipment is the basis of several pre-design methods (23,23,25) for estimating fixed capital investment. Generally, the purchased equipment are divided into three groups: (i) process equipment, (ii) raw-materials handling and storage equipment, and (iii) finished-products handling equipment.

There are normally three sources of obtaining equipment costs: (i) from fabricators or suppliers, (ii) from estimator's file of past purchase orders, and (iii) from published cost data. The first source is the most accurate. The second source is required to update the equipment costs to current costs by an appropriate cost index. The third source will be described in detail as the first and second sources are self-explanatory.

Cost data on the third source are widely scattered in the literature and often require considerable time to find. And even when cost data are found for the equipment one is interested in, costs may not be given for units of the sizes one wants. Moreover, inflation rapidly renders cost data obsolete. Much work has been done in trying to overcome these problems (13,22,60,61). In general, these approaches attempt to compensate for size and time differences.

Factor That Scales Up Size

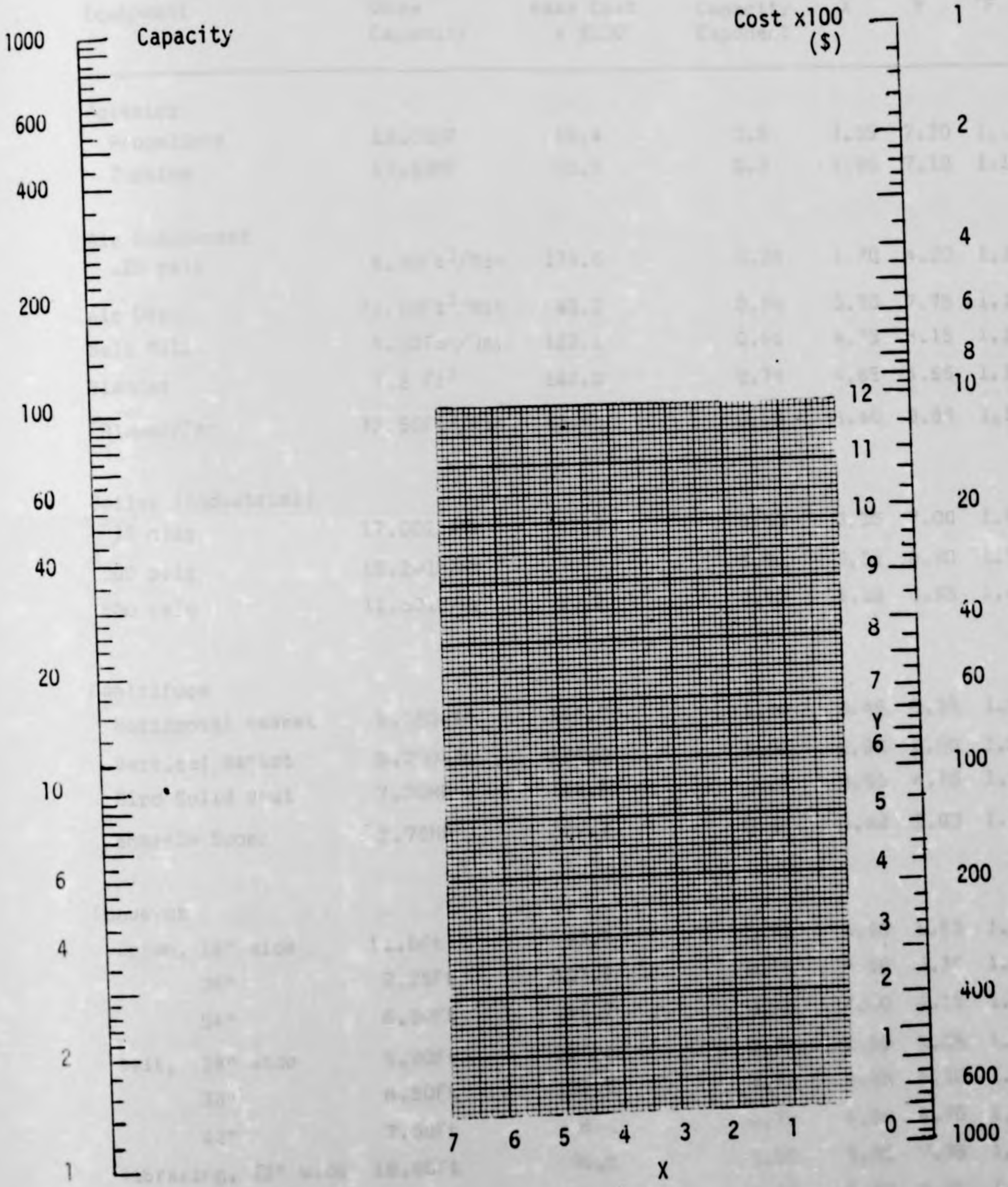
A variety of technique has been derived to correlate the cost of equipment with a capacity factor. The capacity factor may be based on geometry (basket diameter for a centrifuge), design parameter (heat transfer area for a dryer), energy requirement (horsepower for an agitator) or production rate (tons/hour for a crusher).

The normal procedure of this type involves plotting, on log-log coordinates, the available cost values against the capacity factor, with the rectangular grid coordinates X and Y in between. This type of plotting is known as Nomograph, which is shown in Figure 4.11 and is used in conjunction with Table 4.14, which has been compiled for pyrometallurgical industry. However, the data compiled here is far from sufficient for definitive or detailed estimates to be carried out for the non-ferrous metal production processes, but merely add to the data bank for future research (see Chapter 10).

4.5.2 Purchased-Equipment Installation

The installation of equipment involves costs for labour, foundations, structures (i.e. supports, ladders and platforms), insulation and painting. Table 4.15 shows percentage variation of the breakdown of installation cost as a percentage of the purchased equipment cost.

Figure 4.11 Nomograph for Process Equipment



Basis : 1980 Cost Data

Table 4.14 Nomograph Co-Ordinates For Equipment (62)

Equipment	Base Capacity	Base Cost x $100	Capacity Exponent	X	Y	+F
Agitator						
Propellers	18.00HP	58.4	0.5	3.35	7.20	1.12
Turbine	17.50HP	60.7	0.3	1.90	7.10	1.12
Air Compressor						
125 psig	6.30Ft^3/Min	174.6	0.28	1.70	4.20	1.11
Air Dryer	21.00Ft^3/Min	48.2	0.56	3.70	7.75	1.10
Ball Mill	8.50Ton/Day	122.1	0.65	4.75	5.15	1.10
Blender	7.2 Ft^3	148.0	0.78	4.85	4.65	1.12
*Blower/Fan	32.50Ft^3/Min	32.6	0.68	4.40	8.85	1.10
Boiler (Industrial)						
15 psig	17.00lb/Hr	62.1	0.50	3.35	7.00	1.40
300 psig	15.20lb/Hr	70.3	0.58	3.35	6.90	1.40
600 psig	11.50lb/Hr	93.2	0.62	4.10	5.95	1.40
Centrifuge						
Horizontal Basket	9.25D-In	114.7	1.16	6.45	5.35	1.57
Vertical Basket	8.25D-In	124.3	1.00	5.80	5.00	1.57
Bird Solid Bowl	7.30HP	145.8	0.38	3.50	4.70	1.27
Sharple Super	2.78HP	387.7	0.68	4.40	2.00	1.22
Conveyor						
Apron, 18" wide	11.0Ft	93.2	0.70	4.50	5.95	1.20
36"	9.25Ft	113.9	0.70	4.50	5.35	1.20
54"	6.60Ft	165.7	0.70	4.50	4.35	1.20
Belt, 18" wide	9.90Ft	107.3	0.78	4.80	5.55	1.25
36"	8.50Ft	124.3	0.78	4.85	5.10	1.25
42"	7.30Ft	146.5	0.78	4.80	4.70	1.25
Vibrating, 12" wide	18.80Ft	56.2	1.00	5.80	7.35	1.15
18"	12.50Ft	85.1	1.00	5.80	6.20	1.15
26"	10.20Ft	106.5	1.00	5.80	5.60	1.15

cont'd

Screw, 9" wide	13.10Ft	79.9	0.80	5.00	6.35	1.10
12"	12.40Ft	85.1	0.80	4.95	6.20	1.10
16"	11.00Ft	99.1	0.80	4.95	5.80	1.10
Crane						
Span, 10'	6.25T	177.6	0.60	3.90	4.20	
30'	3.80T	279.7	0.60	3.95	2.90	
50'	2.58T	426.2	0.60	3.95	1.75	
100'	2.15T	503.1	0.60	3.95	1.30	
Crusher						
Cone	7.40T/Hr	143.5	0.85	5.25	4.75	1.08
Gyratory	14.30T/Hr	75.5	1.20	6.75	6.55	1.08
Jaw	12.00T/Hr	88.0	1.20	6.80	6.10	1.08
Pulverizer	21.40T/Hr	48.8	0.35	2.40	7.90	1.10
Dryer						
Pan	6.75Ft^2	161.3	0.59	4.00	4.45	1.25
Rotary	4.60Ft^2	233.8	0.55	3.75	3.35	1.25
Drum	3.75Ft^2	285.6	0.68	4.20	2.80	1.60
Elevator						
Bucket, 5"x4"	17.00Ft	62.1	0.46	3.10	7.05	1.35
16"x8"	12.80Ft	83.6	0.46	3.10	6.25	1.35
Filter						
Plate & Press	15.20Ft^2	71.0	0.58	3.90	6.70	1.80
Pressure Leaf, wet	16.00Ft^2	65.8	0.49	3.40	6.95	1.65
Pressure Leaf, dry	7.70Ft^2	136.1	0.44	3.05	4.85	1.65
Hydraulic Press						
100 psig	2.90Ft^2	370.0	0.95	5.60	2.10	1.78
1000 psig	2.00Ft^2	532.7	0.95	5.70	1.10	1.78

cont'd

Mill						
Bill	10.50T/Hr	100.6	0.65	5.30	5.75	1.78
Roller	2.80T/Hr	378.8	0.65	4.35	2.00	1.78
Hammer	7.60T/Hr	139.1	0.85	5.25	4.80	1.78
Mixer						
Propeller	16.80HP	62.9	0.60	3.95	7.00	1.38
Turbine	11.80HP	91.0	0.30	2.00	6.00	1.38
Mixer/Blender						
Horizontal Ribbon						
1-2T	11.00T	98.4	0.40	2.75	5.80	
3-5T	6.25T	177.6	1.10	6.20	4.20	
Scrubber, FRP						
2000-400CFM	16.00CFM	66.6	0.20	1.05	6.90	
5000-35,000CFM	10.00CFM	104.3	0.70	4.55	5.65	

* Divide cost from Nomograph by 10

\+ Mulitply cost from Nomograph by F to obtain "installed cost"

Table 4.15 Installation Cost Breakdown For The Purchased-Equipment Cost (13,48)

Component	Range, %	Mean, %
Labour	5-35	20
Foundations	4-12	8
Structures	3-7	5
Insulation	0-4	2
Painting	1-3	2

This is based on the analyses of the total installed costs of equipment in one of the non-ferrous metal smelting processes (48). Therefore, installation costs for equipment are estimated to vary from 13-61% of the purchased-equipment cost. The last column in Table 4.14 presents the installed cost factor for various types of equipment. An average value of 32 percent of purchased equipment is taken to estimate the installation cost.

4.5.3 Instrumentation And Controls

Major offline items, sensing devices, control devices, control panels and panel-mounted instruments are made up of instrument costs. In addition, installation-labour costs and field assembly material are included for instrumentation and controls. Total instrumentation cost may vary from 6-30% of the purchased cost for all equipment depending on the amount of control required.

For the non-ferrous metal smelting processes, an average value of 7 percent of the purchased equipment is normally used to estimate the total instrumentation cost (48).

4.5.4 Electrical Equipment And Materials

The electrical equipment cost consists of power distribution and control, power feeders and motor runs, lighting, communication, grounding and cathodic protection, and pole lines. And the cost for electrical installations consists primarily of installation labour and materials. Table 4.16 shows that four major electrical-installation components costs as percentage of total electrical cost. An average value of 10 percent of purchased equipment is taken to estimate the electrical installation cost (48).

Table 4.16 Electrical-Installation Component Costs As Percentage Of Total Electrical Cost (13)

Component	Range,%	Median, %
Power wiring	25-50	40
Lighting	7-25	12
Transformation and service	9-65	40
Instrument control wiring	3-8	5

4.5.5 Material Handling And Storage

Conveyor system, launder, overhead crane and hopper are made up of materials and installation-labour costs, whereas mobile equipment consists of only equipment costs. They constitute the major portion of the capital cost required for material handling and storage. But for the purpose of cost modelling they are included in the purchased equipment instead of taking this cost as a percent of purchased-equipment cost, in this case zero.

4.5.6 Piping And Process Gas Handling

The cost for piping covers labour, valves, fittings, pipe, supports and other items involved in the complete erection of all piping. This piping is not used for transporting raw-material, intermediate product or finished product but for transporting steam, water, air, oxygen, fuel oil, gas and sewer. For the normal chemical processing plant, the process-plant piping can run as high as 100 percent of purchased-equipment cost, but for non-ferrous metal processing plant, the piping cost only represents approximately 5 percent of purchased-equipment cost (48).

Water-cooled hoods, flue system, installation labour and materials constitute the costs for process gas handling. Fugitive emmisions from smelting vessels are captured at their sources to reduce risk of health impairment of the operating personnel. This cost accounts 5 percent of purchased-equipment cost (48).

4.5.7 Service Facilities

Service facilities consist of two cost components - services and utilities. Services represent all the remaining items of direct investment that are necessary for a fully operating unit. It includes laboratories, shops and lunchroom, changes houses, gatehouses, waste disposal, fire protection, storage area, etc. Utilities refer in general, to the production of energy and its transportation to and from the battery limit as well as to other buildings on the plant site. It consists of compressed-air plant; electric power supply; water supply including pumps; cooling tower and outside water lines; fuels, chemical, gas and oxygen supply, etc. All these services facilities account for an average value of 49 percent of the purchased-equipment cost (48).

4.5.8 Buildings Including Services

Costs for heating, lighting, plumbing, ventilation, and other building services are included in buildings cost, which consists of expenses for labour, materials, and supplies involved in the erection of all buildings connected with the plant. An average value of 30 percent of purchased-equipment cost is considered for buildings including services (48).

4.5.9 Yard Improvements

Yard-improvements cost includes demolition, cleanup, grading, roads, sidewalks, railroad sidings, fencing, and landscaping and accounts for approximately 11 percent of the purchased-equipment cost for the non-ferrous metal smelting plants. Table 4.17 shows the range in variation for various components of yard improvements in terms of the fixed capital investment.

Table 4.17 Typical Variation In Percent Of Fixed Capital Investment For Yard Improvements (13)

Yard Improvement	Range, %	Median, %
Site clearing	0.4-1.2	0.9
Roads and walks	0.2-1.2	0.6
Railroads	0.3-0.9	0.6
Fences	0.1-0.3	0.2
Yard and fence lighting	0.1-0.3	0.2
Parking areas	0.1-0.3	0.2
Landscaping	0.1-0.2	0.1
Other improvement	0.2-0.6	0.4

4.5.10 Land (13)

The price of land plus surveys and fees are made up of land cost, which varies considerably from site to site. As a rough approximation, land cost is taken to be 1-2 percent of fixed capital investment or 4-8 percent of purchased-equipment cost. As land cost does not depreciate with time, this cost should not be included in the fixed capital investment when estimating annual production costs.

4.5.11 Engineering And Supervision

The costs for project management, process engineering, design and drafting, procurement, construction services, general services and their respective supervision constitute the capital investment for engineering and supervision. This cost, since it cannot be directly charged to equipment, materials or labour, is normally considered an indirect cost in the fixed capital investment and is approximately 33 percent of the purchased-equipment cost. Table 4.18 shows the mean value as a percentage of purchased-equipment cost for various components of engineering and supervision.

Table 4.18 Mean Value As A Percentage Of Purchased-Equipment Cost For Engineering And Supervision (13)

Component	Mean, %
Project management	2.8
Process engineering	8.0
Design and drafting	15.0
Procurement	4.5
Construction services	1.6
General services	2.2

4.5.12 Construction Expenses

Another indirect plant cost is under the item of construction or field expense, which includes construction equipment, temporary facilities, craft benefits, payroll burdens, field supervision, and other construction overhead. Table 4.19 shows breakdown of construction expense components with percentage variation in the fixed capital investment. For non-ferrous metal smelting plants, an average value of 9 percent of the fixed capital investment or 39 percent of the purchased-equipment cost is considered.

Table 4.19 Typical Variation In Percent Of Fixed Capital Investment For Construction Expense (13)

Component	Range, %	Median, %
Temporary facilities	1.5-3.0	2.3
Construction equipment	2.0-6.0	4.0
Craft benefits	1.6-3.3	2.5
Payroll burdens	0.5-5.0	2.8
Field supervision	0.2-2.0	1.1
Miscellaneous	0.3-0.8	0.5
Total construction expense	6.0-14.0	10.0

4.5.13 Contractor's Costs

Contractor's costs are made up of contractor's fee or profit margin and contingencies.

The contractor's fee varies according to complexity of the project, but is normally estimated to be 5 percent of the direct and indirect plant cost or 18 percent of the purchased-equipment cost (13).

The contingencies are an important factor in cost estimates to compensate for unpredictable circumstances, such as accidental events, change in general economic conditions, imperfections of estimating methods, small design changes, and oversights. Depending on the length of time for the project and the risks involved in the country where the plant is to be built, contingency factor can range from 8-20% of the direct and indirect plant costs, with 10 percent being considered a fair average value (13).

4.5.14 Interest During Construction

A charge should be made of the "idle" capital during the construction period, i.e. interest should be charged on the amount disbursed at the rate provided for under the terms of the loan. Average interest rate on capital during construction for 1980 is taken to be 12 percent of the direct and indirect plant cost or 39 percent of the purchased-equipment cost. For the sake of argument, a simple interest rate on $M200 loan is taken to be 20%, and the plant takes two years for construction completion, then the average interest can be calculated as follows:-

<u>Amount Disbursed At ½ A Year At A Time</u>

½ year, $\$50\text{x}10^6\text{x}.10 = 5\text{x}10^6$

1 year, $\$(50+50)\text{x}10^6\ \text{x}.10 = 10\text{x}10^6$

1½ years, $\$(100+50)\text{x}10^6\ \text{x}.10 = 15\text{x}10^6$

2 years, $\$(150+50)\text{x}10^6\ \text{x}.10 = 20\text{x}10^6$

Total interest $= 50\text{x}10^6$

<u>Amount Disbursed All At A Time</u>

$\$200\text{x}10^6\ \text{x}.20\text{x}2 = \$80\text{x}10^6$

i.e. total interest $= \$80\text{x}10^6$

$\therefore$ Average interest rate $= \dfrac{50\text{x}10^6}{80\text{x}10^6}\ \text{x}\ 20\% = 12.5\%$

4.5.15 <u>Start-up Expense</u> (13)

There are a number of expenses to be made before the plant can operate at maximum design conditions, such as costs of training the operating staff, changes in materials and equipment for part of the original design, etc. These expenses may range from zero to as high as 12 percent of the fixed capital investment depending on quality of design, etc. In general, an allowance of 7 percent of the fixed capital investment or 31 percent of the purchased-equipment cost for this item is satisfactory. The average percentage values of purchased-equipment cost are all summarized in Table 4.12.

4.6 Conclusion

The purpose of this chapter has been for the reader and myself to get familiarized with the existing five levels of cost estimates according to quality and quantity of information available for the non-ferrous metal smelting industry. Several popular cost indices have been reviewed and PEI Cost Index was chosen for the reason given in sub-section 4.4.8 to update the cost data.

An attempt to breakdown the fixed capital investment items for a non-ferrous metal smelting process is given; each item is allocated with an average percentage value of the purchased-equipment cost (i.e. ratio factor). The average ratio factors are derived from several references, i.e. 13,19, and 48, and they are summarized as shown in Table 4.12, with calculated overall Lang factor = 4.45. The average ratio factors are good enough to be incorporated into the cost model, which is going to be derived in Chapter 5, as a constant factor.

Provided detailed flowsheets and process information are available, preliminary, definitive and detailed estimates can be performed by the experienced estimators. As detailed information is highly confidential and do not exist in the literature, no attempt is made to these cost estimates for the non-ferrous metal smelting industry. However, they are reviewed here in order that the techniques of detailed estimating and accuracy-information relationship which exist, may be understood to assist in the research.

Three rapid cost estimating methods described as order of magnitude estimates are reviewed and they are useful for quick guidance of investment decision. However, they are unfortunately, not suitable for novel projects assessment.

Finally, several methods except Bridgwater's method are applicable to chemical and petrochemical industries and they have been reviewed under study estimates. They are all directed at pre-design cost estimating situations and prepared from limited amount of flowsheet and process information. As such, the methods within the estimate classification groups are of particular interest for the research. Therefore, a cost model will be derived based on study estimates.

CHAPTER FIVE

DEVELOPMENT OF CAPITAL COST ESTIMATION MODEL

Having reviewed the technological background and the elements of cost estimation for the non-ferrous metal smelting industry, it is necessary to state the conditions of the cost model being developed as follows:-

1) The basic requirements of the cost model.
2) Identification and selection of those factors which influence the fixed capital investment.

The conditions are discussed in detail and then they are incorporated into the cost model.

5.1 The Basic Cost Model Requirements

The two basic requirements of the cost model being derived are as follows:-

1) The estimates should be accurate within certain limits that are acceptable for screening alternatives at pre-design stage.
2) The model should require a limited amount of process information and flowsheet for quick estimates.

Each is described as follows.

5.1.1 Estimate Accuracy

Nichols (1) has first made use of five levels of estimate as defined by AACE to relate accuracy as a function of available information and showed graphically the relationship between probable accuracy and quantity and quality of information as in Figure 5.1, which shows an envelope of variability. Nichols further pointed out there is a high probability that the actual cost will be more than the estimated cost and that the positive spread is likely to be wider than the negative, eg. +40 and -20 percent for a study estimate. This phenomenon has been supported by Bauman (2).

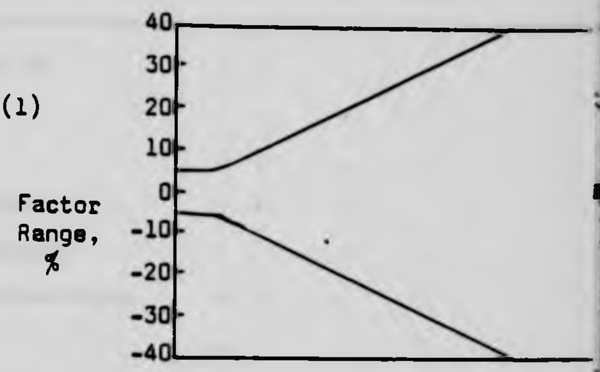
Nevertheless, from the literature survey, it was noted that the conventional way of expressing accuracy as an error range of ± X% of the actual investment still persists in recent estimating methods. Till Allen and Page (3) challenged the assumption by considering that the limiting error can range from -100% to ∞ % and that these extremes are of equal significance. They derived a relationship between equally significant errors of $+X_1\%$ and $-X_2\%$ as

$$X_1 = 100X_2/(100 - X_2)$$

$$X_2 = 100X_1/(100 + X_1)$$

The results from the relationship are presented graphically in Figure 5.2. Thus, it can be seen that at low errors, X_1 and X_2 are approximately equal, but as errors increase, the value of X_1 becomes greater and greater than the value of X_2. The logic behind this approach is accepted and will be used in this thesis. As the studies by Nichols gave first indication of the accuracy levels according to the quantity

Figure 5.1 Nichols Probable Accuracy Versus Information Envelope (1)



		Detailed Estimate ±5% Range	Definitive Estimate ±10% Range	Preliminary Estimate ±20% Range	Study Estimate ±30% Range	Order Of Magnitude Estimate >±30% Range
Site	Location	•	•	•	•	
	General description	•	•	•		
	Soil bearing	•	•	•		
	Location & dimensions R.R., roads, impounds, fences	•	•	•		
	Well-developed site plot & topographical map	•	•			
	Well-developed site facilities	•				
Process Flowsheet	Rough sketches				•	
	Preliminary			•		
	Engineered	•	•			
Equipment List	Preliminary sizing & material specifications			•	•	
	Engineered specifications	•	•			
	Vessel sheets	•	•			
	General arrangement, (a) Preliminary		•	•		
	(b) Engineered	•				

cont'd

Building And Structures	Approximate sizes & type of construction			●	●
	Foundation sketches		●	●	
	Architectural & construction	●	●	●	
	Preliminary structural design			●	
	General arrangements & elevations	●	●		
	Detailed drawings	●			
Utility Requirements	Rough quantities (steam, water, electricity, etc.)				●
	Preliminary heat balance			●	
	Preliminary flowsheets			●	
	Engineered heat balance	●	●		
	Engineered flowsheets	●	●		
	Well-developed drawings	●			
Piping	Preliminary flowsheet & specifications			●	●
	Engineered flowsheet	●	●		
	Piping layouts & schedules	●			
Insulation	Rough specifications			●	
	Preliminary list of equipment & piping to be insulated		●		
	Insulation specifications & schedules	●	●		
	Well-developed drawings or specifications	●			
Instrumentation	Preliminary instrument list			●	
	Engineered list & flowsheet	●	●		
	Well-developed drawings	●			

cont'd

Electrical	Preliminary motor list - approximate sizes			•	•	
	Engineered list & sizes	•	•			
	Substations, number & sizes, specifications	•	•	•		
	Distribution specifications	•				
	Preliminary lighting specifications			•		
	Preliminary interlock, control, & instrument wiring specification		•			
	Engineered single-line diagrams (power & light)	•	•			
	Well-developed drawings	•				
Man-hours	Engineering & drafting	•	•	•	•	
	Labour by craft	•				
	Supervision	•				
Project Scope Standard Processes	Product, capacity, location & site requirements. Utility & service requirements. Building & auxiliary requirements. Raw materials & finished product handling & storage requirements.					•

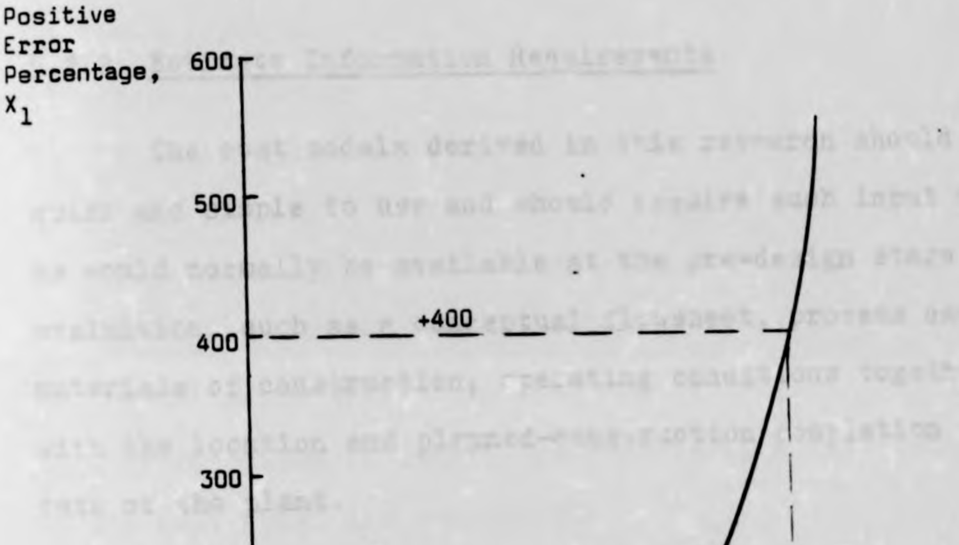


Figure 5.2 Curve Of Percentage Errors Relationship

and quality of information (see Figure 5.1), it is expected to achieve +30% to -25% at the study level of estimating being attempted in this thesis. These accuracy limits, +30% to -25% are considered to be adequate whether or not a proposed project should be given further consideration and to compare alternative designs (1,2,4).

5.1.2 Estimate Information Requirements

The cost models derived in this research should be quick and simple to use and should require such input data as would normally be available at the pre-design stage of evaluation, such as a conceptual flowsheet, process capacity, materials of construction, operating conditions together with the location and planned-construction completion date of the plant.

The information requirements are best met by estimates that are calculated as simple mathematical models, and study estimates (as described in sub-section 4.3.3) are well suited to this form of representation.

The cost models derived are incorporated into computer programs written in BASIC, which can generate the necessary analytical information in a fraction of a minute instead of a day normally required, and thereby allow the evaluator to concentrate upon his primary functions of analysis and interpretation.

5.2 Identification And Selection Of Those Factors Which Influence The Fixed Capital Investment

A thorough review of the literature (see Chapter Two to Four) has shown that a number of variables or factors can be identified to influence the fixed capital investment. They are:-

1) Process size
2) Recycle factor
3) Modular Equipment steps
4) Lang factors
5) Process materials of construction
6) Process operating conditions
7) Location effects

Each is described in detail and their merits for inclusion in the cost model are considered.

5.2.1 Process Size

The capital cost is related with process size. Previous research workers (see sub-section 4.4.3) have attempted to define and represent process size in their estimating methods. Basically, process size can be consistently defined and measured by means of mass balance information. Nevertheless, another approach is to represent process size based on materials flows in a variety of ways; either as process feed (input), process throughput, or process capacity (output). They are measured either on a weight or volumetric basis.

5.2.1.1 Process Feed

Generally, processes are designed to produce a specified capacity, but they are sometimes specified to handle a certain quantity as feed, eg. waste disposal processes and gas cleaning processes. Hence, a relationship between capital cost and process feed for such plants can be established.

However, besides the two above mentioned applications, the use of process feed is not suitable for pre-design cost estimation for the reasons given as follows:-

(a) Complex mixture of unknown composition needs to be determined, which is often difficult. Examples of such feeds include crude oil and mineral ores.

(b) Process feed is not often a practical means of representing process size unless process development is at its advanced stage and mass balance calculations have been performed.

5.2.1.2 Process Throughput

Process throughput is a true measure of the material flows within the plant. Consequently, it has led to a few of the researchers attempting to define process throughput and incorporating it into their cost models in order to improve better accuracy. Nevertheless, it poses difficulty to define what exactly process throughput means.

Allen and Page (5) have defined process throughput as a product function of process feed, flow factor and phase factor (see sub-section 4.3.3.3.2). This can provide quite accurate throughput, but it does require complete process flowsheet showing number of input and output process streams of each main plant item. Bridgwater (6) has postulated the process throughput as a function of process capacity, Q and "conversion" factor, S on mass basis, i.e. throughput = $Q/S^{0.5}$, where S is determined by mass balance on the reactor. And Gore (7) has two ways of calculating process throughput. He either obtained process throughput by multiplying the process capacity by a "recycle factor", which was derived empirically from the gas-phase processes he studied or by averaging the two quantities: number of lb moles of feed reactants and recycle, and number of lb moles of product and recycle. It was noted that the derivation of recycle factor is not described and therefore, it should be treated with caution.

Generally, process throughput is defined as average throughput, either as arithmetic, weighted or logarithmic average per unit time of the total feed plus recycle flows within the plant. It requires detailed flowsheets and mass balance and therefore, is not suitable for pre-design cost estimation.

5.2.1.3 Process Capacity

Of all the three alternatives, process capacity is the most popular employed in cost estimating model because:-

(a) Most processes are designed to produce a given output, which is always known right from the conceptual design development stage.

(b) It requires no mass balance information and therefore, is suitable for conceptual type screening study work.

For this thesis, process capacity is defined as the quantity of product(s) produced at its optimum operation (i.e. defined as the maximum production capacity that could be achieved without further installation of fixed-capital investment items, such as equipment and service facilities) in a given time and based on the following conditions:-

(a) Product is hereby defined as Copper, Zinc, Lead and Tin.

(b) A standard operating year of 330 days is adopted.

(c) For multi-product process, eg. Zn-Pb Imperial Smelting Process, total capacity is taken.

5.2.1.4 Weight Or Volumetric Basis

At the beginning of this section, we have mentioned the process material flowrates are either measured on:-

(a) Weight or

(b) Volumetric basis

On reflection, it will be apparent that the larger the material volume flow within the plant, the larger the equipment volumes and thus the cost. Then, volumetric basis would seem to be more representative than weight basis to assess relative process sizes. Nevertheless, this is only true for gas phase process where volume/mass ratios are often significantly higher than liquid or solid phase process. Besides, the calculation of material volumes can be troublesome especially in situations where the required physical property data, such as temperature, pressure, density and molecular weight is not available. Therefore, for solid-liquid phase and high density processes, such as non-ferrous metal smelting processes, the weight basis as units of measurement is more suitable and indicative than volumetric basis and hence, it will be adopted in the thesis.

5.2.1.5 Relationship Between Capital Cost And Process Capacity

As noted from sub-section 4.3.2.3, there is a general relationship between capital cost and process capacity known as cost-capacity exponential method, from which it leads to the development of multiplicative type of model, such that:-

$$C = Q^b . f(x)$$

where C = capital cost
Q = process capacity
b = capacity exponential factor
$f(x)$ = other relevant variables or factors

There are a few methods to determine b. The first is an overall exponential method adopted by most previous researchers or estimators, and the earlier applications of the methods were mostly based on six-tenth power law for many types of processes. It is crude and inaccurate as each capacity exponential factor can vary from 0.3-1.0 from process to process. However, accuracy can be improved by cost-capacity correlation, where b is determined for each specific process.

The second method is due to Timms (4), in which accuracy can be improved by limiting the use of an average capacity exponential factor to processes operating in the same phase. Examination of the literature has revealed that equipment designed to process gaseous and liquid material have much lower cost-capacity exponents than those designed to handle solid phase material, and Timms suggested three average values for an equipment capacity exponent depending on the process phase of operation:-

(a) Volumetric (gas) - average component = 0.61(0.4-0.68)
(b) Liquid - average exponent = 0.63(0.55-0.75)
(c) Solid - average exponent = 0.75(0.7-0.9)

and he provided a formula for any type of process

$$\text{Capacity exponential factor} = \frac{N_g.x + N_1.y + N_s.z}{N}$$

where N_g, N_1, N_s = number of gas, liquid and solid functional units
x, y, z = gas, liquid and solid phase exponent
N = total number of functional units ($=N_g+N_1+N_s$)

However, the three average values are suspect as the data used to derive them is limited.

The final method was given by Allen and Page (5) who proposed a cost-weighted exponent, such that:-

$$EXP = \sum_{i=1}^{N} c_i e_i / \sum_{i=1}^{N} c_i$$

where EXP = overall plant exponent (capacity exponential factor)

c_i = the base cost of main-plant item i

e_i = the exponent of main-plant item i

N = number of main-plant items

The method is most accurate but requires detailed cost data, Since no equivalent data to relate cost to capacity for non-ferrous metal smelting processes, the concept of deriving individual capacity exponential factor based on cost-weighted exponent method was unable to be carried out. This left the first method of using overall exponent as the method of measuring the cost-capacity relationship. Thus, regression analysis on published cost-capacity data sets was carried out for each non-ferrous metal smelting process and the results of correlation were shown to be significant within 95% confidence limit (see Appendix A). The value of capacity exponent for each process was found to be:-

(a) For Copper process - 0.85

(b) For Zinc process - 0.96

(c) For Lead process - 0.95

(d) For Tin process - 0.93

5.2.2 Recycle Factor

As mentioned in previous sub-section 5.2.1.2, Gore has incorporated his empirically derived recycle factor in process capacity to obtain process throughput, which is claimed to be more accurate representation of materials flow within the process and thus, it gives better accuracy in the cost estimation. Stallworthy's method also developed a correlation based on study of each stream - mainstream, recycle streams and side streams. Nevertheless, the correlation is still based on plant capacity, and includes separate ratio of stream to main stream on a weight basis.

Though the recycle factor or ratio overcomes the assumption that the flows are constant throughput the process especially referring to chemical and petrochemical processes, it means that considerably more information is required. In addition, recycle factor is inappropriate to incorporate into cost model derived for the non-ferrous metal smelting processes as the recycled materials require separate equipment to process (for instance, in a copper smelting process, the Outokumpu Flash furnace or the Noranda Reactor is characterized by the high content of metallics produced in the primary slag. Hence a slag cleaning step is economically justified to recover copper, eg. electric furnace) and thus, its cost has been taken into account by its modular equipment steps. Thus, recycle factor has been rejected for the reasons given above.

5.2.3 Modular Equipment Steps

At the conceptual stage of process development, little information about the non-ferrous metal production process is available. However, basic information which is generally available is the block diagram flowsheet. Unlike the chemical or petrochemical processes, the non-ferrous metal smelting processes consist of not only process steps but also metallurgical sections (see Figure 2.1,2.2,2.3 and 2.4). If Figure 2.1 is examined closely, it is seen that Crushing, Grinding, Smelting, Casting, etc. are examples of process steps, but Charge Preparation, Acid Plant, Copper Refinery and Effluent Treatment are examples of metallurgical sections. Since the process steps or functional units are very different from the metallurgical sections, it is obviously unsuitable to base on block diagram flowsheet which consists of comninations of process steps and metallurgical sections, to count the number of process steps for the cost modelling point of view. Hence, a concept of modular equipment steps is introduced so that consistency in the cost modelling would be achieved. Table 2.1 shows a typical list of modular equipment steps for primary production of copper, lead, lead and tin.

Modular equipment step is defined as all the equipment that is necessary to achieve or serve a function in any process stream and the equipment do not include other direct costs, such as purchased-equipment installation, instrumentation and controls (installed), electrical equipment and materials (installed), piping and process gas handling flues (installed), building (including services), yard improvements, services facilities and land, and indirect costs, such engineering and supervision, construction expenses, contractor's fee, contingency and interest during construction.

Also, the number of units or equipment if they serve the same function or purpose within a metallurgical section are counted as one modular equipment step (eg. there are usually more than two belt conveyors served in the charge preparation section, but they are counted as one modular equipment step). The differences between process steps or functional units and modular equipment steps are as follows:-

1) The process step consists of equipment which is necessary to achieve a chemical or physical transformation of the major stream, or it is a significant piece of plant which carries out an operation on the main process stream within the whole plant whereas the modular equipment step consists of equipment that is necessary to achieve or serve a function in any process stream within a metallurgical section.
2) The process steps include for examples, a distillation column and rotary vacuum filter, but exclude pumps, heat exchangers, reboilers and hoppers which are subsidiary to a unit operation or unit process whereas modular equipment steps include every main plant equipment items.
3) The process steps include not only purchased-equipment cost but also direct and indirect costs whereas modular equipment steps include only purchased-equipment cost in the cost modelling.
4) If there are two distillation columns within the plant, they are counted as two process steps in the process

step approach, but they are counted as one modular equipment step if they serve the same function within a metallurgical section or two modular equipment steps in two different metallurgical sections in the modular equipment step approach.

Table 5.1, which is extracted from Table 2.1, illustrates examples showing the functions of modular equipment steps in a copper process.

The number of modular equipment steps bears a relationship with the total plant cost as follows:-

$$C = N.f(x)$$

There is a strong argument for adopting this approach since it is recognized that N is a crucial variable in calculating plant cost and thus, Table 2.1 is included in order to familiarize oneself with the type of modular equipment steps in a process. And although there are cost differences between different steps, there are averaged out by equi-probability over the process as a whole.

Table 5.1 Example Showing The Functions Of Modular Equipment Steps In A Copper Process

Metallurgical Section	Modular Equipment Step	For The Function Of
Concentrate Handling	Weighing machines	Weighing concentrates.
	Sampling equipment	Chemical analysis.
	Conveyors	Transporting the concentrate to Charge Preparation Section

Metallurgical Section	Modular Equipment Step	For The Function Of
Charge Preparation	Hoppers	Temporary storage of feed.
	Dryers	Drying the concentrates.
	Crushers	Crushing the concentrates into smaller sizes.
	Screens	Separating the appropriate sizes from over- or undersizes.
	Belt-Scale feeders	Proportioning.
	Mixers	Mixing the proportions.
	Pelletizers	Making feed into bullet form.
	Cyclones	Separating the dusts from gases.
	Stacks	Delivering gases to atmosphere.
	Conveyors	Transporting feed materials within the Metallurgical Section and eventually to next section.
Smelting	Hoppers	Temporary storage of feed.
	Blowers	Delivering air and oxygen to the smelting and converting furnaces.
	Charging machines	Feeding to the smelting furnaces.
	Smelting furnaces	Smelting the feed into matte.
	Converting furnaces	Converting matter into blister.
	Slag cleaning furnaces	Recovery of copper from slag.

Metallurgical Section	Modular Equipment Step	For The Function Of
	Cranes, Mobile equipment	Transporting blister and slag.
	Pots, Settlers	Holding liquid metal.
Gas Cleaning	Blowers	Delivering flue gases from the furnaces.
	Cyclones	Separating the dusts from gases.
	Waste heat boilers	Extracting heat from the hot flue gases.
	Baghouses, Cottrell, Electrostatic, Precipitators	Dust elimination.
Water Treatment	Pumps	Delivering the waste waters.
	Neutralizers	Neutralizing the free acid.
	Clarifiers	Separating solids slurry.
	Filters	Filtering the remaining solid suspension.
	Tanks	Temporary storage.
Anode Casting	Holding furnaces	Holding the hot molten metal.
	Anode furnaces	Oxidation and reduction cycles.
	Casting machines	Producing continuous copper strips.
	Stamping presses	Stamping.
	Stacking machines	Assembling stamped copper strips on a rack.
	Mobile equipment	Transporting copper strips to electrolytic refinery.

Metallurgical Section	Modular Equipment Step	For The Function Of
Electrolytic Refinery	Pumps	Circulating electrolytes.
	Cells	Depositing copper onto cathode from anode.
	Cranes	Cathode handling.
	Stripping machines	Stripping.
	Melting furnaces	Melting.
	Casting machines	Producing continuous copper slabs.
	Stacking machines	Assembling refined copper slabs on a rack.
	Mobile equipment	Transporting to warehouse.
Acid Plant	Packed towers	Removing most of the remaining impurities.
	Cooling towers	Cooling the gases.
	Mist precipitators	Complete removal of remaining impurities.
	Drying towers	Removal of all water vapour.
	Blowers	Delivering the gases.
	Converters	Converting SO_2 to SO_3.
	Heat exchangers	Cooling the gases.
	Absorbing towers	Converting SO_3 to H_2SO_4.
	Tanks	Storage.

5.2.4 Lang Factors

In a series of three articles (8,9,10), Lang has attempted to build up average factors for converting delivered equipment costs into total plant cost. Based on his exhaustive examination of the cost distributions for fourteen process plants, Lang concluded that there were three types of processes, each of which requires its own estimating factors as follows:-

(a) For solid phase processes, total plant cost

$$= (\Sigma E)(1.43)(1.10)(1.50)(1.31) = 3.10\Sigma E$$

(b) For solid/fluid phase processes, total plant cost

$$= (\Sigma E)(1.43)(1.25)(1.50)(1.35) = 3.63\Sigma E$$

(c) For fluid phase processes, total plant cost

$$= (\Sigma E)(1.43)(1.60)(1.50)(1.35) = 4.74\Sigma E$$

where the sub-factor 1.43 which is the same for all process types, accounts for foundations, supports, insulation, installation of equipment, chutes and vents; the second sub-factor, which varies with the types of process, allows for the cost of piping (i.e. this sub-factor is least for the solid phase processes and greatest for the fluid phase processes); the third sub-factor accounting for construction, civil engineering, etc. is the same for each process type; the final sub-factor allows for overhead charges.

It is noted that Lang factors can be conveniently combined into direct and indirect cost factors, i.e. the first two sub-factors form the direct cost factor and the last two, the indirect cost factor. With the exception of instrumentation and control, several researchers (10,11,12, 13) have demonstrated that the direct costs, such as installation, electrical systems, pipework, etc. do correlate with delivered equipment costs. Therefore, they can be calculated as percentage values of delivered equipment cost and a direct cost factor can be derived for a particular process. Thus, three direct cost factors are estimated for three types of investment, namely a factor of 2.54 for new plant on new site, 1.99 for new unit on existing site and 1.54 for extension on existing site (14). Table 5.2 shows how three direct cost factors can be estimated.

On reflection, it is apparent that indirect costs per unit size, such as engineering and supervision, construction expenses, etc. decrease directly with the increase in size of the plant. Hence, O'donnel (15) has made use of this phenomenon to correlate the indirect costs with total plant cost. His cost data has been updated by ENR Construction Cost Index to a based year of Mid-1980 and replotted as the indirect cost factors versus direct costs as shown in Figure 5.3 for the purpose of cost modelling. Note that the direct costs are based on carbon steel as the major materials of construction, since the use of alloys or other special materials of construction for equipment will affect the relationship between the indirect cost factors and the direct costs. Thus, total plant cost would be:-

$$C = \text{Direct Costs} \times \text{Indirect Cost Factor} \times \text{Materials Of Construction Factor}$$

From a correlation of indirect cost factor, L_I with direct costs, DC (see Figure 5.3), a regression line is shown to be:-

$$L_I = 2.354 - 0.0543 \ln DC$$

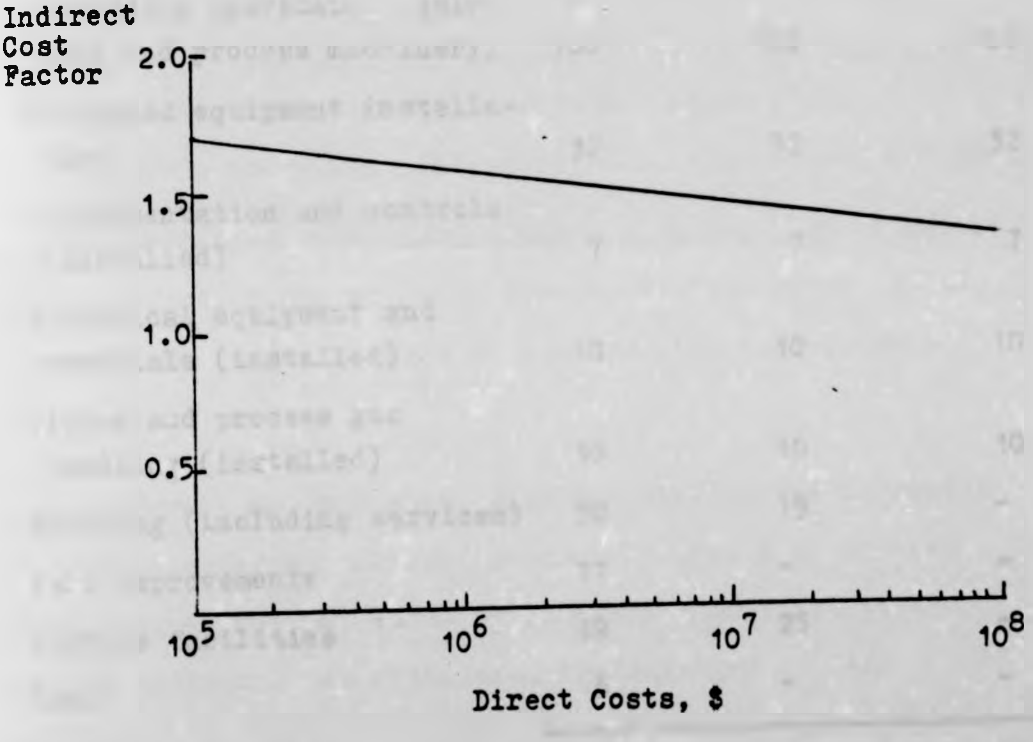


Figure 5.3 Correlation Of Indirect Cost Factors With Direct Costs

Table 5.2 Direct Cost Factors For Estimating Three Types Of Fixed Capital Investment Based On Delivered Equipment Cost

Item	The Fixed Capital Investment For:- New Plant On New Site	New Plant On Existing Site	Extension On Existing Site
Direct Costs			
Purchased equipment-delivered (including fabricated equipment and process machinery)	100	100	100
Purchased equipment installation	32	32	32
Instrumentation and controls (installed)	7	7	7
Electrical equipment and materials (installed)	10	10	10
Piping and process gas handling (installed)	10	10	10
Building (including services)	30	15	-
Yard improvements	11	-	-
Service facilities	49	25	-
Land	5	-	-
Total direct plant cost	254	199	154
The direct cost factor, L_D	2.54	1.99	1.54

5.2.5 Process Materials Of Construction

Fixed capital investment is significantly influenced by materials of construction. Many previous research workers have attempted to incorporate a material of construction factor in their estimating models.

In the early stages of process development, the process materials of construction are either usually known or can be guesstimated from the following information:-

(a) Chemical and physical properties of the process materials handled, eg. density, corrosion, erosion, etc.

(b) Process operating conditions, i.e. temperature and pressures

Perry and Chilton (16) have given a detailed list of materials of construction depending on the information given in (a). However, no cost-materials of construction relationship is given.

Zevnik and Buchanan, Page and Stallworthy attempted to relate materials of construction to (b), i.e. process temperatures and pressures by adopting a multiplicative factor approach. Nevertheless, the validity of this approach was doubtful by Page (17), who recognised that the three variables are dependent on each other. If temperature and/or pressure increase(s) beyong certain level, they may cause a step change in materials of construction, whereas the basic assumption of using a multiplicative approach is that the variables are continuous functions.

Also, if temperature and pressure are included as separate variables in a cost model and should pressure and/or temperature changes are accounted for, they are accounted for twice. This is an argument for not including a materials of construction factor at all if above situation existed. Gore (7), in fact, has neglected the materials of construction factor in his correlation.

However, both information (a) and (b) are equally significant in determining process materials of construction and so, determination of a material of construction factor must be based on these variables, and to attempt to define process materials of construction as a function of both variables mathematically is extremely difficult due to many complex relationships present and random step changes involved. Substantial and reliable data is necessary, which is not freely available and hence, this approach has not been attempted.

Timms (4) has developed an equation to determine the installed cost material ratios based on the published information (18,19,20), namely (i) material cost ratios for equipment taking carbon steel as the base material, f_m and (ii) overall Lang factor, L as follows:-

$$F_m = \frac{f_m}{L} + (1 - \frac{1}{L})$$

where F_m = the ratio of the total installed cost of a process step compared to its cost if constructed in carbon steel.

This principle may be extended to deduce an overall process materials of construction factor by employing an arithmetical averaging technique such that:-

$$M = \frac{F_m(1) + F_m(2) + ... + F_m(N)}{N}$$

or $$M = \sum_{1}^{N} ((f_m/L + (1 - 1/L))/N$$

where $F_m(1)$, $F_m(2)$, ...$F_m(N)$ = installed cost material of construction ratio of the individual process steps

N = number of process steps

It is considered that the determination of overall factor by using above equation from a knowledge of the actual process materials employed would have advantages over the previous approach since, instead of being based on obscure mathematical relationships, they would be based on actual material cost ratios. Table 5.3 shows the installed cost material ratios for several materials of construction, where carbon steel is taken as base material.

Appendix B gives selection of materials of construction for non-ferrous metal smelting processes. For the purpose of cost modelling,the major materials of construction for the smelting process is considered to be stainless steel, in which the average installed cost material ratios or overall materials of construction factor is given by:-

$$M = \frac{F_m(1) + F_m(2) + F_m(3)}{3} = \frac{1.13 + 1.2 + 1.29}{3} = 1.2$$

The factor of 1.2 will be used in the cost modelling.

Table 5.3 Installed Cost Material Ratios (F_m) (4)

Material		f_m	f_M
Carbon steel		1.0	1.0
Stainless steel	410	1.5	1.13
	304	1.8	1.2
	316	2.15	1.29
Monel		2.5	1.38
Aluminium		1.5	1.13
Titanium		7.89	2.72
Glass-lined carbon steel		3.17	1.54
Rubber-lined carbon steel		1.64	1.16
Phenolic-lined carbon steel		1.23	1.06

5.2.6 Process Operating Conditions

Most of the previous researchers (7,17,21,22,23) have pinpointed out that the severity of the process operating conditions has an impact on fixed capital investment and thus, they have attempted to measure this impact by defining a relationship between cost and the process temperatures and pressures.

However, to define a relationship between cost and the process temperatures and pressures for the chemical and petrochemical industries has proved to be very difficult because a number of complex and contrasting inter-relationships are involved. For instance, in most chemical processes, liquid reaction rate increases with temperature increase. This reduces the reactor size required (i.e. it reduces the cost of reactor), but inversely may necessitate more expensive materials of construction. This effect is different for gas-phase systems,i.e. increased temperature causes either increased volume (i.e. increased size which means increased cost) and/or increased pressure (i.e. reduced size which means reduced cost, but additional pressure vessel cost is imposed). In the case of pressure effect by the Chatelier's principle, a pressure increase may deviate a gaseous reaction from the optimum and therefore, it increases recycle streams and hence cost. Thus, you can see that the pressure and temperature effects on cost are very complex and often unpredictable.

Besides these complex and contrasting inter-relationships, there are predictable temperature and pressure effects on cost, which are summarized as follows:-

1) Temperature effect on cost is predictable, such that as the temperature increases, costs are expected to increase (and vice versa) due to:-
   (a) possible change in materials of construction,
   (b) increased control for safety reasons,

   (c) increased insulation requirement, and
   (d) increase in numbers of ancilliary heat transfer equipment.

2) Pressure effect on cost is predictable, such that as pressure increases, costs are expected to increase due to:-
   (a) possible change in materials of construction,
   (b) increased equipment thicknesses,
   (c) increased control for safety reasons, and
   (d) increased in number of compressors.

Although temperature and pressure effects do influence the fixed investment cost for chemical and petrochemical processes, they do not necessarily have the same impact on cost for the non-ferrous metal smelting processes because the smelting processes are all operating at atmospheric pressure and at high temperature. In the case of operating at high temperature, the temperature effect on cost due to change in equipment size is negligible for solid-phase processes. Moreover, the predictable temperature effects on cost have been absorbed by other variables included in the cost model, such as materials of construction factor, modular equipment steps. Thus, process operating conditions as a factor in the derived cost model have been rejected for the reasons given above.

5.2.7 Location Effects

It is known that a similar plant built in different locations or countries do not cost the same. By a similar plant is meant a plant producing the same product by the same process from similar raw materials.

Mendel (24) has published a paper in which he described how location affects US plant-construction costs as a function of wage rates and labour productivity, and Johnson (25), based on his accumulated cost data, has worked out the relative costs for material and process equipment and of engineering work. He then produced a list of location indices applicable to most of the major western industrialized countries. The location indices are shown in Table 5.4.

Table 5.4 Johnson Location Indices (1969 Base)

Country	Index
USA/Spain	1.0
UK	0.9
Scandinavia	1.1
Germany	0.85
France	0.9
Japan	0.82
Italy	0.84
India	1.35

Later researcher, Miller (26) has provided a concise and systematic approach to estimate construction costs at different location or countries. He considered the following factors significant in creating capital differences:-

(a) Climate influences on foundation, building and equipment design.

(b) Labour rates and productivity.

(c) Indirect construction costs.

(d) Material and equipment costs, including the effects of tariffs, sales taxes, and rates of currency exchange.

(e) The extent to which material and equipment is indigenous or imported.

(f) Economic environment including such factors as availability of labour and general market conditions.

(g) Special factors, such as extensive overtime, travelling and hiring expenses.

The approach Miller described applies only to the UK, US Gulf Coast and Canada, with the location factors for three sites being, respectively 1.0, 1.15 and 1.3.

Bridgwater (27), the most recent researcher, expanded the subject and based on actual data from published sources and from discussions with industrial contacts including contractors and process companies from many countries, he produced a list of location factors. These location factors are shown in Table 5.5. Though the location factors prepared by Bridgwater are for chemical plants of similar function, there is no reason not to believe that they do apply to metallurgical plants as well.

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Table 5.5 Location Factors For Chemical Plants Of Similar Function (27)

Countries	UK = 1.0	US = 1.0
Australia	1.4	1.3
Austria	1.1	1.0
Belgium	1.1	1.0
Canada	1.25	1.15
Central Africa	2.0	2.0
Central America	1.5	1.0
China (imported element)	1.2	1.1
(indigenous element)	0.6	0.55
Denmark	1.1	1.0
Eire	0.9	0.8
Finland	1.3	1.2
France	1.05	0.95
Germany (West)	1.1	1.0
Greece	1.0	0.9
Holland	1.1	1.0
India (imported element)	2.0	1.8
(indigenous element)	0.7	0.65
Italy	1.0	0.9
Japan	1.0	0.9
Malaysia	0.9	0.8
Middle East	1.2	1.1
Newfoundland	1.3	1.2
New Zealand	1.4	1.3
North Africa (imported element)	1.2	1.1
(indigenous element)	0.8	0.75
Norway	1.2	1.1
Portugal	0.8	0.75
South Africa	1.25	1.15
South America (North)	1.5	1.35
South America (South)	2.5	2.25
Spain (imported element)	1.3	1.2
(indigenous element)	0.8	0.75

cont'd

Countries	UK = 100	US = 1.0
Sweden	1.2	1.1
Switzerland	1.2	1.1
Turkey	1.2	1.0
UK	1.0	0.9
US	1.1	1.0
Yugoslavia	1.0	0.9

However, complications exist which need to be considered before using any published location factor, eg. Bridgwater's factors. Because the major factors, such as productivity, exchange rates, inflation and labour cost, which influence location factors, are constantly changing relative to each other with time. Then, it is expected that location factors will also change with time and thus, they are applicable for short terms only, say two to three years after their publication.

5.3 Cost Model Derivation

The research at this stage takes on a mathematical aspect whereby the relationship between the dependent factor, i.e. cost and independent factors, i.e. process capacity, modular equipment steps, Lang factors, process materials of construction and location factor has to be derived. Generally, one can consider these variables to be additive, multiplicative or both in form in the cost model.

Initially, my research intention was to derive a novel cost model based on real data. Unfortunately, I came to realize during my industrial visits in Britain that most of the cost data required are considered to be confidential by the firms. My task was further complicated when I took the alternative route by looking into the published cost data. A thorough search of all published cost data from all sources of abstracts including up-to-date search has been undertaken but of no previal. The problem is that not only cost data are considered to be confidential by the firms in today's competitive society, but it has been so for many years in the past. Thus, published cost data are very limited. The data that has been collected are really not sufficient for the novel cost model derivation and they include:-

1) Cost-capacity data (see Appendix A)
2) Breakdown of fixed capital investment items for a non-ferrous metal production process (see section 4.5).

This lack of data problem has had an effect on the subsequent development on the thesis.

Although this impassable barrier (lack of data) has led me no alternative to pursuing my initial objective (novel cost model derivation based on real data), the data that were collected as mentioned above enlightened me to pursue on alternative course in the cost model derivation. To overcome this major problem, the following steps have been taken for the cost model derivation:-

1) To use exponential capacity factor (see Table A-2) and specimen data (see Table A-4) obtained from the cost-capacity correlation for each process.
2) To derive Lang factors or direct and indirect cost factors for the non-ferrous metals production processes (see Section 4.5 and sub-section 5.2.4).
3) To identify the variables or factors that influence the fixed capital investment and these variables discussed are all multiplicative in structure (see section 5.2).

A thorough literature review (see Chapter 4) has shown that a multiplicative model is best suited for the additive cost model demands 'almost' a complete set of data which is not available in the research. This can be demonstrated by the additive cost model derived for the chemical plant (28) as follows:-

$$I = E(A(1+F_m) + A_f(F_l+F_p)_f + A_s(0.65F_l)_s + C + B)$$

where I = total battery-limits investment

E = indirect cost factor

A = total cost of all battery-limits equipment estimated on an FOB basis. This cost is exclusive of any incremental cost for alloy materials when such materials are used only because of their corrosion-resisting properties.

F_m = cost factor for miscellaneous items, such as insulation, instruments, foundations, structural steel, buildings, wiring, painting, freight and supervision

F_l = cost factor for field labour

F_p = cost factor for piping materials, such as pipe, valves, fittings, hangers and supports

C = incremental cost of alloy materials provided these materials are used only for their corrosion-resisting properties

B = cost of all equipment estimated on an erected basis

Subscripts

f pertains to fluid-processing equipment

s pertains to solid-handling equipment

As can be seen from the additive cost model given above, it does require a lot of detailed cost data which are not available for my research. Thus, the additive cost model has been rejected for these reasons and multiplicative cost model is adopted for this research. It is expressed as follows:-

$$C = f(x_1, x_2, x_3, \ldots\ldots x_n)$$

or $$C = kx_1^a.x_2^b.x_3^c.\ldots\ldots x_n^n$$

where C = cost

$x_1, x_2, x_3, \ldots x_n$ = relevant factors

K = model constant

a, b, c, ... n = exponential factors

It has been shown that in sub-section 5.2.1.5, only a capacity exponential factor, b exists in the cost equation (as b represents the overall capacity exponential factor for the whole plant). Therefore, by substituting the relevant factors (reasons for this choice of factors have been explained in their appropriate preceeding sub-sections), we obtain two general cost equations:-

(1) $C = (K_1.N.Q^b.L_D).L_I.M.L_F$

(2) $C = K_2.N.Q^b.L.M.L_F$

where C = fixed capital investment
K_1, K_2 = model constant
N = number of modular equipment steps
Q = process capacity
b = capacity exponential factor
L_D = direct cost factor
L_I = indirect cost factor
L = simple overall Lang factor
M = process materials of construction factor
L_F = location factor

Finalised Cost Models

Based on the discussions listed in section 5.2, the average value of factors have been decided for the determination of model constant in the two general cost equations respectively. They are summarized as follows:-

Factor	Copper Process	Zinc Process	Lead Process	Tin Process	Overall Processes*
N	53	53	47	38	48
L_D	2.54	2.54	2.54	2.54	2.54
L	4.45	4.45	4.45	4.45	4.45
M	1.20	1.20	1.20	1.20	1.20
b	0.82	0.95	0.96	0.93	0.94

* Overall processes are defined as processes including copper, zinc, lead and tin, i.e. all the cost cost-capacity data from each process which are used for the overall cost-capacity correlation. Note that the number of modular equipment steps, N for overall processes is taken to be an average value of 48 for the four processes.

Since all the data obtained have been based on US dollars, the location factor, L_F is taken to be 1.0. In the case of indirect cost factor, L_I in the first cost equation, the total direct costs, DC (i.e. the product of K_1, N, Q^b and L_D) have to be determined first and then the indirect cost factor, L_I is obtained either from Figure 5.3 given in sub-section 5.2.4 or from the equation: $L_I = 2.354 - 0.0543 \ln DC$ by substituting the value of DC. Three process capacities with average fixed capital investments (i.e. specimen data extracted from Table A-4 in Appendix A) are employed respectively to determine the model constants K_1 and K_2.

In the first cost equation, the determination of model constant, K_1 involves by trial and error until both sides of the cost equation become equal. But, in the second cost equation, the determination of model constant, K_2 is straight forward and it only involves direct substitution of known values of factors into cost equation, where $K_2 = C/N.Q^b.L.M.L_F$. The results for K_1 and K_2 are tabulated in Table 5.6 and 5.7.

Table 5.6 Results Of Model Constant, K_1 Determination For Multiplicative Cost Models For Each Individual Metal And All Metals, Using First Cost Equation (i.e. Direct And Indirect Cost Factors' Method)

Process	Process Capacity $Q \times 10^3$ tpy	Fixed Capital Investment $C \times 10^6$	Model Constant	Average Model Constant, K_1
Copper	50	97	61	63
	100	172	63	
	150	240	64	
Zinc	50	70	11	11
	100	135	11	
	150	199	12	
Lead	50	80	13	13
	100	154	13	
	150	228	13	
Tin	50	79	21	22
	100	151	22	
	150	220	22	
Overall	50	78	15	16
	100	150	16	
	150	219	16	

Table 5.7 Results Of Model Constant, K_2 Determination For Multiplicative Cost Models For Each Individual Metal And All Metals, Using Second Cost Equation (i.e. Simple Overall Lang Factor's Method)

Process	Process Capacity $Qx10^3$tpy	Fixed Capital Investment $C \times \$10^6$	Model Constant	Average Model Constant, K_2
Copper	50	97	49	
	100	172	49	49
	150	240	49	
Zinc	50	70	9	
	100	135	9	9
	150	199	9	
Lead	50	80	10	
	100	154	10	10
	150	228	10	
Tin	50	79	17	
	100	151	17	17
	150	220	17	
Overall	50	78	12	
	100	150	12	12
	150	219	12	

By substituting the known values of capacity exponential factor and average model constants K_1 and K_2 into the first and the second cost equation respectively, the following multiplicative cost models are produced as follows:-

1) For the first cost equation, i.e. multiplicative cost models for each individual metal and all metals, using direct and indirect cost factors' method, we obtain:-

(i) For copper process, $C = 63.N.Q^{0.82}.L_D.M.L_F$

(ii) For zinc process, $C = 11.N.Q^{0.95}.L_D.M.L_F$

(iii) For lead process, $C = 13.N.Q^{0.96}.L_D.M.L_F$

(iv) For tin process, $C = 22.N.Q^{0.93}.L_D.M.L_F$

(v) For overall processes, $C = 16.N.Q^{0.94}.L_D.M.L_F$

2) For the second cost equation, i.e. multiplicative cost models for each individual metal and all metals, using simple overall Lang factor's method, we obtain:-

(i) For copper process, $C = 49.N.Q^{0.82}.L.M.L_F$

(ii) For zinc process, $C = 9.N.Q^{0.95}.L.M.L_F$

(iii) For lead process, $C = 10.N.Q^{0.96}.L.M.L_F$

(iv) For tin process, $C = 17.N.Q^{0.93}.L.M.L_F$

(v) For overall processes, $C = 12.N.Q^{0.94}.L.M.L_F$

Note that the above cost models are based on the common time of Mid-1980 and predict costs in millions of US dollars at this time. Thus, cost index, such as Process Economics International (PEI) Plant cost index is used to update cost at different base year.

It is also hereby emphasized that the cost models are based on the average values of fixed capital investment at various process capacities, which result from the correlation of cost-capacity data for each individual metal and all metal given in Appendix A. These cost-capacity data do not specify the particular type of furnace used in the process, eg. a copper process can either have a reverberatory furnace or a Outokumpu design, each has its own specific capacity value and there is a general relationship between capital cost and specific capacity as mentioned earlier (see sub-section 2.7.5). And since the cost models are derived from specimen data obtained from cost-capacity correlations, they only give average fixed capital investment at certain process capacity. Therefore, the above relationship should be included in order to take into account for the processes having higher specific capacity values will offer lower fixed capital investment and vice versa.

The literature review (see Chapter 2) has shown that about 20% reduction in fixed capital investment can be achieved through improvement of specific capacity of a smelting furnace. Based on this argument and the existing specific capacities of different furnaces or processes given in Table 2.6 (see sub-section 2.7.5), a general relationship of percentage of average fixed capital investment and specific capacity for each metal process can be represented by a graph as shown in Figure 5.4, 5.5 and 5.6. A lead process is not included as the data has not been found in the literature. Note in the figures that overall 20% reduction in fixed capital investment has been assumed for the existing metal smelting processes at the lowest and the highest specific capacity and that the mid-point of the lowest and the highest specific capacity for each metal process is plotted against 100% of average fixed capital investment, and they are summarized below:-

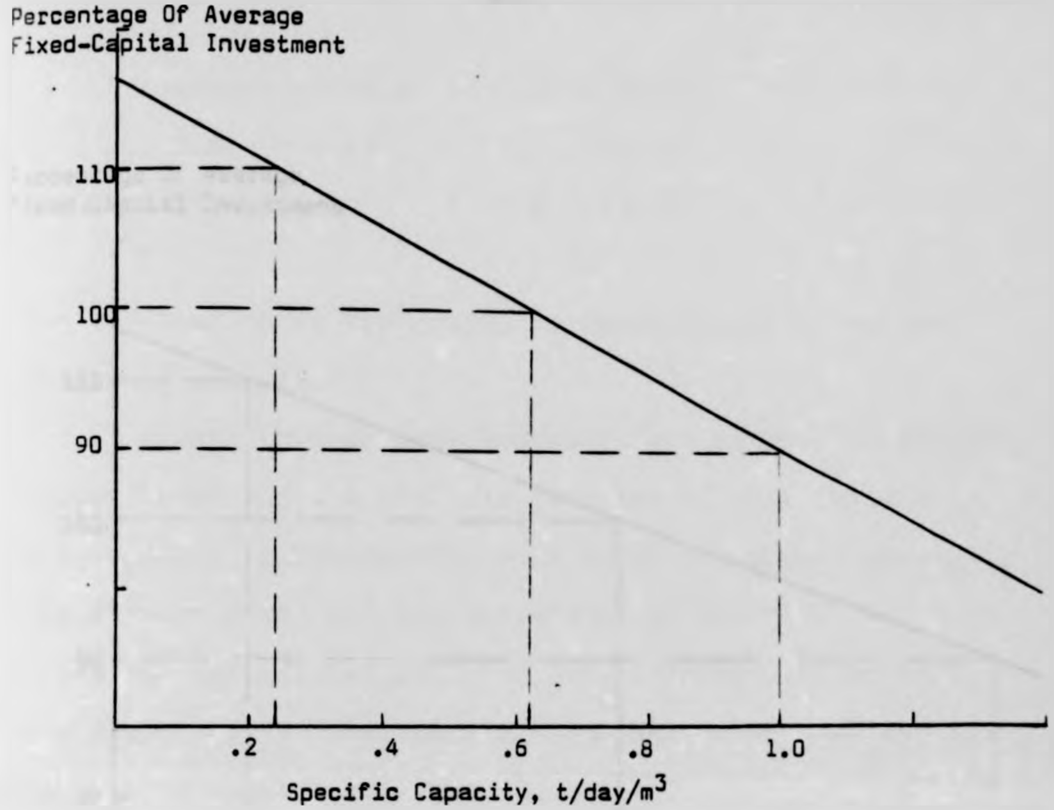


Figure 5.4 Relationship Of Average Fixed-Capital Investment (%) And Specific Capacity For Copper Processes

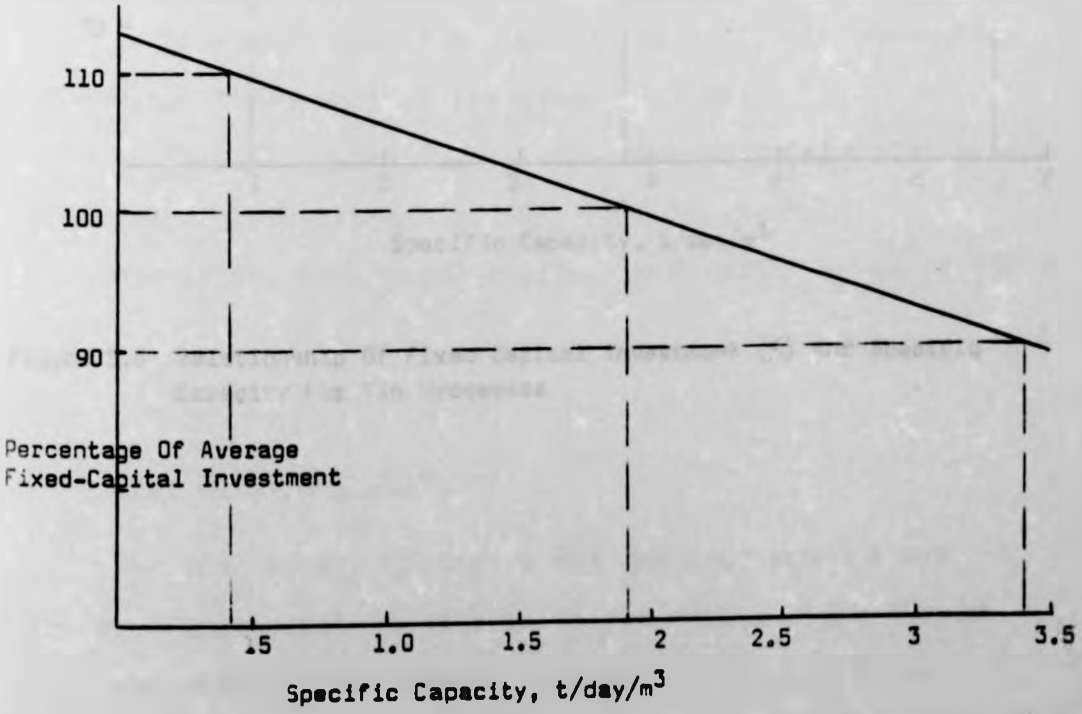


Figure 5.5 Relationship Of Average Fixed-Capital Investment (%) And Specific Capacity For Zinc Processes

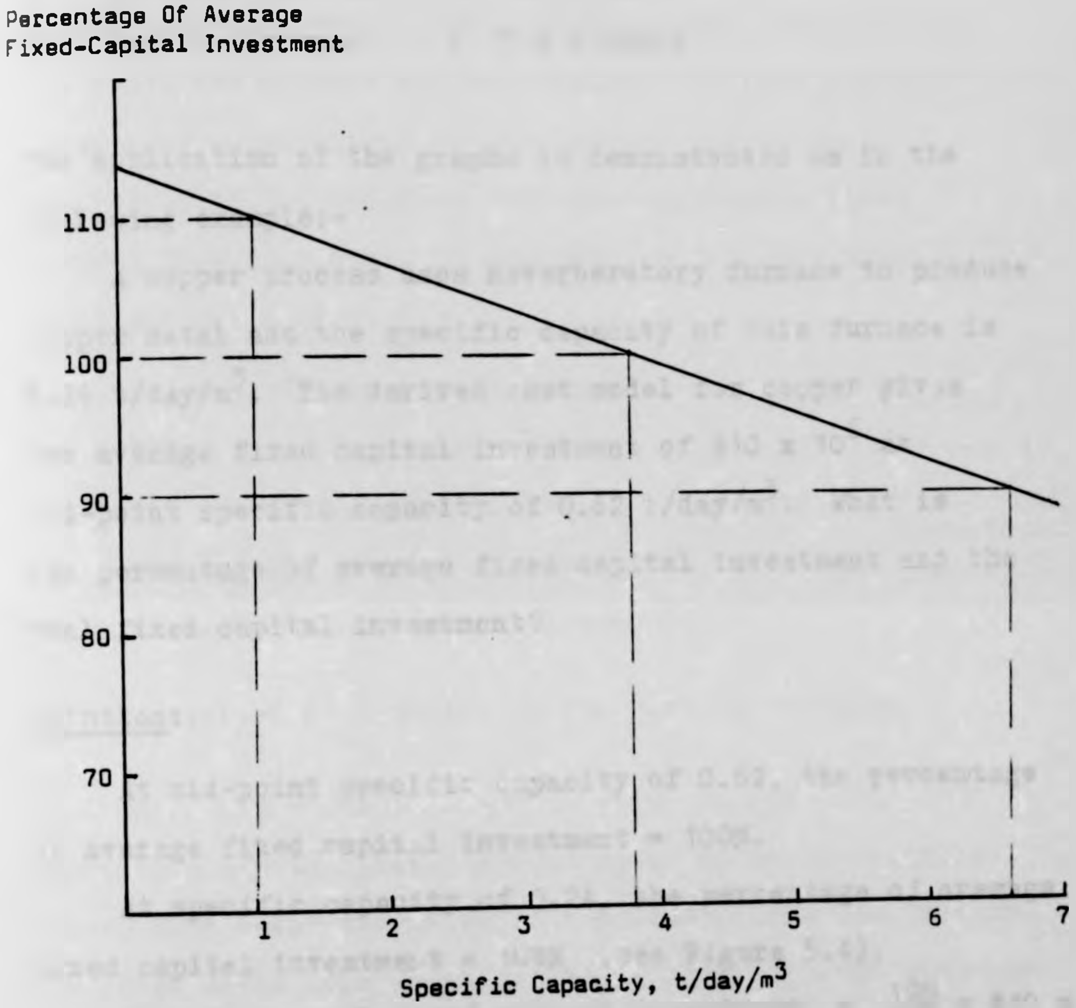


Figure 5.6 Relationship Of Fixed Capital Investment (%) And Specific Capacity For Tin Processes

1) For copper process - 0.62 t/day/m^3

2) For zinc process - 1.9 t/day/m^3

3) For tin process - 3.8 t/day/m^2

The application of the graphs is demonstrated as in the following example:-

A copper process uses Reverberatory furnace to produce copper metal and the specific capacity of this furnace is 0.24 t/day/m^3. The derived cost model for copper gives the average fixed capital investment of \$10 x 10^6 at mid-point specific capacity of 0.62 t/day/m^3. What is the percentage of average fixed capital investment and the real fixed capital investment?

Solution:

At mid-point specific capacity of 0.62, the percentage of average fixed capital investment = 100%.

At specific capacity of 0.24, the percentage of average fixed capital investment = 108% (see Figure 5.4).

Therefore, real fixed capital investment $= \frac{108}{100} \times \$10 \times 10^6$

$= \$10.8 \times 10^6$

5.4 Cost Model Selection

The cost models listed in the previous section are the most appropriate that will be produced in this thesis. The next phase in the research requires that these cost models are required to calculate the fixed capital investments at certain process capacities, so that their results are compared with the source data. Table 5.8 shows updated source data with their respective process capacities in the first two columns and the results of fixed capital investment calculations in the rest of the columns. Their results are obtained from the regression lines derived from cost-capacity correlation for each individual metal and all metals, i.e.

$Y = 0.82X + 1.374$ for copper process

$Y = 0.95X + 0.536$ for zinc process

$Y = 0.96X + 0.62$ for lead process

$Y = 0.93X + 0.735$ for tin process

$Y = 0.94X + 0.685$ for overall processes

where $Y = \text{Log } C$
$X = \text{Log } Q$
and C = fixed capital investment
Q = process capacity

and the derived cost models in the previous section.

Table 5.9 shows the tabular form comparison of cost correlations with updated source data, in which probable errors have been calculated so that deductions can be made. The large deviations which can be as high as +288% occurred in row 1 and 4 of copper process, row 8 of zinc process and row 6 of lead process. These large deviations from the source data may due tc wrong assumption that total process capacity at a certain capital cost is taken instead of an expansion in process capacity. The rest of the small deviations may be explained by:-

Table 5.8 Results Of Fixed Capital Investment Calculation

cont'd

Process	Process Capacity tpax10^3	Capital Cost At 1980 $ x 10^6	Capital Cost At 1980	
			Cost-Capacity Correlation	Overall-Cost Capacity Correlation
Copper	36.0	36.2	74.6	57.6
	45.0	117.3	89.6	71.0
	53.0	116.3	102.5	82.9
	65.0	68.2	121.2	100.4
	65.0	181.7	121.2	100.4
	65.0	223.5	121.2	100.4
	118.0	247.5	197.5	175.8
	130.0	371.2	213.9	192.6
	150.0	148.0	240.5	220.3
	150.0	259.8	240.5	220.3
	163.4	210.0	258.0	238.6
	180.0	210.0	279.3	261.5
Zinc	16.4	18.9	24.4	27.5
	16.4	21.9	24.4	27.5
	27.3	29.6	39.6	44.4
	27.3	45.4	39.6	44.4
	27.3	50.3	39.6	44.4
	27.3	65.1	39.6	44.4
	60.0	175.4	83.6	93.1
	72.7	33.8	100.3	111.5
	80.0	89.0	109.8	122.0
	80.0	89.0	109.8	122.0
	91.0	125.0	124.1	137.7
	120.0	260.0	161.4	178.6
Lead	37.3	42.9	60.0	59.6
	28.0	48.5	45.6	45.5
	45.8	54.8	73.1	72.2
	54.5	109.5	86.3	85.1

cont'd

Table 5.8 cont'd

Process	Capital Cost At 1980 ($\$x10^6$) Obtained From			
	Cost Model A[1]	Overall Cost Model A[2]	Cost Model B[3]	Overall Cost Model B[4]
Copper	77.4	69.5	75.5	65.1
	92.2	85.0	90.7	80.4
	104.9	98.6	103.7	93.7
	123.2	118.5	122.6	113.5
	123.2	118.5	122.6	113.5
	123.2	118.5	122.6	113.5
	197.1	203.0	200.0	198.9
	212.7	221.5	216.5	217.8
	238.0	252.0	243.5	249.2
	238.0	252.0	243.5	249.2
	254.6	272.2	261.1	270.1
	274.7	297.0	282.7	295.8
Zinc	26.1	34.1	25.7	31.1
	26.1	34.1	25.7	31.1
	41.7	54.1	41.7	50.2
	41.7	54.1	41.7	50.2
	41.7	54.1	41.7	50.2
	41.7	54.1	41.7	50.2
	85.5	110.2	88.2	105.3
	101.9	131.1	105.8	126.1
	111.2	142.9	115.9	138.0
	111.2	142.9	115.9	138.0
	125.0	160.6	131.0	155.8
	161.0	206.1	170.3	202.0
Lead	64.1	63.9	61.4	59.7
	49.2	49.3	46.7	45.6
	77.5	77.0	74.8	72.4
	91.0	90.1	88.4	85.3

cont'd

Table 5.8 cont'd

cont'd

Process	Process Capacity tpax10^3	Capital Cost At 1980 \$ x 10^6	Capital Cost At 1980	
			Cost-Capacity Correlation	Overall-Cost Capacity Correlation
Lead	90.9	165.3	141.1	137.6
	100.0	79.6	154.6	150.5
	100.0	220.6	154.6	150.5
Tin	1.82	3.45	3.64	3.48
	3.20	6.26	6.15	5.92
	3.60	8.00	6.86	6.61
	4.73	8.36	8.85	8.55
	5.20	9.20	9.66	9.34

Table 5.9 Tabular Form Comparison Of Cost Correlations With Source Data

cont'd

Process	Source Data \$x10^6	Cost-Capacity Correlation	Probable Error	Overall Cost-Capacity Correlation	Probable Error
Copper	36.2	75.0	+107	57.9	+60
	117.3	89.6	- 24	71.0	-39
	116.3	102.5	- 12	82.9	-29
	68.2	121.2	+ 78	100.4	+47
	181.7	121.2	- 33	100.4	-45
	223.5	121.2	- 46	100.4	-55
	247.5	197.5	- 20	175.8	-29
	371.2	213.9	- 42	192.6	-48
	148.0	240.5	+ 63	220.3	+49
	259.8	240.5	- 7	220.3	-15
	210.0	258.0	+ 23	238.6	+14

cont'd

Table 5.8 cont'd

Process	Capital Cost At 1980 ($x10^6$) Obtained From			
	Cost[1] Model A	Overall Cost[2] Model A	Cost Model[3] B	Overall[4] Cost Model B
Lead	145.8	142.9	144.5	138.0
	159.2	155.8	158.4	150.9
	159.2	155.8	158.4	150.9
Tin	4.27	3.38	3.71	2.82
	7.09	5.64	6.27	4.80
	7.88	6.28	7.00	5.36
	10.07	8.04	9.02	6.93
	10.96	8.76	9.86	7.58

Refer footnotes on next page.

Table 5.9 cont'd

Cost Model A	Probable Error	Overall Cost Model A	Probable Error	Cost Model B	Probable Error	Overall Cost Model B	Probable Error
77.7	+115	69.5	+92	75.9	+110	65.1	+80
92.2	- 21	85.0	-27	90.7	- 23	80.4	-31
104.9	- 10	98.6	-15	103.7	- 11	93.7	-19
123.2	+ 81	118.5	+74	122.6	+ 80	113.5	+66
123.2	- 32	118.5	-35	122.6	- 33	113.5	-37
123.2	- 45	118.5	-47	122.6	- 45	113.5	-49
197.1	- 20	203.0	-18	200.0	- 19	198.9	-20
212.7	- 43	221.5	-40	216.5	- 42	217.8	-41
238.0	+ 61	252.0	+70	243.5	+ 64	249.2	+68
238.0	- 8	252.0	- 3	243.5	- 6	249.2	- 4
254.6	+ 21	272.2	+30	261.1	+ 24	270.1	+29

Footnotes to Table 5.8

1 Multiplicative cost models for each individual metal, using direct and indirect cost factors' method

2 Overall multiplicative cost model for all metals, using direct and indirect cost factors' method

3 Multiplicative cost models for each individual metal, using simple overall Lang factor's method

4 Overall multiplicative cost model for all metals, using simple overall Lang factor's method

Table 5.9 cont'd

Process	Source Data $\$x10^6$	Cost-Capacity Correlation	Probable Error	Overall Cost-Capacity Correlation	Probable Error
Copper	210.0	279.3	+ 33	261.5	+24
Zinc	18.9	24.4	+ 29	27.5	+45
	21.9	24.4	+ 11	27.5	+26
	29.6	39.6	+ 34	44.4	+50
	45.4	39.6	- 13	44.4	- 2
	50.3	39.6	- 21	44.4	-11
	65.1	39.6	- 39	44.4	-32
	175.4	83.6	- 52	93.1	-47
	33.8	100.3	+197	111.5	+230
	89.0	109.8	+ 23	122.0	+37
	89.0	109.8	+ 23	122.0	+37
	125.0	124.1	- 1	137.7	+10
	260.0	161.4	- 38	178.6	-31
Lead	42.9	60.0	+ 40	59.6	+39
	48.5	45.6	- 6	45.5	- 6
	54.8	73.1	+ 33	72.2	+32
	109.5	86.3	- 21	85.1	-22
	165.3	141.1	- 15	137.6	-17
	79.6	154.6	+ 94	150.5	+89
	220.6	154.6	- 30	150.5	-32
Tin	3.45	3.64	+ 5	3.48	+ 1
	6.26	6.15	- 2	5.92	- 5
	8.00	6.86	- 14	6.61	-17
	8.36	8.85	+ 15	8.55	+ 2
	9.20	9.66	+ 5	9.34	+ 2

cont'd

Table 5.9 cont'd

Cost Model A	Probable Error	Overall Cost Model A	Probable Error	Cost Model B	Probable Error	Overall Cost Model B	Pro-bable Error
274.7	+31	297.0	+41	288.7	+37	295.8	+41
26.1	+38	34.1	+80	25.7	+36	31.1	+64
26.1	+19	34.1	+56	25.7	+17	31.1	+42
41.7	+41	54.1	+83	41.7	+41	50.2	+70
41.7	- 8	54.1	+19	41.7	- 8	50.2	+10
41.7	-17	54.1	+ 7	41.7	-17	50.2	0
41.7	-36	54.1	-17	41.7	-36	50.2	-23
85.5	-51	110.2	-37	88.2	-50	105.3	-40
101.9	+201	131.1	+288	105.8	+213	126.1	+273
111.2	+25	142.9	+61	115.9	+30	138.0	+55
111.2	+25	142.9	+61	115.9	+30	138.0	+55
125.0	0	160.6	+28	131.0	+ 5	155.8	+25
161.0	-38	206.1	-21	170.3	-34	202.0	-22
64.1	+49	63.9	+49	61.4	+43	59.7	+39
49.2	+ 1	49.3	+ 2	46.7	- 4	45.6	- 6
77.5	+41	77.0	+40	74.8	+36	72.4	+32
91.0	-17	90.1	-18	88.4	-19	85.3	-22
145.8	-12	142.9	-14	144.5	-13	138.0	-16
159.2	+100	155.8	+96	158.4	+99	150.9	+90
159.2	-28	155.8	-29	158.4	-28	150.9	-32
4.27	+24	3.38	- 2	3.71	+ 7	2.82	-18
7.09	+13	5.64	-10	6.27	0	4.80	-23
7.88	- 2	6.28	-21	7.00	-12	5.36	-33
10.07	+20	8.04	- 4	9.02	+ 8	6.93	-17
10.96	+19	8.76	- 5	9.86	+ 7	7.58	-18

1) The following factors significantly in creating capital cost differences:-

   (a) Climatic influences on foundation, building and equipment design

   (b) Labour rates and productivity

   (c) Indirect construction costs

   (d) The extent to which material and equipment is indigenous or imported

   (e) Special factors, such as extensive overtime, travelling and hiring expenses

2) Cost indices to update older data - It should be understood that such indices seldom fully reflect the true situation of market forces, supply and demand, premium payment and cost inflation. Moreover, the weighting of the various commodities used in the make-up of an index may not be fully representative or sensitive enough for a particular piece of equipment or material, and therefore the emerging index number would well be unrepresentative of the true pattern of price movements.

3) Taking the wrong assumption of the average number of modular equipment steps to derive model constants in the cost equations. The deviations in terms of percentage variations or probable errors resulting from variations and/or wrong assumptions in numbers of steps of different processes can be shown in Table 5.10 and 5.11. The percentage variations in creating capital cost differences with 5 steps more than it should be,

Table 5.10 Percentage Variations In Numbers Of Modular Equipment Steps Of Different Processes, Using Direct And Indirect Cost Factors' Method

cont'd

Process	Process Capacity $x10^3$tpa	No. Of Modular Equip. Steps	Fixed Capital Invest-ment x $\$10^6$	Five Steps More	Fixed Capital Invest-ment x $\$10^6$	Percentage Variation %
Copper	50	53	100.2	58	109.3	9.1
	100	53	173.0	58	188.6	9.0
	150	53	238.0	58	259.5	9.0
	Average percentage variation = 9.0					
Zinc	50	53	72.4	58	78.9	9.0
	100	53	163.3	58	148.6	9.0
	150	53	197.2	58	215.1	9.1
	Average percentage variation = 9.0					
Lead	50	47	84.0	52	92.6	10.2
	100	47	159.2	52	175.4	10.2
	150	47	231.2	52	254.9	10.2
	Average percentage variation = 10.2					
Tin	50	38	83.1	43	93.6	12.6
	100	38	154.4	43	173.9	12.6
	150	38	221.7	43	249.7	12.6
	Average percentage variation = 12.6					
Overall	50	48	55.0	53	93.5	10.0
	100	48	159.0	53	174.8	9.9
	150	48	229.2	53	252.0	9.9
	Average percentage variation = 9.9					

Table 5.10 cont'd

Process	Five Steps Less	Fixed Capital Investment x $\$10^6$	Percentage Variation %
Copper	58	91.1	-9.1
	48	157.3	-9.1
	48	216.4	-9.1
	Average percentage variation = 9.1		
Zinc	48	69.8	-9.1
	48	123.9	-9.1
	48	179.3	-9.1
	Average percentage variation = -9.1		
Lead	42	75.4	-10.2
	42	142.9	-10.2
	42	207.6	-10.2
	Average percentage variation = -10.2		
Tin	33	72.6	-12.6
	33	134.9	-12.6
	33	193.7	-12.6
	Average percentage variation = -12.6		
Overall	43	76.5	-10.0
	43	143.0	-10.1
	43	206.2	-10.0
	Average percentage variation = -10.0		

Table 5.11 Percentage Variations In Numbers Of Modular Equipment Steps Of Different Processes, Using Simple Overall Lang Factor's Method

Process	Process Capacity $x10^3$tpa	No. Of Modular Equip. Steps	Fixed Capital Invest-ment $x \$10^6$	Five Steps More	Fixed Capital Invest-ment $x \$10^6$	Percentage Variation %
Copper	50	53	98.9	58	108.2	9.4
	100	53	174.6	58	191.1	9.4
	150	53	243.4	58	266.4	9.4
	Average percentage variation = 9.4					
Zinc	50	53	74.1	58	81.1	9.4
	100	53	143.2	58	156.8	9.5
	150	53	210.5	58	230.4	9.4
	Average percentage variation = 9.5					
Lead	50	47	81.4	52	90.1	10.7
	100	47	158.4	52	175.2	10.6
	150	47	223.7	52	258.6	10.7
	Average percentage variation = 10.7					
Tin	50	38	80.9	43	91.5	13.1
	100	38	154.1	43	174.4	13.2
	150	38	224.7	43	254.2	13.1
	Average percentage variation = 13.1					
Overall	50	48	80.4	53	88.7	10.3
	100	48	154.2	53	170.2	10.4
	150	48	225.7	53	249.2	10.4
	Average percentage variation = 10.4					

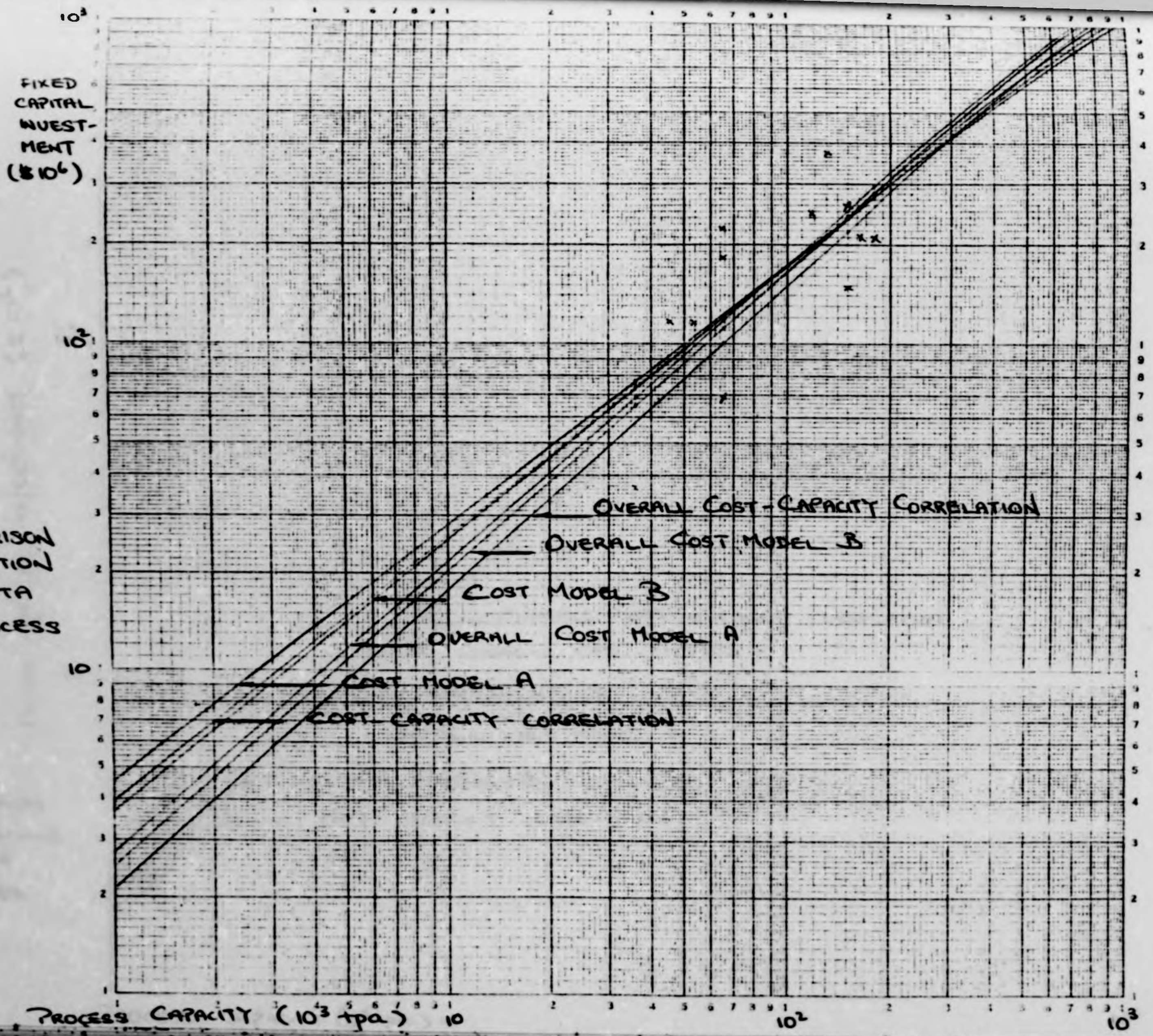
Table 5.11 cont'd

Process	Five Steps Less	Fixed Capital Investment x $\$10^6$	Percentage Variation %
Copper	48	89.6	-9.4
	48	158.1	-9.4
	48	220.5	-9.4
	Average percentage variation =-9.4		
Zinc	48	67.2	-9.3
	48	129.7	-9.4
	48	190.7	-9.4
	Average percentage variation = -9.4		
Lead	42	72.7	-10.7
	42	141.5	-10.7
	42	208.9	-10.7
	Average percentage variation = -10.7		
Tin	33	70.2	-13.2
	33	133.8	-13.2
	33	195.1	-13.2
	Average percentage variation = -13.2		
Overall	43	72.0	-10.4
	43	138.1	-10.4
	43	202.2	-10.4
	Average percentage variation = -10.4		

may range from +9 to +12.6% for each individual metal and all metals in cost model A and from +9.4 to 13.1% in cost model B. Similarly with 5 steps less than it should be, it may range from -9.1 to -12.6% in cost model A and from -9.4 to -13.1% in cost model B.

Also, Figure 5.7, 5.8, 5.9 and 5.10 show graphical comparison of cost correlations with updated source data for copper, zinc, lead and tin respectively. As it can be seen from the graphs, the cost correlations are all linear. As expected, with the exception of overall cost model A for copper process, both cost and overall cost model A for copper, zinc, lead and tin process possess greater overall economy of scale than the rest of the cost correlations. This is due to the fact that they possess further economy of scale in indirect cost (as discussed in sub-section 5.2.4) as compared with the rests which only possess economy of scale in process capacity. The exception can be explained by the fact that its economy of scale in process capacity or capacity exponential factor has been changed from 0.82 to 0.94 even though there is further economy of scale in indirect cost for overall cost model A which can only improve the overall economy of scale from 0.94 to 0.90. Note also that the deviation among the six cost correlations is largest at low process capacity and smallest at high process capacity. This is because they have each possessed different overall economy of scale in the cost correlations.

FIGURE 5.7
GRAPHICAL COMPARISON
OF COST CORRELATION
WITH SOURCE DATA
FOR COPPER PROCESS



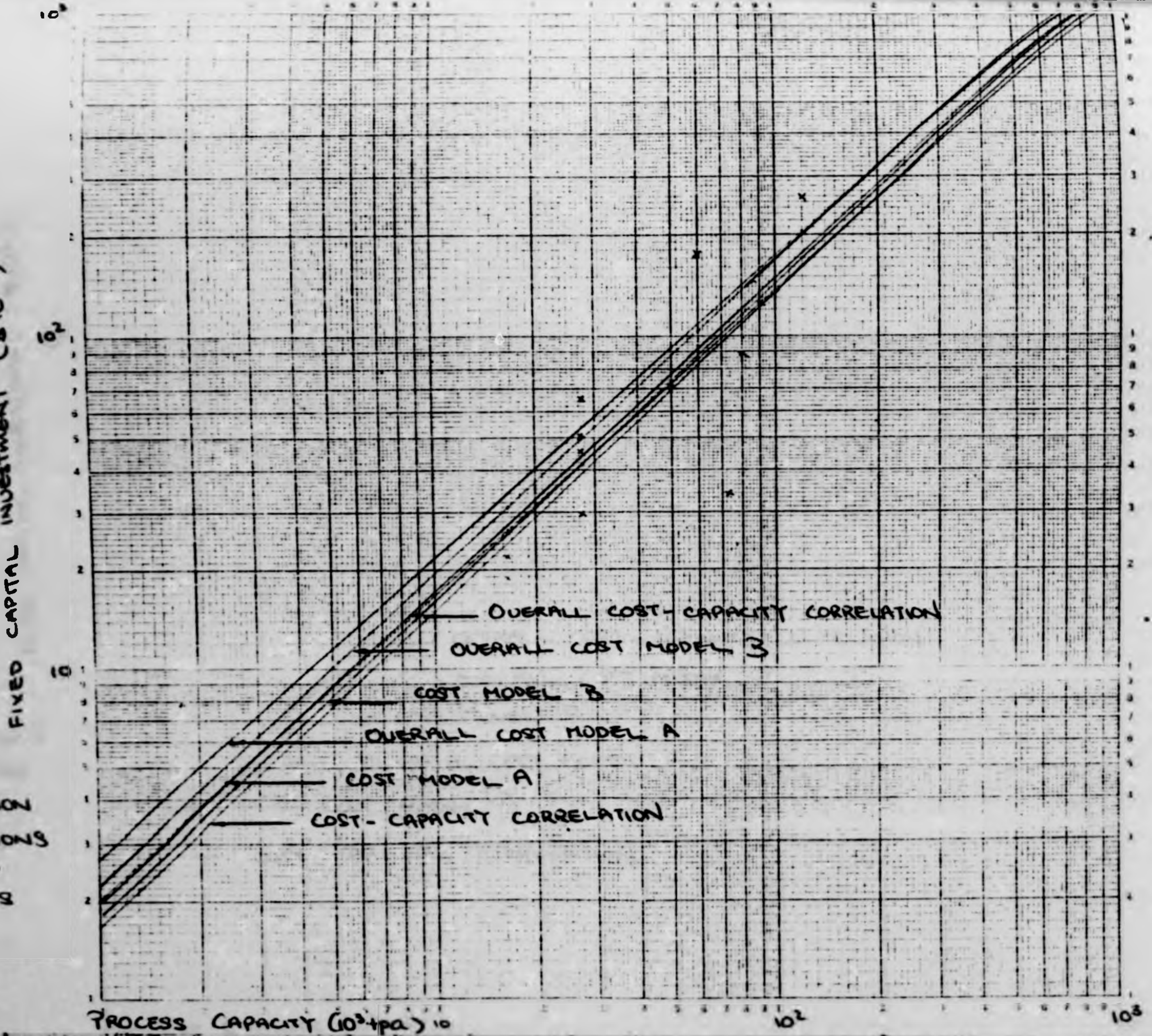


FIGURE 5.8
GRAPHICAL COMPARISON
OF COST CORRELATIONS
WITH SOURCE DATA
FOR ZINC PROCESS

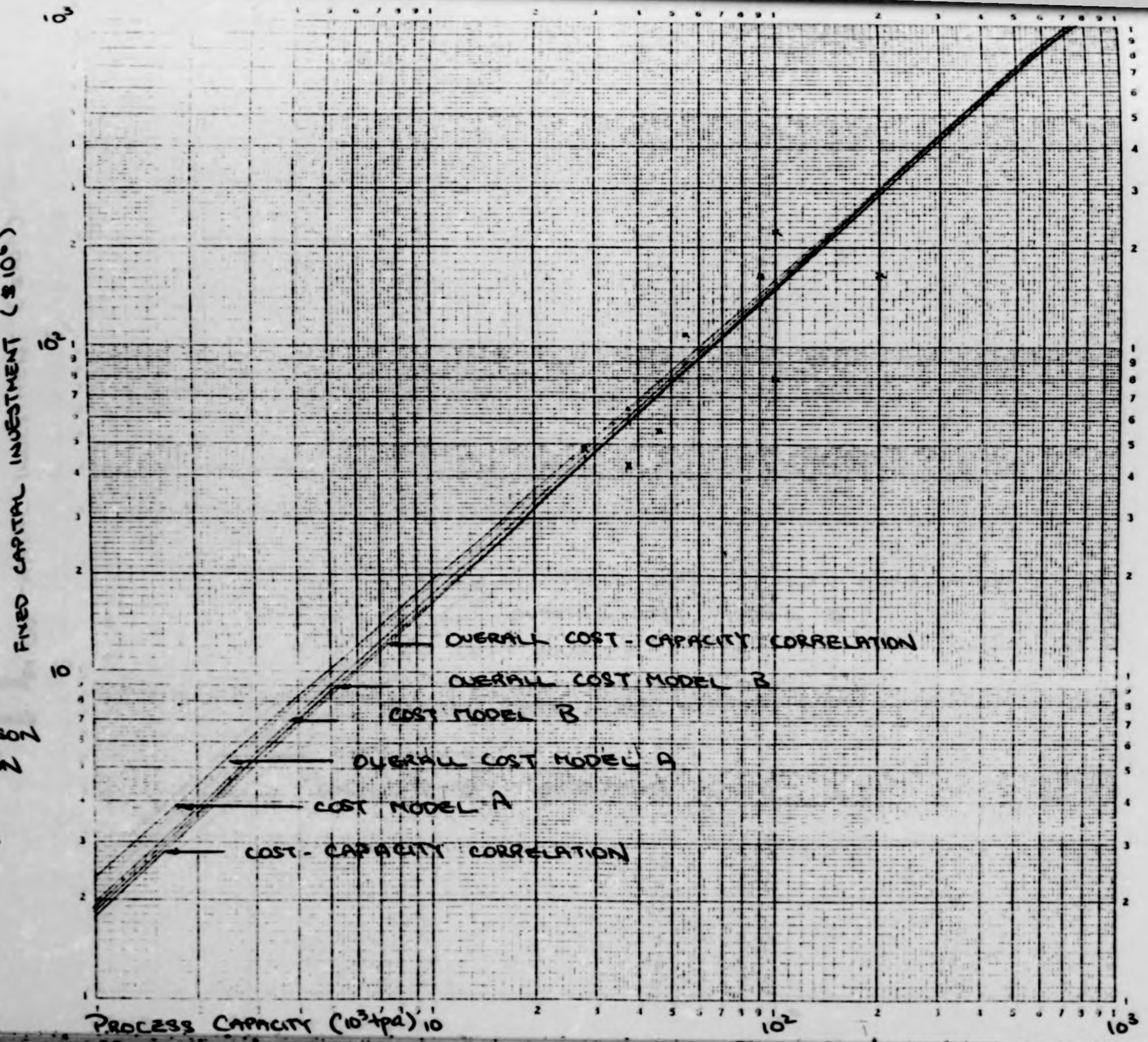


FIGURE 59
GRAPHICAL COMPARISON
OF COST CORRELATION
WITH SOURCE DATA
FOR LEAD PROCESS

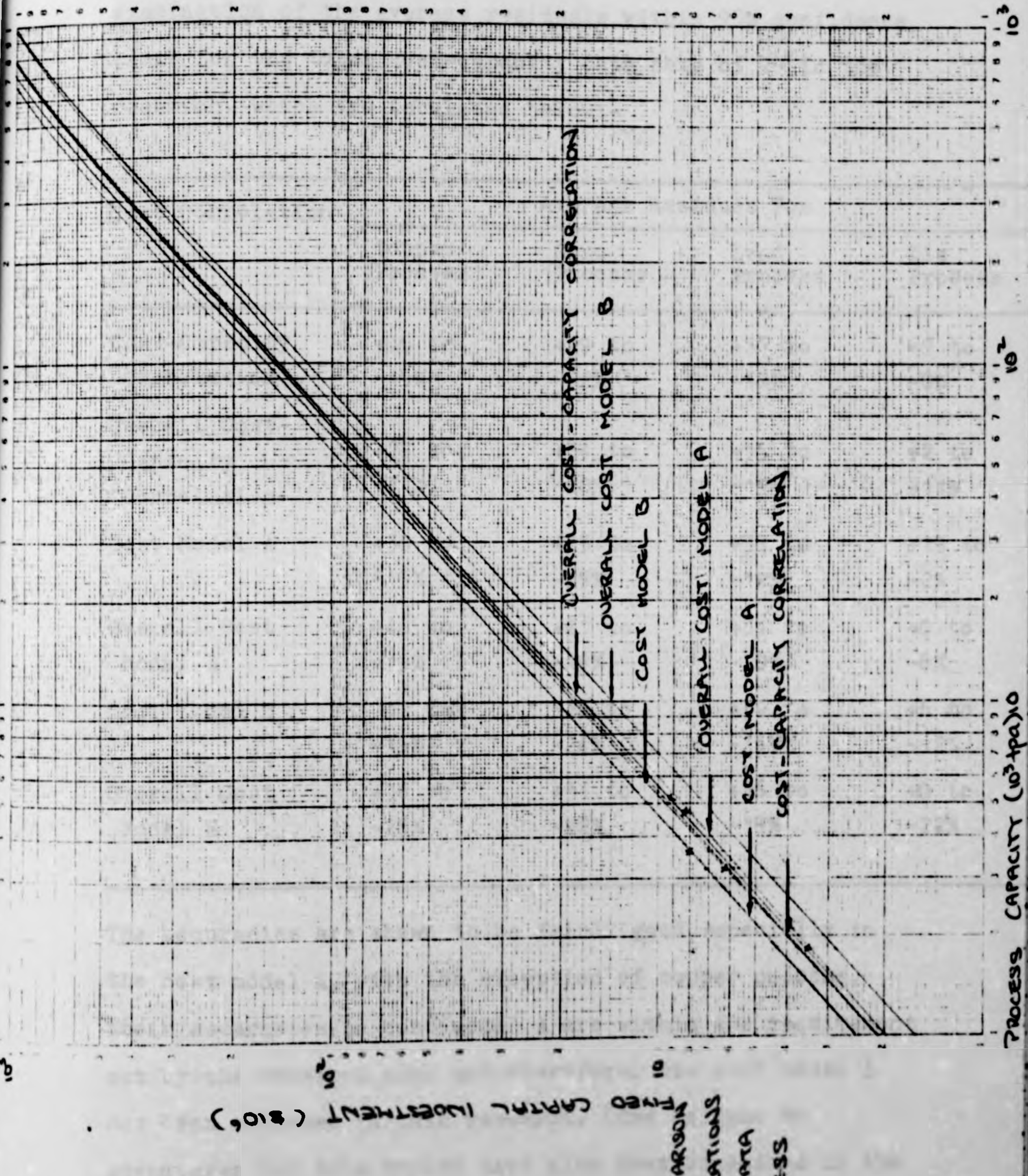


FIGURE 5.10
GRAPHICAL COMPARISON
OF COST CORRELATIONS
WITH SOURCE DATA
FOR TIN PROCESS

The accuracies of the cost correlations disregarding the abnormally large deviations were found by the examination of the average residuals within 95% confidence limit for the total cost-capacity data sets of 29 in the research, which are tabulated below:-

Cost Correlation	Average Residues For			
	Copper Process	Zinc Process	Lead Process	Tin Process
Cost-Capacity Correlation	+40 to -19%	+29 to -22%	+37 to -18%	+8 to -8%
Overall Cost-Capacity Correlation	+29 to -31%	+34 to -20%	+35 to -19%	+2 to -11%
Cost Model A	+38 to -19%	+25 to -25%	+31 to -19%	+19 to -2%
Overall Cost Model A	+46 to -19%	+41 to -19%	+31 to -20%	+0 to -8%
Cost Model B	+42 to -19%	+26 to -24%	+39 to -16%	+6 to -12%
Overall Cost Model B	+36 to -23%	+31 to -22%	+36 to -19%	+0 to -22%

The accuracies are shown to be fairly good, especially in the cost model A, with the exception of copper process, their accuracies in cost model A are within the requirement set by the research aims and therefore, the cost model A has been selected in this research. (The reasons or advantages for this choice have also been discussed in the next section). In order to show the validity of the accuracies' claim, each non-ferrous metal production process of known process and cost data is available to test the model. The results are as follows:-

1) <u>Copper Process (Not Specified)</u> (29)

<u>Cost Data</u>

Fixed capital investment = \$M75

Location = USA (L_F=1.0)

Year of construction completion = 1975

Average direct cost factor for new plant, new site, L_D = 2.54

Actual base cost (USA/1980) $= 75 \times 10^6 \times \frac{219}{140}$

$= \$117.3 \times 10^6$

<u>Process Data</u>

Materials of construction = Stainless steel (M=1.2)

Process capacity, Q $= 45 \times 10^3$ tons/annum

Number of modular equipment steps, N = 53

E Estimated Cost, $C_{base} = (63.N.Q^{0.82}.L_D).L_I.M.L_F$

$= (63 \times 53 \times (45 \times 10^3)^{0.82} \times 2.54$

$\times L_I \times 1.2 \times 1.0$

$= 55.5 \times 10^6 \times L_I \times 1.2$

From the graph of indirect cost factor versus direct cost (see Figure 4.3), L_I = 1.39 when direct cost $= 55.5 \times 10^6$

(Alternatively, L_I can be obtained by substituting direct cost into $L_I = 2.354 - 0.0543 \ln DC$).

$$\therefore \text{ Estimated Cost, } C_{base} = 55.5 \times 10^6 \times 1.386 \times 1.2$$

$$= \underline{92.3 \times 10^6 \text{ (i.e. 79\% of actual base cost)}}$$

2) Zinc Process (Not Specified) (30)

Cost Data

Fixed capital investment = \$M 138

Location = UK (L_F=0.9)

Year of construction completion = 1981

Actual base cost (USA/1980) = $\$138 \times 10^6 \times \frac{219}{241}$

= $\$125.4 \times 10^6$

Average direct cost factor, L_D = 2.54

Process Data

Materials of construction = Stainless steel (M=1.2)

Process capacity = 91×10^3 tons/annum

Number of process steps = 53 (see Table 2.1)

$$\text{Estimated Cost, } C_{base} = (11.N.Q^{0.95}.L_D).L_I.M.L_F$$

$$= (11 \times 53 \times (19 \times 10^3)^{0.95} \times 2.54) \times L_I \times 1.2 \times 0.9$$

$$= 76{,}136{,}270 \times 1.369 \times 1.2 \times 0.9$$

$$= \underline{112.5 \times 10^6 \text{ (90\% of actual base cost)}}$$

3) Lead Process (Not Specified) (31)

Cost Data

Fixed capital investment = \$M 70

Location = USA ($L_F = 1.0$)

Year of construction completion = 1975

Actual base year (USA/1980) = $\$70 \times 10^6 \times \frac{219}{140}$

= $\$109.5 \times 10^6$

Average direct cost factor, L_D = 2.54

Process Data

Materials of construction = Stainless steel ($M = 1.2$)

Process capacity = 54.5×10^3 tons/annum

Number of process steps = 47 (see Table 2.1)

$$\text{Estimated Cost, } C_{base} = (13.N.Q^{0.96}.L_D).L_I.M.L_F$$

$$= (13 \times 47 \times (54.5 \times 10^3)^{0.96} \times 2.54 \times L_I \times 1.2 \times 1.0$$

$$= (54{,}678{,}372) \times 1.387 \times 1.2 \times 1.0$$

$$= \underline{91 \times 10^6 \quad \text{(83\% of actual base cost)}}$$

4) Tin Process (Not Specified) (32)

Cost Data

Fixed capital investment = \$M 9.2

Location = Thailand($L_F = 1.0$

Year of construction completion = 1980

Actual base cost (USA/1980) = $\$9.2 \times 10^6$

Average direct cost factor, L_D = 2.54

Process Data Materials of construction = Stainless steel ($M=1.2$)

Process capacity = 5.2×10^3 tons/annum

Number of process steps = 38 (see Table 2.1)

Estimated Cost, $C_{base} = (22.N.Q^{0.93}.L_D).L_I.M.L_F$

$= (22 \times 38 \times (5.2 \times 10^3)^{0.93} \times 2.54) \times L \times 1.2 \times 1.0$

$= 6{,}066{,}289 \times 1.506 \times 1.2 \times 1.0$

$= 11 \times 10^6$ (100% of actual base cost)

5) Secondary Recovery Of Lead (33)

Cost Data Fixed capital investment = \$M 32

Location = USA ($L_F=1.0$)

Year of construction completion = 1982

Actual base cost (USA/1980) = $32 \times \frac{219}{245}$

$= \$28.6 \times 10^6$

Average direct cost factor, L_D = 2.54

Process Data Materials of construction = Stainless steel ($M=1.2$)

Process capacity = 30×10^3 tons/annum

Number of process steps = 28 (see Table 3.1)

Estimated Cost, $C_{base} = (13.N.Q^{0.96}.L_D).L_I.M.L_F$

$= (13 \times 28 \times (30 \times 10^3)^{0.96} \times 2.54) \times L_I \times 1.2 \times 1.0$

$= 18{,}364{,}179 \times 1.446 \times 1.2 \times 1.0$

$= 31.9 \times 10^6$ (111% of actual base cost)

All the calculation results are based on average fixed capital investments at mid-point specific capacity. Their results are considered good as their accuracies range from +19% to -21%, which is within the accuracy range required in the research.

Note that due to lack of cost data in the secondary industry, only one example is given to the secondary recovery of lead from battery scrap.

5.5 Cost Model Comparison

The cost model A selected in the research is different from and more advantageous then the cost model B and the conventional cost models (6,7,17) in a sense that is is divided into three parts: direct costs (as defined in Table 4.12), indirect cost factor and other factors, such as materials of construction factor and location factor. The general cost model A is given below:-

$$C = \underbrace{(K.N.Q^b.L_D)}_{(1)}.\underbrace{L_I}_{(2)}.\underbrace{(M.L_P)}_{(3)}$$

where (1) = Direct costs

(2) = Indirect cost factor

(3) = Other factors

The advantages of the cost model A are as follows:-

(a) In some of the conventional cost models (6,7,17), the model constant, K changed as a function of process throughput or capacity, Q i.e. K decreases as Q increases, whereas the model constant derived in this thesis remains unchanged. This is due to the fact that economy of scale exists in the indirect costs (as discussed in sub-section 5.2.4), such that indirect costs per unit size (process throughput or capacity) decreases directly with the increase in size of the plant. Hence, by separating the capital cost into direct costs and indirect costs, this makes the model constant unchanged.

(b) The derived cost model A is more flexible than the conventional cost models in that it offers three types of investments:-

(i) New plant on new site
(ii) New plant on existing site
(iii) Extension on existing site

whereas the conventional cost models only offer the first type of investment

(c) As can be seen from the general cost model A, by substituting the direct cost factor of either 2.54, 1.99 or 1.54 (see Table 5.2), therefore, we can estimate three types of investments as mentioned in (b) and at the sametime, we have reduced indirectly estimate error by a factor of 2.54, 1.99 or 1.54 in direct costs which in turn reduce overall cost estimate error. In other words, it will improve estimate accuracies.

CHAPTER SIX

DEVELOPMENT OF TOTAL PRODUCT COST MODEL

A general cost model for estimating the fixed capital investment required for a non-ferrous production process is presented in the last chapter. Determination of the necessary capital investment is only one part of a complete cost estimate. Another equally important part is the estimation of total product cost or total operating cost. The total product cost can generally be broken down as shown in Figure 6.1, which is used as a check list for the operating cost elements (1).

Operating costs can be calculated on two basis: (i) Unit-of-product basis and (ii) Time basis. Unit-of-product basis is usually expressed as cost per thousand units of meansurement, eg. dollars per thousand pounds or per thousand gallons. This cost can be calculated from a knowledge of the requirements and their rates for the cost elements per unit of product. Time basis can be expressed as daily, monthly or annual operating cost. A daily, monthly or annual operating cost is calculated from the daily, monthly or annual product rate or capacity, and from the daily, monthly or annual quantities and rate for labour, raw-materials, utilities and other cost elements. However, the annual operating cost is probably the best choice for estimation of total product cost because:-

Figure 6.1 Check List For Operating Cost Elements

Raw materials	Direct production costs	Manufacturing costs	Total product cost
Operating labour			
Steam			
Electricity			
Fuel			
Refrigeration			
Water			
Maintenance and repairs			
Operating supplies			
Laboratory charges			
Royalties			
Depreciation	Fixed charges		
Taxes			
Insurance			
Medical	Plant overhead costs		
Safety and protection			
General plant overhead			
Payroll overhead			
Packaging			
Restaurant			
Recreation			
Salvage			
Control laboratories			
Plant superintendance			
Storage facilities			
Executive salaries	Administrative expenses	General expenses	
Clerical wages			
Engineering and legal costs			
Office maintenance			
Communications			

cont'd

Sales offices	Distribution and marketing expenses	General expenses	Total product cost
Salesmen expenses			
Shipping			
Advertising			
Technical sales service			
Research and development			
Financing			

(a) The effect of seasonal variation is smoothed out.

(b) It permits more-rapid calculation of operating costs at less than full capacity.

(c) It provides a convenient way of considering infrequently occuring but large expenses, eg. annual turn-around costs or replacement costs of a refractory.

Hackney (2) has classified operating costs into three categories:-

(a) Direct or variable costs (applying directly to the product and varying linearly with production rate).

(b) Semi-variable costs (varying non-linearly with production rate, eg. maintenance and repair costs tend to be lower at low production rates, but will be substantial even at zero production).

(c) Indirect or fixed costs.

This distinction is made here purely to point out one source of error in estimates for reduced production rates or for varied process capacities. In his three-category system, direct or variable items include raw material costs, byproduct credits, packaging and royalties. Semi-variable costs include depreciation, taxes, insurance, plant overhead, and general expenses.

In estimating the total product cost, the best source of information is data from similar or identical processes and most companies have extensive records of their existing operations, so that quick and reliable estimates of total product cost can be obtained for similar processes. Note also that adjustments for increased costs due to inflation must be made, and differences in plant site and geographical location must be considered. Besides, there are a few published data for quick estimation of operating costs and they are summarized as shown in Table 6.1

Nevertheless, the above sources of information for operating cost estimation are not suitable for new processes. Therefore, methods for estimating total product cost in the absence of specific information are discussed in the following sections and operating cost models are derived. The various cost elements are presented in the order shown in Figure 6.1.

6.1 Manufacturing Costs

Manufacturing costs are also known as operating costs, which include all expenses directly connected with the manufacturing operation. These expenses are divided into three groups as follows:-

(1) Direct production costs,
(2) Fixed charges, and
(3) Plant-overhead costs.

6.1.1 Direct Production Costs

These costs involve expenditures for raw-materials (including byproducts) direct operating labour; supervisory and clerical labour directly connected with the manufacturing operation; maintenance and repairs; operating supplies; utilities; and royalty.

Table 6.1 Published Data For Quick Estimation Of Operating Costs

	Peters & Timmerhaus (1)	Aries & Newton (3)	Jelen (9)	Holland, Watson & Wilkinson (5)	(6,7,8)
<u>Direct Production Costs</u>					
a) Raw materials	RMC	RMC	RMC	RMC	RMC
b) Operating labour	DLC	DLC	DLC	DLC	DLC
c) Operating supervision	10-25%DLC	10-25%DLC	10-25%DLC	-	10-20%DLC
d) Utilities	UC	UC	UC	UC	UC
e) Maintenance & Repair	2-10%C	2-10%C	3-6%C	1-5%C	2-6%C
f) Operating supplies	0.5-1%C	15%(e)	0.5-1%C	1-5%C	1-5%C
g) Laboratory charges	10-20%DLC	10-20%DLC	20%DLC	10-20%DLC	10-20%DLC
h) Patent & royalties	0-6%AS	1-5%AS	1-5%AS	1-5%AS	0-2%AS
<u>Fixed Charges</u>					
i) Depreciation	10%C	-	5-10%C	-	6-10%C
j) Taxes	1-4%C	1-2%C	2%C	2%C	1-2%C
k) Insurance	0.4-1%C	1%C	1%C	1%C	1-2%C
h) Rent	8-10% of rented property	-	-	-	-
<u>Plant Overhead Costs</u>					
m) General overhead	50-70% (b+c+e)	50-100%DLC	40-60%DLC	50-150%DLC	50-100%DLC
n) Payroll overhead		15-20%DLC	18-30%DLC	15-20%DLC	15-25%DLC

cont'd

General Expense

o) Administration	40-60%DLC	-	50%DLC	-	50%DLC
p) Distribution & Marketing	2-20%AS	-	1-3%AS (shipping)	-	-
q) Research & Development	2-5%AS	-	-	-	0-1%AS
r) Financing	0-7%C	-	6-8%C	-	8-12%C

where RMC = Annual raw materials cost
DLC = Annual direct (operating) labour cost
UC = Annual utilities cost
C = Fixed capital investment
AS = Annual sales

It should be recognized that some of the variable costs listed here as part of the direct production costs have an element of fixed cost in them, and they are called semi-variables, eg. maintenance and repair.

6.1.1.1 Raw Materials

The first cost item on the check list (Figure 6.1) is raw materials involved in the process. The amount of raw materials which must be supplied per annum can be determined from a knowledge of raw materials or concentrates assay, M (see Table 7.2) and overall metal loss, L expressed in percentage of metal product during processing (overall metal loss is only known through experience in the process involved, but literature review has shown that it may range from 0.5-2%). Therefore, the annual raw materials cost, RMC should be based only on the actual amount of concentrates consumed as determined from the annual output or process capacity, Q (defined earlier) and the net smelter value, NSV (as defined in Appendix C and its value is expressed in cents per pound of product), and is given below:-

$$RMC = \text{Actual Amount (lbs)} \times NSV$$

$$= (\text{Theoretical Amount (lbs)} \times \text{Actual Ratio}) \times NSV$$

$$\therefore \quad RMC = \left(\frac{2240 \times Q \times 100 (\text{lbs})}{M}\right) \times \frac{M}{(M-L)} \times \left(\frac{M^2}{100^2}(S-TSC)\right) \quad \text{(in cents/lb)}$$

$$= 0.224 \times Q \times M^2 \times (S-TSC)/(M-L) \quad \text{(in US Dollars)}$$

The prospective suppliers for raw materials are the miners who sell concentrates to the smelters according to the prices that are determined by the smelter contract (see Appendix C). Besides, even though bulk shipments are cheaper than smaller-container shipments, they require greater storage facilities and inventory. Consequently, the demands to be met in the smelter should be considered when deciding on the cost of raw materials.

6.1.1.2 Operating Labour

The estimation of operating labour cost is an important part of the total product cost because many other direct production costs, such as operating supervision, laboratory charges and plant overhead, are normally estimated as a percentage of operating labour (1,3,4,5). In addition, administration is often charged as a percentage of operating labour costs.

Labour requirements can often be estimated either from company experience with similar processes, or from literature information on similar processes (9). Another method of estimating labour requirements for a process is based on a careful study of various process steps in the process flowsheet. Wessel (10) made a study of the operating labour requirements in the US chemical industry and presented the data as a plot of man-hours per ton per processing step versus process capacity in tons per day in log-log paper. These data can be represented by the regression line as follows:-

$$\ln L = 2.93 - 0.788 \ln T + A$$

where L = operating labour, man-hours per ton per processing step

T = process capacity, tons/day

A = constant = 0.32 for batch operations

= 0 for operations with average labour requirements

= -0.54 for well instrumented continuous process operations

The above regression line may be conveniently expressed as:-

$$L = K_L.N.Q^{-0.788}$$

where L = operating labour, man-hours per ton

K_L = 25.8 for batch operation

= 18.7 for operation with average labour requirements

= 10.9 for well instrumented continuous process operation

N = process steps

Based on the same form of Wessel's labour-requirement equation and the limited data, such as process capacity, operating labour, number of process steps, the constant, K_L can be determined for non-ferrous metal production processes as follows:-

Process	Process Capacity Tons/ Annum	Labour Requirement, mhs/ton	Labour Requirement, mhs/ton	No. Of Modular Equipment Steps	K_L
Copper (6)	100,000	1,182,584	4,826	53	793
Zinc (8)	107,000	263,755	2,465	53	427
Lead (11)	100,000	269,280	2,693	47	499

Note that, the K_L value of 793 for copper process is exceptionally high. This is because copper process employs electrolytic refining which requires a large number of work-force than that of fire refining employed by zinc and lead process. On the other hand, the K_L values for zinc and lead process, i.e. K_L = 427 and 499 respectively are in agreement with each other. Therefore, their average value of 463 can be taken to represent K_L for the non-ferrous metal production processes. The operating labour requirement equation becomes:-

$$L = 463 \times N \times Q^{-0.788} \quad \text{(in man-hours/ton)}$$

(with the exception of any process that exploys electrolytic refining, then K_L will be 793 instead of 463).

Note that the above equation is based on processes with average labour requirements and no account has been taken to base on batch operation or well instrumented continuous process operation as there are insufficient data to do so.

For the purpose of economic evaluation, the annual direct labour cost, DLC will be:-

$$DLC = 463 \times N \times Q^{-0.788} \times Q \times R$$
$$= 463 \times N \times Q^{0.212} \times R \quad \text{(in US dollars)}$$

where R = direct labour rate (in US dollars per hour)

6.1.1.3 Direct Supervision

This cost item covers the expenses for foreman and direct operating supervision. It is closely related to the direct operating labour, complexity of the process, and product quality standards. The cost for direct supervision is estimated to average between 10 and 20% (6,7,8).

Direct supervision is considered to be a fixed expense at the level required for 100% capacity operation.

6.1.1.4 Utilities

The cost for utilities, such as electricity, process and cooling water, fuel oil, natural gas, coke, oxygen and compressed air varies widely depending on the amount of consumption, plant location, and source. The required utilities can sometimes be estimated in the early stages of development from available information about similar processes. However, such information cannot be employed for new processes. Therefore, it is useful to derive a utilities cost equation for a particular industry.

Bridgwater (12) wrote and checked a utilities cost equation for the chemical industry derived by Fidgett (13), who based on the analysis of the utilities costs of wide variety of processes and correlated these costs with such factors as number of process steps, N and process capacity, Q, and also used fixed capital investment, C as a factor to update utilities cost in the following equation:-

$$\text{Utilities Cost} = 0.748 \times (C/Q)^{0.751} \times N^{0.774}$$

The above equation can be modified into a suitable form that can be used by the non-ferrous metal production processes, such that:-

$$UC/Q = \text{annual utilities cost/ton}$$

$$= f(N,M)$$

or $UC/Q = K_U \times N \times M^c$

where K_U is utilities constant, which needs to be determined from the known average values of limited data, i.e. process capacity, number of process steps, concentrate assay and annual utilities cost. Note that the concentrate assay, M is included in the equation as it is considered to be an important determinant towards utilities cost in the non-ferrous metal production processes, and that the assay exponential factor, C is obtained from the correlation of average smelter charge ratio with concentrate assay. Their results of correlation are given in Table 6.2.

Table 6.2 Results Of Correlation

Process	Assay,m %	Average Smelter Charge Ratio x 100	Correlation Coefficient	Standard Error Of Estimation	Exponential Factor For Assay, C
Copper	20	100	-0.99	4.0×10^{-5}	-0.275
	30	87			
	40	82			
Zinc	50	100	-0.99	7.4×10^{-9}	-0.293
	60	95			
Lead	50	100	-0.99	1.76×10^{-4}	-0.774
	60	84.5			
	70	77.2			
Tin	20	100	-0.96	4.1×10^{-2}	-1.511
	35	66.4			
	50	34.5			
	70	14.5			

Note: Average smelter charge ratio is calculated as follows:-

	Total Smelter Charge*				Average Smelter Charge	Average Smelter Charge Ratiox100
Copper	1974	1975	1976	1977		
20%	16.5	20.4	22.7	21.0	20.15	100
30%	17.4	16.5	18.3	18.1	17.52	87
40%	17.4	15.5	16.4	16.3	16.4	82

* Extracted from Table C-5 to C-8 in Appendix C

The determination of utilities constant, K_U is illustrated in Table 6.3 and the final utilities cost equation for each process is summarized as follows:-

1) For copper process, $UC = 4 \times Q \times N \times M^{-0.275} \times \frac{PPI}{378.4}$

2) For zinc process, $UC = 4 \times Q \times N \times M^{-0.293} \times \frac{PPI}{378.4}$

3) For lead process, $UC = 21 \times Q \times N \times M^{-0.774} \times \frac{PPI}{378.4}$

4) For tin process, $UC = 1703 \times Q \times N \times M^{-1.511} \times \frac{PPI}{378.4}$

Table 6.3 Determination Of Utilities Constant

Process	Process Capacity Q tons/ annum	No. Of Modular Equip. Steps N	Annual Utilities Cost, UC \$/ annum (1980 basis)	Concentrate Assay, M %	Exponential Factor For Assay, C	Constant K_U \$/ton
Copper (51)	100,000	53	7,448,000	27	-0.275	4
Zinc (80)	107,400	53	7,217,200	55	-0.293	4
Lead (82)	100,000	47	4,686,080	50	-0.774	21
Tin (81)	15,250	38	1,607,911	70	-1.511	1703

Note:

$$K_U = \frac{UC}{M^C x Q x N}$$

The utilities costs are updated to Mid-1980 as base year used in the utilities cost equation. The Producer Price Index, fuels and related products, and power, PPI (see Table 6.4) is used for updating the utilities cost.

Table 6.4 The Producer Price Index, Fuels And Related Products, And Power (14)

Year	Producer Price Index, Fuels And Related Products, And Power, PPI
1970	106.2
1971	115.2
1972	118.6
1973	134.3
1974	208.3
1975	245.1
1976	265.6
1977	302.2
1978	322.5
1979	348.6
1980*	378.4
1981*	408.7
1982*	436.2
1983*	462.0

* Estimated

The reasons to use PPI instead of C as a factor to update the utilities cost are as follows:-

(a) The use of fixed capital investment, C as a factor to update the utilities cost implies that the investment and utilities cost escalate equally. Nevertheless, cost changes of the two in recent years do not support this assumption.

(b) Statistic analyses have shown that some components of operating cost, such as utilities and raw-materials costs correlate closely with the industrial commodities component of the Producer Price Index (14). Obviously, it gives better indication of utilities escalation ratio than that of investment. Forecasts of the index are offered by many econometric modelling services, such as INFORUM at the University of Maryland, Data Resources, INC. and Chase Econometrics Associates.

6.1.1.5 Maintenance And Repairs

In order to keep a plant in good operating condition, a considerable amount of expense for maintenance and repairs is unavoidable. These expenses include the cost for maintenance labour and materials, especially replacement of refractory for the smelting furnaces. Depending on the severity of operating conditions, and corrosiveness and erosiveness of processing materials involved, up to two replacements of refractory per annum can occur.

In non-ferrous metal smelting industry (6,7,8), annual cost for maintenance and repairs ranges from 2-6% of the fixed capital investment.

6.1.1.6 Operating Supplies

Operating supplies include reagents (eg. silica, iron, lime and soda ash), chemicals, lubricating oil, instrument charts, and similar supplies that cannot be considered as raw materials or maintenance and repair materials. The annual cost for this type of supplies (6,7,8) ranges from 1-5% of the fixed capital investment.

6.1.1.7 Laboratory Charges

The cost of laboratory analyses for control of operations and of product quality is covered in this item. It is usually calculated by estimating the man-hours involved and multiplying this by an appropriate rate. For quick estimates, this cost is taken as 10-20% of the operating labour cost (1,3,5).

6.1.1.8 Patents And Royalties

Many smelting processes are covered by patents and therefore, payments for the use of the patent must be made either as a paid-up royalty or as a running royalty. A paid-up royalty is a set amount for patent, rights and usually considered as part of the investment whereas running royalty is based on the amount of material produced.

Even though the company involved in the operation obtained the original patent, a certain amount of the total expense involved in the development and procurement of the patent right should be borne by the plant as an operating expense. Patent and royalty costs for patented processes (8) ranges from 0-2% of every sales dollar.

6.1.2 Fixed Charges

Certain expenses are always present in a process plant regardless of production rate. These expenses that are invariant with the production rate are designated as fixed charges. Fixed charges include depreciation local taxes and insurance, and they are a direct function of the fixed capital investment.

6.1.2.1 Depreciation

Depreciation is an allowance, as a cost for exhaustion and wear and tear on property in a process plant (for cash flow analysis, it is an allowance for tax relief). There are three widely used methods for calculating depreciation: (i) straight line, (ii) double-declining balance and (iii) sum of the years' digits. But, a straight-line method is usually assumed for engineering projects (1,6,7). In this method, an effective life expectancy and a zero salvage value at the end of the life expectancy are assumed, with due consideration being given to possibilities of obsolescence and economic changes. The difference between initial cost and the zero salvage value divided by the effective life expectancy gives the annual cost due to depreciation.

Many process equipment installations can be assumed to have a depreciation rate of 8%, indicating an effective life expectancy of 12½ years. However, installation subject to rapid deterioration or obsolescence should be depreciated at rates up to 20%, or possibly higher. For complete plant of non-ferrous metal production processes (6,7) including the usual proportion of long-life improvements, such as road, railroads, sewers, foundation and buildings, the annual depreciation rate ranges from 6-10% of the fixed capital investment, with the average value of 8% used in economic evaluation.

6.1.2.2 Local Taxes

The magnitude of local property taxes depends on the particular locality of the plant and the regional laws. Annual taxes for plants in highly populated areas may range from 2-4% of the fixed capital investment (15). But, for non-ferrous metal production plants, annual taxes are about 1-2% as they are normally situated in less populated areas.

6.1.2.3 Insurance

Many companies insure against losses from fire, explosions and product liability. The cost of this insurance depends on the nature of the process and on the extent of available protection facilities. On an annual basis, the insurance rate amounts to 1-2% of the fixed capital investment (6,7,8).

6.1.3 Plant Overhead Costs

Plant overhead costs include general overhead and payroll overhead. Expenses connected with general overhead are hospital and medical services, general engineering, safety services, packaging, restaurant and recreation facilities, salvage services, control laboratories, plant protection, distribution of utilities, shops, lighting, warehouse and storage facilities, janitor services, and interplant communications.

Payroll overhead include such costs as pension, social security, vacation allowances, life insurance, and redundancy. These charges are closely related to direct operating labour. For general overhead, it is estimated between 50-100% and for payroll overhead between 15-25% of direct operating labour cost (6,7,8).

6.2 General Expenses

Besides the manufacturing costs, other general expenses are involved in any company's operations. These general expenses include:-

1) Administrative expenses
2) Distribution and marketing expenses
3) Research and development expenses
4) Financing expenses

6.2.1 Administrative Expenses

Administrative expenses include costs for executive salaries, clerical wages, engineering and legal expenses, office maintenance including office supplies and upkeep on office buildings, and general communications. This cost item may vary markedly from plant to plant, but can be approximated as 40-60% of the operating labour (6,7,8).

6.2.2 Distribution And Marketing Expenses

Distribution and marketing expenses are costs incurred in the process of selling and distributing the various products. These costs include expenditures for products handling, containers, shipping, sales offices, salesmen, technical sales services, and advertising. These costs are in the range of 2-20% of selling price of the product for most chemical plants. However, they are negligible for non-ferrous metal smelting industry (6,7,8), as there are no marketing expenses involved and the transportation cost is borne by the buyers.

6.2.3 Research And Development Expenses

Research and development expenses are incurred by any progressive concern which wishes to remain in a competitive industrial position. These costs include salaries and wages for all personnel directly connected with this type of work, research facilities, and consultant fees related to developing new ideas or improved smelting processes. These costs are about 0-1% of every sales dollar (6,7,8).

6.2.4 Financing Expenses

Financing expenses that cover costs involved in procuring the money, necessary for the fixed capital investment and for working capital are usually limited to interest on borrowed capital. The interest rate for borrowed capital is influenced by the current economic situations, the company's credit standing and the term of the loan. The estimator should be alert to changes in all these factors, so that a reasonable interest rate is used. Annual nominal interest rate ranges from 8-12% of the total value of the borrowed capital for 1980 (1,4).

6.3 Total Product Cost Model

After reviewing the operating cost elements in the preceding section, the average value for each is taken and the summation of each cost element gives the total product cost in the form of equation. They are shown as follows:-

Raw material	RMC				
Operating labour		DLC			
Operating supervision		0.15DLC			
Utilities			UC		
Maintenance and repairs				0.04C	
Operating supplies				0.03C	
Laboratory charges		0.15DLC			
Patent and royalties					0.01AS
Depreciation				0.08C	
Taxes				0.01C	
Insurance				0.01C	

cont'd

General overhead	0.75DLC		
Payroll overhead	0.20DLC		
Administration	0.50DLC		
Research and development			0.005AS
Financing		0.10C	

Total product cost = RMC + 2.75DLC + UC + 0.27C + 0.015AS

The total product cost model derived above takes typical or mean values of all constituent elements of operating cost and provides no mechanism for adjustment in unusual circumstances. Bridgwater (16) has made a study of operating costs for the chemical industry and he has overcome this handicap by providing the typical, minimum and maximum values for each operating cost element together with circumstances that could affect the cost. His approach has been adopted here, but with adjusted values of operating costs for the non-ferrous metal smelting industry. They are given below:-

Operating Costs	Typical Value	Minimum Value	Maximum Value
(a) Raw materials	RMC		
(b) Labour	DLC		
(c) Utilities	UC		
(d) Supervision		Low level technology or high labour level	High level technology or low labour level
	0.15DLC	0.10DLC	0.20DLC

cont'd

	Operating Costs	Typical Value	Minimum Value	Maximum Value
(e)	Maintenance and repair	0.04C	Mild conditions, low utilisation 0.02C	Very corrosive, abrasive, high utilisation 0.06C
(f)	Operating supplies	0.03C	Simple process 0.01C	Complex process 0.05C
(g)	Laboratory charge	0.15DLC	Well established 0.10DLC	New product, high specification 0.20DLC
(h)	Patent and royalties	0.01AS	Old process 0	New process 0.02AS
(i)	Depreciation	0.08C		
(j)	Taxes	0.01C	Undeveloped area 0.005C	Developed area 0.02C
(k)	Insurance		Low risk 0.004C	High risk 0.02C
(l)	General overhead	0.75DLC	Large plant 0.5DLC	Small plant 1.0DLC
(m)	Payroll	0.20DLC	Developing country 0.15DLC	Developed country 0.25DLC
(n)	Administration	0.50DLC	Large plant 0.40DLC	Small plant 0.60DLC
(o)	Research and development	0.005AS	Old process 0	New process 0.01AS
(p)	Financing	0.1C	Low interest loan 0.08C	High interest loan 0.12C

Thus, the three levels of total product cost model are summarized in a general form:-

$$\text{Total product cost} = RMC + (K_1 \times DLC) + UC + (K_2 \times C) + (K_3 \times AS)$$

	K_1	K_2	K_3
where total product cost at typical value =	2.75	0.27	0.015
minimum value =	2.25	0.119	0
maximum value =	3.25	0.39	0.03

The above total product cost model will be incorporated in the economic evaluation of non-ferrous metal smelting processes (see Chapter 7 and Chapter 8).

CHAPTER SEVEN

ECONOMIC EVALUATION OF A NON-FERROUS METAL SMELTING PROCESS

7.1 Introduction

The object of this chapter is to show how the operating and capital cost models derived earlier are used to evaluate a non-ferrous metal smelting process. The copper smelting process is chosen for this study, which consists of a smelter, refinery and sulphuric acid plant. The smelter is based on the advanced technology of Mitsubishi Continuous Smelting Process, while the refinery design is based on the Jumbo tank system presently operating in the new No. 3 Tankhouse of the Onahama Smelting and Refinery Co. Ltd. in Japan.

Methods of estimating project profitability employed in the economic evaluation include:-

(a) Rate of return on original investment.
(b) Net present value.
(c) Discounted cash-flow rate-of-return.

7.2 Process Description

Texasgulf Canada's copper smelter and refinery at Timmins has selected the Mitsubishi continuous smelting process and the Onahama No. 3 tankhouse electrolytic refining technology for the production of cathode copper (1). Figure 7.1 shows a generalised flowsheet of the copper smelter and refinery, and Table 7.1 shows the modular equipment steps for

Figure 7.1 Generalised Flowsheet Of The Copper Smelter And Refinery

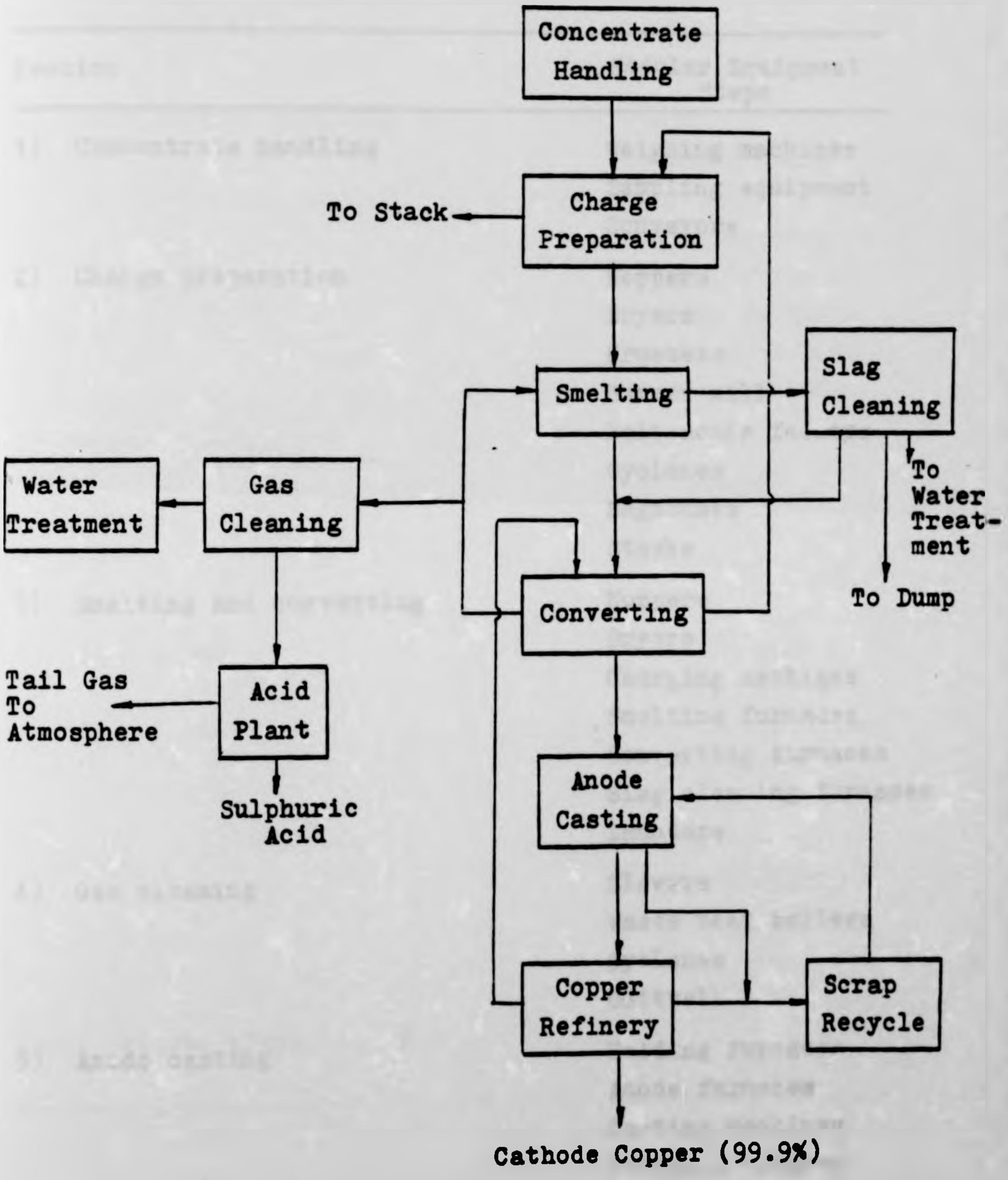


Table 7.1 Number Of Modular Equipment Steps For Each Section In The Generalised Flowsheet Of Copper Smelter And Refinery

Section	Modular Equipment Steps
1) Concentrate handling	Weighing machines Sampling equipment Conveyors
2) Charge preparation	Hoppers Dryers Crushers Hammer mill Belt-scale feeders Cyclones Baghouses Stacks
3) Smelting and converting	Hoppers Dryers Charging machines Smelting furnaces Converting furnaces Slag cleaning furnaces Launders
4) Gas cleaning	Blowers Waste heat boilers Cyclones Cottrell
5) Anode casting	Holding furnaces Anode furnaces Casting machines Stamping presses Stacking machines Mobile equipment

Section	Modular Equipment Steps
6) Scrap recycle	Melting furnace
	Holding furnace
7) Electrolytic refining	Pumps
	Charging cells
	Cranes
	Stripping machine
	Melting furnaces
	Casting machines
	Stacking machine
	Mobile equipment
8) Water treatment	Pumps
	Neutraliers
	Clarifiers
	Filters
	Tanks
9) Acid plant	Packed towers
	Cooling towers
	Mist precipitators
	Drying towers
	Blowers
	Converters
	Heat exchangers
	Absorbing tower
	Tanks

Total process steps = 52

each sections in the flowsheet.

The plant is designed to produce 65,000 tons/annum of cathode copper from a copper concentrate having the chemical analysis shown in Table 7.2. The concentrate contains approximately 5% moisture.

The production of sulphuric acid is a separate process, not necessary for the production of copper but mandatory for air pollution control.

Table 7.2 Chemical Analysis Of A Copper Concentrate (Dry Basis)

Concentrate	Percent
Copper	26.0
Iron	27.8
Sulphur	32.1
Zinc	5.0
Lead	0.96
Selenium	0.06
Indium	0.04
Silicate	4.0
Others*	4.04
Total	100.00

* Others includes 20 troy ounces of silver/ton of concentrate

7.2.1 Concentrate Handling And Charge Preparation

Copper concentrates are sent from mines to the smelter and unloaded to the concentrate storage building, where weighing and sampling operation are carried out. The concentrates are sent to Charge Preparation section by conveyors.

From the wet storage bins, the copper concentrates are fed into a rotary kiln dryer. The dried concentrates at an average 0.5% moisture content are caught in cyclones and a baghouse connected in series, and they are discharged into dry feed bins. The other materials which have been crushed and milled for the smelt, such as limestone, silica flux, slag and reverts are also dried and discharged into dry feed bins, with their respective belt-scale feeders and collector belts. After proportioning, (by means of belt-scale feeders) the combined materials are then charged into smelting furnaces.

7.2.2 Continuous Smelting Furnace Line

The continuous smelting line consists of three furnaces in series: a smelting furnace, a slag cleaning furnace and a converting furnace. These furnaces are interconnected by refractory lines, gravity-flow launders.

The furnace feed upon smelting separates into two layers - a 65% copper matte and a slag containing 30-34% silica. Due to the vigorous agitation of the furnace bath, a slag-matte mixture overflows the smelting furnace and flows via a natural gas heated launder to the slag cleaning furnace.

The slag cleaning furnace is heated by three in-line, 24-inch-diameter carbon electrodes. The copper and magnetite content of the furnace slag is reduced as it proceeds lengthwise down the furnace. The resultant slag then overflows into granulating launder. After granulation, the slag is trucked away to disposal area. Meantime, molten matte constantly overflows from an internal furnace forehearth into a natural gas heated launder leading to the converting furnace.

There are six lancing pipes in all, four of which feed a limestone-coolant-oxygen-air mixture (by blowers) to the convert furnace bath for slag formation. The other two direct an oxygen-enriched air blast onto the bath surface, supplying the oxygen (by blowers) necessary for the completion of the copper converting reactions. Blister copper overflows continuously from an internal, forehearth type collecting well into a natural gas heated launder, which leads into a holding furnace.

7.2.3 Anode Casting

The anode furnace charge consists of molten metal from the converter holding furnace and remelted copper in holding furnace from the recycled scrap melting furnace. Air and ammonia poling will be employed for anode furnace oxidation and reduction cycles. The resultant anode charge is then feed via launder into casting machine for producing continuous copper strip. From this copper strip, 145 kg commercial anodes complete with lugs are punched out by a stamping press, assembled on a rack and sent to copper refinery.

7.2.4 Copper Refinery

The electrolytic refinery of copper from the copper anode involves the electrolysis of copper sulphate by passage of a current from anode to an insulable cathode upon which the copper metal is deposited.

The electrolysis of the copper solution is carried out in cells, which are fabricated from mild steel, lined with rubber and PVC. Each cell has 45 anodes and 44 cathodes, spaced 42 mm apart (centre to centre). Sixteen cell lots arranged in line, side by side, are combined in one large tank, with all electrodes suspended in a common bath of electrolyte. The cells are operated with an applied voltage of 4 volts per tank and a current density of 200 amperes per square metre. The copper is deposited on cathode starting sheets.

These cathodes are removed from the tanks by means of a bridge-crane (cathode handling) at regular intervals of time for stripping. The stripped sheets are melted in a furnace (melting) and cast into slabs, (casting). Copper produced by the electrolytic process is of high grade quality, i.e. 99.9% Cu.

7.2.5 Water Treatment

In principle, waste waters from the gas and the slag cleaning section of the plant are recycled to the circuit. It is, however, necessary to remove a proportion of these waste waters from the circuit to avoid accumulation of elements, such as florine and chlorine which are mainly concentrated in the circulating scrubber solution.

These waste water bleed streams must be neutralized and treated for removal of heavy metals before waste disposal. The process involves the following steps. First, free acid is neutralized with limestone in the first tank, which overflows by gravity to the second tank until the final pH level required is achieved. To provide nuclei for particle growth, a stream of underflow solids slurry is pumped from the clarifier to the second continuously agitated neutralization tank. The overflow of the second neutralization tank goes to the clarifier. The effluent from the clarifier flows by gravity into a filter feed tank and is then pumped through the multimedia filters into a capacity effluent storage tank. Finally, overflow from the effluent storage tank is discharged to the river or sea.

7.2.6 Gas Cleaning

The gases at an average temperature of 1200°C from the smelting furnace and converting furnace carry some entrained liquid droplets and suspended solids and travel (by blowers) via a vertically inclined uptake flue into a two-stage waste heat boiler. In the radiation chamber, incoming gases are cooled to between 800°C and 600°C and some dust drops out before entering the second stage c convection chamber, where more dust drops out and the gases are further cooled to about 350°C. About 40% of the solids carry-over from the furnace is collected in the waste-heat boiler hoppers, and is finally returned to the smelting furnace along with balloon flue and cyclone dust.

From the waste heat boilers, the gases enter a common balloon flue where the gases are split to three parallel flue ducts. Each duct discharges into a cyclone and an electrostatic precipitator connected in series. Dust elimination is 99% complete when the gases leave the precipitator. The total dust loading of the gases entering the packed tower at the acid plant will be 0.5 g/m^3 or less. Precipitator dust containing a high zinc fume content will be sent to zinc smelter for zinc recovery.

7.2.7 Acid Plant

The gases from the gas cleaning section are scrubbed with weak acid in a packed tower to remove most of the remaining impurities. A final cooling of the gases takes place in two vertical heat exchangers connected in parallel before it enters a mist precipitator where all remaining impurities are removed. After leaving the mist precipitator, the gases pass through a drying tower countercurrent to a flow of 93% sulphuric acid for removal of all water vapour. The clean dry gases are forced through the plant by the <u>main blower</u>.

The conversion of SO_2 to SO_3 takes place in a "<u>three pass" catalytic converter</u>. As the SO_2 in the gases is converted to SO_3, heat is evolved and the gas temperature rises. If the temperature is allowed to rise excessively, only partial conversion can be obtained. Therefore, the gas is taken from the converter after each pass, cooled in external <u>heat exchangers</u> and returned to the next section of the converter. Upon leaving the final pass of the converter, the gases are cooled to the proper temperature for admission to the <u>absorption tower</u> where the SO_3 gas is scrubbed with 98-99% sulphuric acid to yield the product of the plant. Tail gases are normally vented to the atmosphere.

7.3 The Smelting Costs

The construction and operation of a modern copper smelter requires a large financing resource. Capital costs plus operating costs include provisions, not only for smelting of concentrates but must provide funds for the construction, maintenance, and labour needed to operate a large and efficient air and water pollution control facility. The cost estimate for the 65,000 ton/annum smelting operation presented in this study is based on the cost models (capital and operating) derived earlier and the results of cost estimation are compared with the real capital cost and operating labour requirement given by the two references (1,2) and they are found to be within the accuracy requirement. They are calculated as follows:-

7.3.1 Capital Costs

As mentioned in section 4.2, capital costs include: (i) fixed capital investment and (ii) working capital.

The fixed capital investment is calculated as follows:-

Cost Data

Fixed capital investment = US\$M 200

Location, L_F = Canada (L_F=1.15)

Year of construction completion = 1981 (PEI=236)

Average direct cost factor for new plant, new site, L_D = 2.54

Actual base cost (USA/1980) = $200 \times 10^6 \times \frac{219}{236}$

= $\$185.6 \times 10^6$

Process Data

Materials of construction = Stainless steel (M=1.2)

Process capacity, Q = 65,000 tons/annum

Number of process steps, N = 52

The capital cost model for copper smelting and refining process is:-

$$\text{Estimated Cost, } C_{base} = \underbrace{(63.N.Q^{0.82}.L_D)}_{\substack{\text{Direct}\\ \text{costs, DC}}}.L_I.M.L_F$$

Substituting the required data, we obtain:-

$$C = (63 \times 52 \times (65000)^{0.82} \times 2.54) \times L_I \times 1.2 \times 1.15$$

$$= 73{,}581{,}149 \times 1.3704 \times 1.2 \times 1.15$$

From equation, $L_I = 2.354 - 0.0543 \ln DC$, $L_I = 1.366$ whence $DC = 73{,}581{,}149$

$$\therefore \; C = \underline{\$139 \times 10^6 \text{ (75\% of actual cost)}}$$

Working capital is defined as the funds in addition to fixed capital investment that must be provided to operate the plant. Working capital is estimated from the following items:-

1) Raw-materials inventory (raw-materials and utilities costs/day x 30 days).

2) Product and in-process inventory (total product cost less depreciation per day x 30 days).

3 Account receivable (total product cost less depreciation per day x 30 days).

4 Cash available (total product cost less depreciation less raw materials cost per day x 30 days).

The estimated total capital investment is summarized in Table 7.3.

Table 7.3 Estimated Total Capital Investment

Fixed Capital Cost	139,000,000
Working Capital:	
Raw-materials inventory	737,117
Product and in-process inventory	4,297,407
Account receivable	4,297,407
Cash available	4,062,016
Working Capital Cost	13,393,947
Total Capital Investment	152,393,947

7.3.2 Total Product Cost

The estimated total product cost is based on the average of 330 days of operation per annum over the life of the plant. This allows 35 days downtime per annum for inspection, maintenance, and unscheduled interruptions. The total product cost model derived in section 6.3 is given below:-

$$TPC = RMC + 1.75DLC + UC + 0.27C + 0.015AS$$

where TPC = annual total product cost

RMC = annual raw-materials cost

DLC = annual direct labour cost

UC = annual utilities cost

C = fixed capital investment

AS = annual sales

Raw-Materials Cost Calculation

The annual raw-materials cost derived in sub-section 6.1.1.1 is given below:-

$$RMC = Q \times 22.4 \times \frac{M^2}{100} \times (S-TSC)/(M-L) \quad \text{(dollars)}$$

where Q = 65,000 tons/annum

M = 26%

S = 94.1 ¢/lb (for 1980)

L = metal loss is taken to be 0.8%

and from Table C-5 (see Appendix C), TSC at 20% = 29.0 ¢/lb and at 30% = 24.4 ¢/lb. Therefore, TSC at 26% = 26/(20+30) x (29+24.4)

= 27.8 ¢/lb

$$\therefore \; RMC = 65{,}000 \times 22.4 \times 26^2/100 \times (94.1 - 27.8)/(26 - 0.8)$$

$$= \underline{2{,}589{,}307 \text{ dollars}}$$

Direct Labour Cost Calculation

The direct labour requirements derived in sub-section 6.1.1.2 is given below:-

$$L = K_L \times N \times Q^{-0.788}$$

$$= 793 \times 52 \times 65000^{-0.788}$$

$$= \underline{6.65 \text{ mhrs/ton}}$$ (i.e. 100% of actual direct labour requirements)

Note: The actual direct labour requirements from reference (1) is given below:-

$$L = \frac{163 \text{ men per day} \times 8 \text{ mhrs per man} \times 330 \text{ days per annum}}{65{,}000 \text{ tons per annum}}$$

$$= \underline{6.62 \text{ mhr/ton}}$$

Assuming the direct labour rate for 1980 is $9.00 per hour, the annual direct labour cost will be (6.65 x 9 x 65,000) or$3,890,250

Utilities Cost Calculation

The annual utilities cost derived in sub-section 6.1.1.4 is given below:-

$UC = K_U \times M^c \times Q \times N$

where K_U = utilities constant = 4

c = assay exponential factor = -0.275

M = 26%

Q = 65,000 tons/annum

N = 52

$\therefore \quad UC = 4 \times 26^{-0.275} \times 65{,}000 \times 52$

$= \underline{\$5{,}518{,}983}$

Annual Sales

The annual sales will be given by:-

$AS = S \times Q \times 2240$

$= 94.1 \times 65{,}000 \times 2240/100$

$= \underline{\$1.37 \times 10^8}$

$$\therefore \text{TPC} = \text{RMC} + 1.75\text{DLC} + \text{UC} + 0.27\text{C} + 0.015\text{AS}$$
$$= 2{,}589{,}307 + (2.75 \times 3{,}890{,}250) + 5{,}518{,}983 + (0.27 \times 139 \times 10^6) + (0.015 \times 1.37 \times 10^8)$$
$$= \underline{\$58{,}391{,}478}$$

And, the annual total product cost less depreciation is given by:-

$$\text{TPCLD} = \text{TPC} - 0.08\text{C}$$
$$= 58{,}391{,}478 - 0.08 \times 139 \times 10^6$$
$$= \underline{\$\ 47{,}271{,}478}$$

7.4 Profitability

Profit is the obvious goal of investment in any enterprise, and though there are many others, this is the only one quantifiable and therefore useful for economic evaluation. The ratio relating profit to investment in some manner is known as rate of return on investment. There are a few methods of expressing rate of return on investment (3), such as rate of return on:-

(a) Original investment,
(b) Depreciated investment, and
(c) Average investment.

The rate of return on original investment is only employed for the economic evaluation, i.e.

$$\text{Percent rate of return} = \frac{\text{Annual Profit}}{\text{Original Investment}} \times 100$$

Among the other profitability indicators, the net present value and discounted cash-flow rate-of-return methods are incorporated into cash flow analysis. The methods have been discussed in some depth in previous publications (4,5). They are briefly described as follows:-

The present value, PV for a cash flow C_t occuring in year t from present is given by:-

$$PV = \frac{C_t}{(1+i)^t}$$

The present values can be summed for a capital investment project typically involving negative (expenditure) cash flows and positive (income) cash flows over the entire life of the project, to give a net present value, NPV for the project:-

$$NPV = \sum \frac{C_t}{(1+i)^t}$$

where $1/(1+i)^t$ is the discount factor and i is discounted cash-flow rate-of-return.

The interest rate of return on investment after tax can either be calculated manually as shown in Table 7.4 or by computer as shown in Appendix D-3, in which much detailed-computation results of operating costs are given. The percent of return for the copper smelting process in this case is 26%, which is sufficient to allow the process to be considered economically attractive.

In addition, present value of constant cash flow is computed, based on a 50% corporate tax rate for the ten year period and using discount factors on 20% discount rate of return. Depreciation allowance based on straight-line method is included in the cash flows as an allowance to reduce the annual amount of tax.

Table 7.4 Return On Investment Calculation

Annual sales	$137,000,000
Annual total product cost	58,391,478
Annual depreciation	11,120,000
Annual total product cost less depreciation	47,271,478
Net annual profit before tax	78,608,522
Corporate tax at 50%	39,304,261
Net annual profit after tax, a	39,304,261
Total capital investment, b	152,393,947
Return on investment, (a/b) x 100	26%

CHAPTER EIGHT

ECONOMIC EVALUATION OF NON-FERROUS METAL SMELTING PROCESSES - BY COMPUTER

8.1 Introduction

The use of computers to remove the burden of routine calculations is becoming more prevalent. Versatile computer programs can generate the necessary analytical information in a fraction of a minute instead of a day normally required by means of manual calculation, and thereby allow the evaluator to concentrate upon his primary functions of analysis and interpretation.

This chapter describes two such computer programs, effectively employed for the economic evaluation of non-ferrous metal smelting processes. Both computer programs are written in BASIC on VAX system at Stirling University. The first program called EVAL is used to assess the potential economic worth of those smelting projects in the early stages of development when minimum information is available. The program is based on the cost estimating models derived earlier and translate the available data into a complete profit and loss statement encompassing all of the cost elements associated with manufacture of the product. The second program called CFA presents cash flow analysis, in which net present value and discounted cash-flow rate-of-return methods are used in the program.

8.2 EVAL Program Description

The EVAL program is designed to be as simple and as versatile as possible in a sense that firstly, it does not require specific knowledge or detailed background with regard to operating and capital costs and secondly, all you need to do is to type in the input data required for the program. The input data is listed in Table 8.1. Other cost-generating components not directly required as inputs are produced by specific sub-programs, such as:-

1) Fixed-capital investment,
2) Raw-materials,
3) Direct labour, and
4) Utilities.

and then, the master display program uses the outputs of the sub-programs, together with built-in relationships (see Table 8.2) for determining total product cost and working capital to generate a complete profit and loss statement, and return on investment of a mature year.

As mentioned earlier, the EVAL program is designed to be as versatile as possible. In this interest, the sub-programs for determining fixed capital investment, raw-materials cost, direct labour cost and utilities cost can be bypassed at the user's option, and they can be entered as direct data input to the master display program.

The structure of the EVAL program is depicted in detail diagramatically in Figure 8.1. Note that the program

Table 8.1 Data Required For The Economic Evaluation Of Non-Ferrous Metal Smelting Processes

---

Process Inputs

1) Type of process eg. Copper, Zinc, Lead or Tin.
2) Concentrate Assay in percentage.
3) Process capacity in ton/annum.
4) Number of process steps.

Economic Inputs

1) Location factor.
2) Year of construction completion.
3) Direct labour rate in US dollar or Pound Sterling/hour.
4) Byproduct credit.
5) Average annual metal price in US cents or pence/Pound.
6) Tax rate in percentage.
7) Exchange rate for currency.

Optional Inputs

1) Cost Index.
2) Fixed capital investment.
3) Direct labour cost.
4) Raw-materials cost.
5) Utilities cost.

Table 8.2 Costs Set By Built-In Relationships

Supervision	15% of direct labour
Maintenance	4% of fixed capital investment
Operating supplies	3% of fixed capital investment
Laboratory charge	15% of direct labour
Royalties	1% of annual sales
Depreciation	8% of fixed capital investment
Local taxes	1% of fixed capital investment
Insurance	1% of fixed capital investment
General overhead	75% of direct labour
Payroll overhead	20% of direct labour
Administration	50% of direct labour
Research & Development	½% of annual sales
Financing	10% of fixed capital investment
Working capital	Raw-materials inventory (raw-materials and utilities costs per day x 30 days) + Process in progress plus product inventory (total product cost less depreciation per day x 30 days) + Account receivable (total product cost less depreciation per day x 30 days) + Cash available (total product cost less raw-materials cost per day x 30 days)

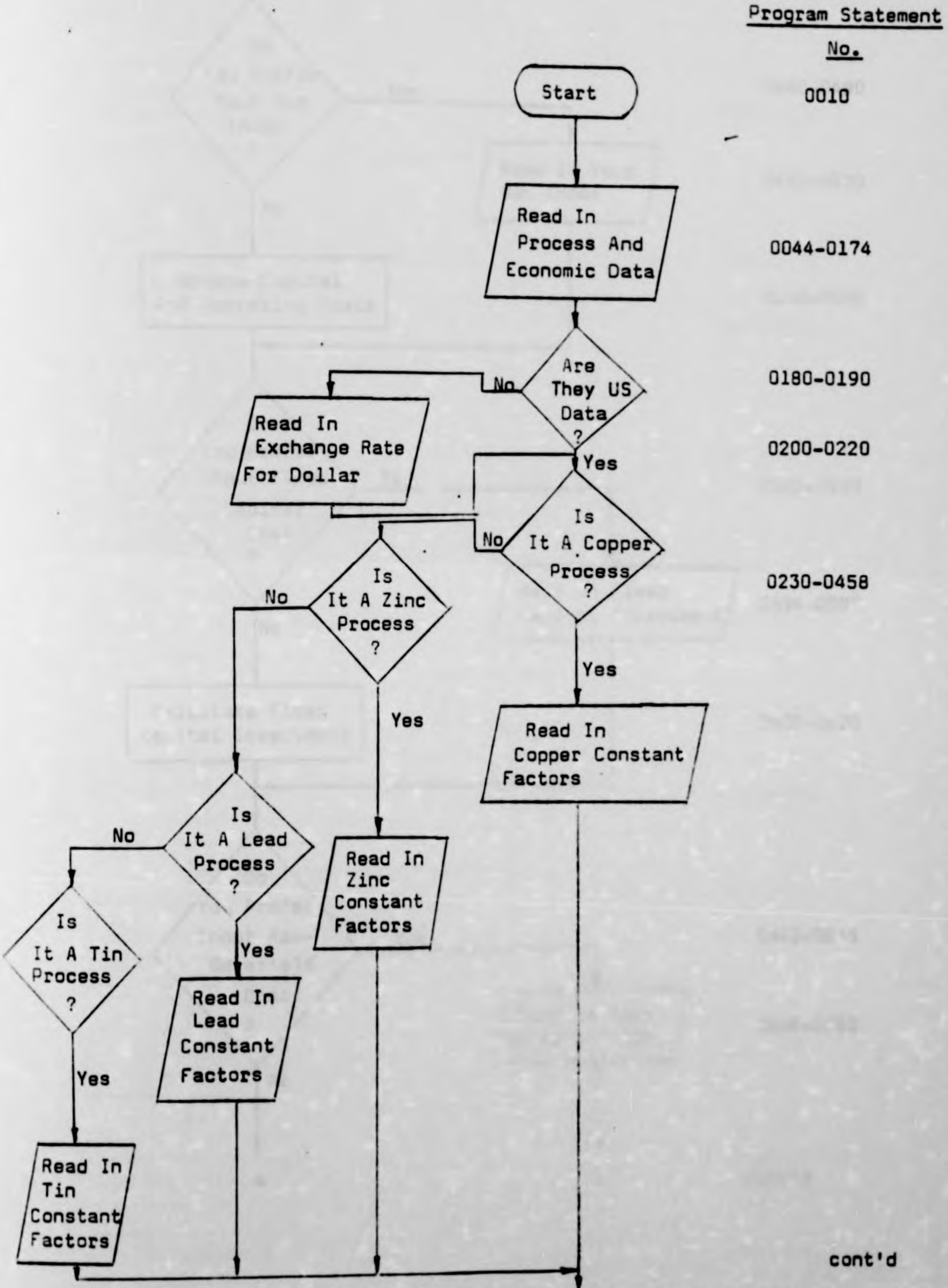


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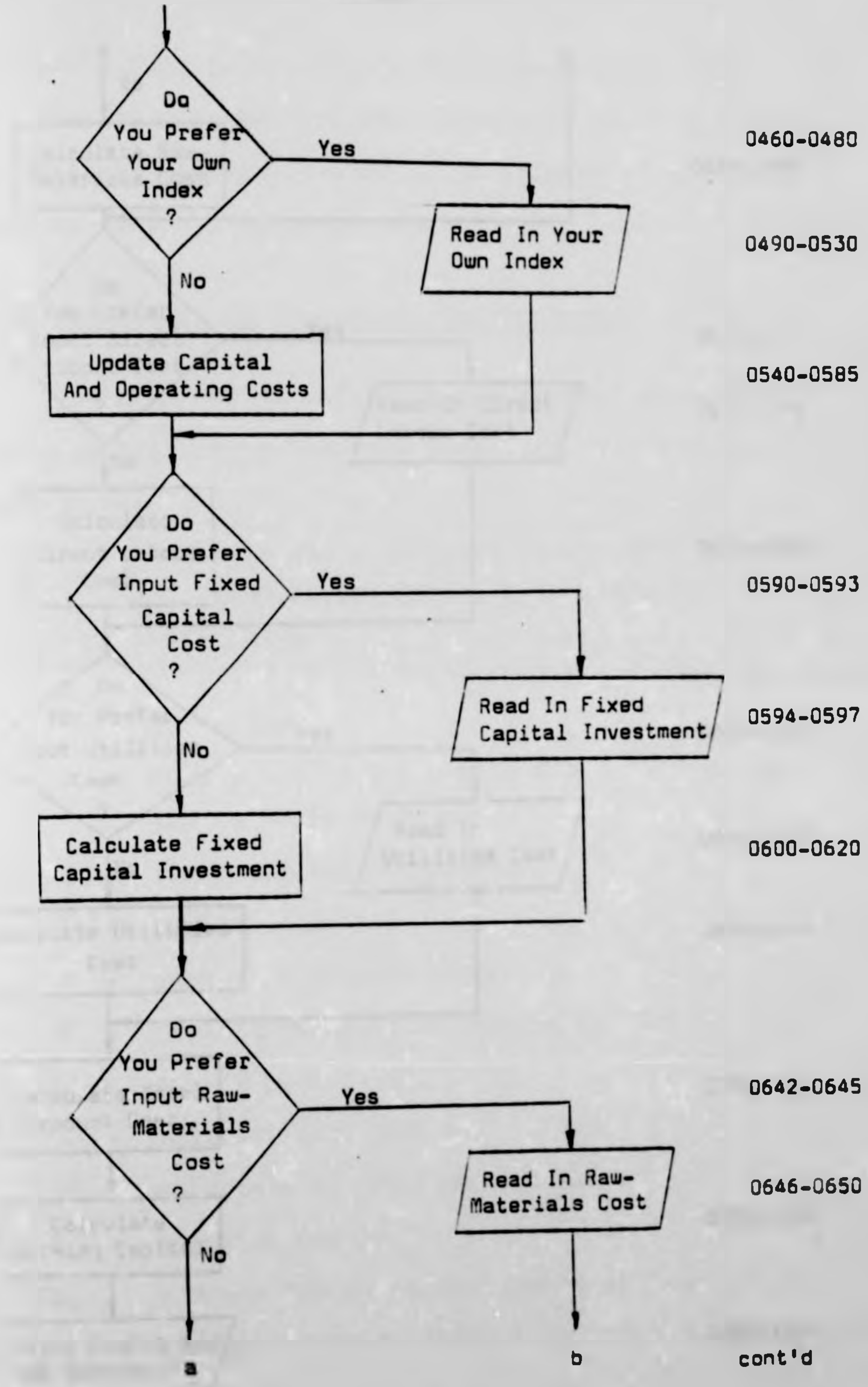
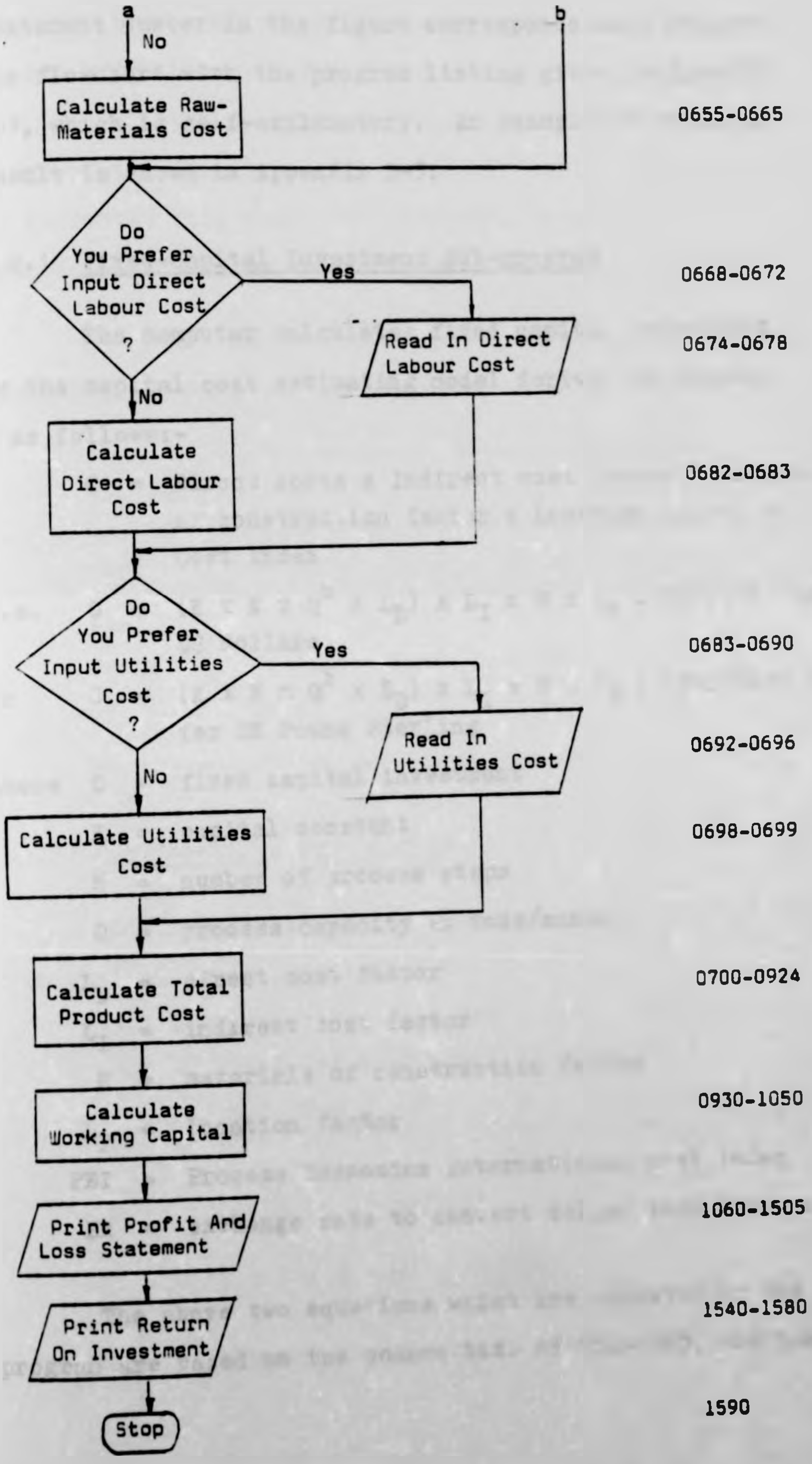
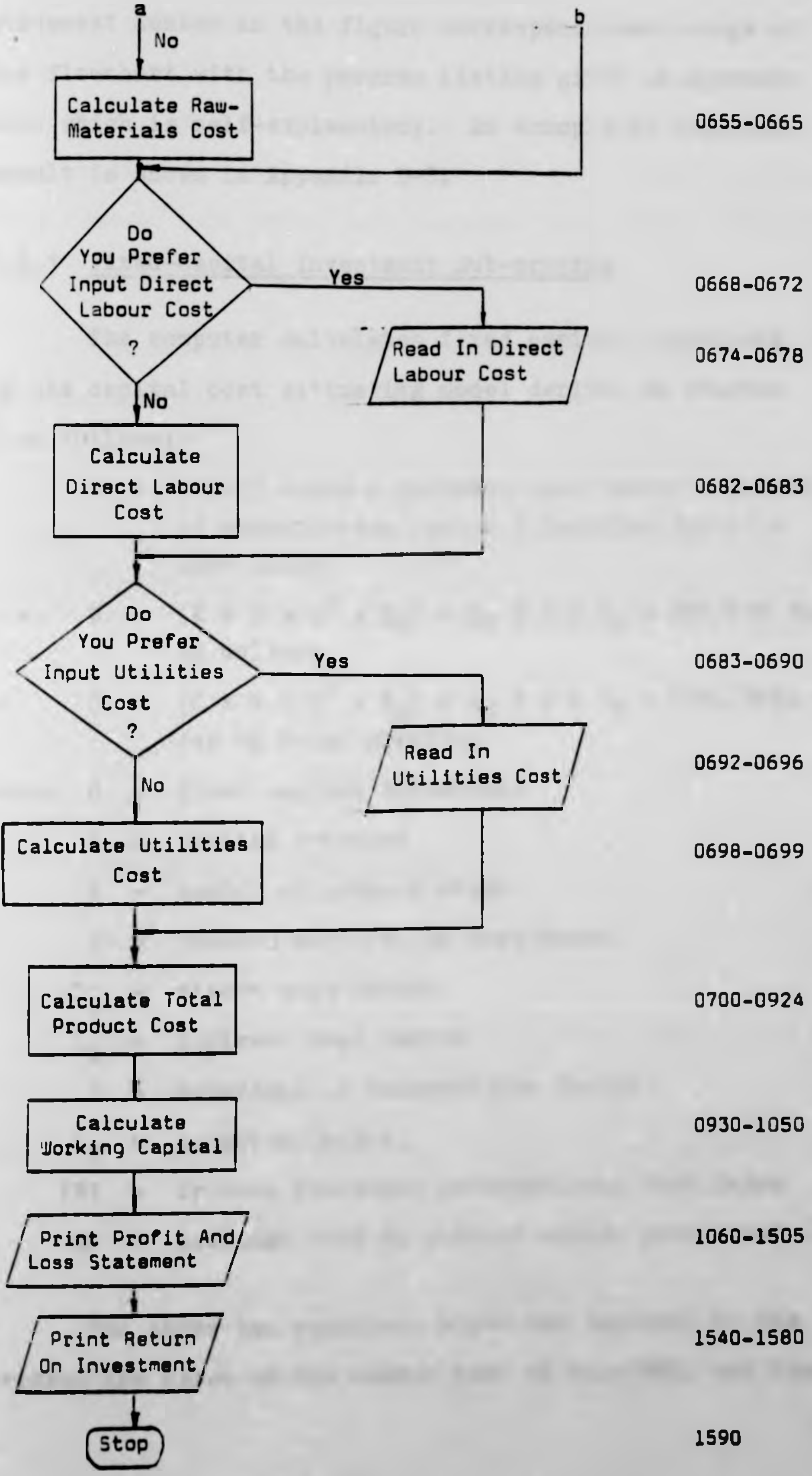
Figure 8.1 Flowchart For Economic Evaluation Of Non-Ferrous Metal Smelting Processes


Do You Prefer Your Own Index ?
Yes
No
Read In Your Own Index
Update Capital And Operating Costs
Do You Prefer Input Fixed Capital Cost ?
Yes
No
Read In Fixed Capital Investment
Calculate Fixed Capital Investment
Do You Prefer Input Raw-Materials Cost ?
Yes
No
Read In Raw-Materials Cost
a
b
0460-0480
0490-0530
0540-0585
0590-0593
0594-0597
0600-0620
0642-0645
0646-0650

cont'd


a
b
No
Calculate Raw-Materials Cost
0655-0665
Do You Prefer Input Direct Labour Cost ?
Yes
0668-0672
Read In Direct Labour Cost
0674-0678
No
Calculate Direct Labour Cost
0682-0683
Do You Prefer Input Utilities Cost ?
Yes
0683-0690
Read In Utilities Cost
0692-0696
No
Calculate Utilities Cost
0698-0699
Calculate Total Product Cost
0700-0924
Calculate Working Capital
0930-1050
Print Profit And Loss Statement
1060-1505
Print Return On Investment
1540-1580
Stop
1590


a
No
b
Calculate Raw-Materials Cost
0655-0665
Do You Prefer Input Direct Labour Cost ?
Yes
0668-0672
Read In Direct Labour Cost
0674-0678
No
Calculate Direct Labour Cost
0682-0683
Do You Prefer Input Utilities Cost ?
Yes
0683-0690
Read In Utilities Cost
0692-0696
No
Calculate Utilities Cost
0698-0699
Calculate Total Product Cost
0700-0924
Calculate Working Capital
0930-1050
Print Profit And Loss Statement
1060-1505
Print Return On Investment
1540-1580
Stop
1590

statement number in the figure corresponds each stage of the flowchart with the program listing given in Appendix D-1, which is self-explanatory. An example of computer result is shown in Appendix D-3.

8.2.1 Fixed-Capital Investment Sub-program

The computer calculates fixed capital investment by the capital cost estimating model derived in Chapter 5 as follows:-

C = Direct costs x Indirect cost factor x Material of construction factor x Location factor x Cost index

i.e. $C = (K \times N \times Q^{b} \times L_D) \times L_I \times M \times L_P \times PEI/219$ for US dollars

or $C = (K \times N \times Q^{b} \times L_D) \times L_I \times M \times L_P \times (PEI/385) \times ER$ for UK Pound Sterling

where C = fixed capital investment
K = capital constant
N = number of process steps
Q = process capacity in tons/annum
L_D = direct cost factor
L_I = indirect cost factor
M = materials of construction factor
L_P = location factor
PEI = Process Economics International Cost Index
ER = exchange rate to convert dollar into Pound Sterling

The above two equations which are employed by the program are based on the common time of Mid-1980, and the former predicts costs in millions of US dollars and the latter in millions of Pound Sterling at this time. Thus, cost index, such as Process Economics International (PEI) plant cost index is used to update US and UK cost respectively at different base year. The computer program also allows user to input his own cost index if necessary.

The built-in constants used by the program for each process are summarized as follows:-

Process	K	b	L_D	M
Copper	63	0.82	2.54	1.2
Zinc	11	0.95	2.54	1.2
Lead	13	0.96	2.54	1.2
Tin	22	0.93	2.54	1.2

8.2.2 Raw-Materials Sub-program

The raw-materials cost, RMC per annum is calculated from the following equation:-

RMC = Theoretical quantity x Actual ratio x Raw-materials cost (cent or pence/lb)

$$\text{or} \quad RMC = \left(\frac{Q \times 2240 \times 100}{M}\right) \times \left(\frac{M}{M-L}\right) \times \left(\frac{M \times (S-TSC)}{100^2}\right) \times \frac{1}{100}$$

(dollars or pounds)

$$= 0.224 \times Q \times M^2 \times \frac{(S-TSC)}{(M-L)}$$

where RMC = raw-materials cost in dollars or pounds/annum

Q = process capacity in ton/annum

M = actual metal content in percentage

L = metal loss during processing (usually taken to be 0.8%)

S = annual average metal price in cents or pence/lb

TSC = total smelter charge in cents or pence/lb

The total smelter charge for each non-ferrous metal smelting process is calculated from one of the regression lines given in Table C-9 (see Appendix C) according to the assay range. For instance, if the concentrate assay for a copper process is within 15-25%, then the computer will select the appropriate regression line, i.e.

$$TSC = 1.868Y - 3669.6$$

from the Table C-9. The assay range used by the program is summarized below:-

Process	Assay range, %
Copper	15 - 45
Zinc	45 - 65
Lead	45 - 75
Tin	15 - 75

8.2.3 Direct Labour Sub-program

The computer calculates direct labour cost by means of the cost model derived in Chapter 6 (sub-section 6.1.1.2) as follows:-

$$L = K_L \times N \times Q^{-0.788} \text{ (man-hours/ton)}$$

or $$DLC = K_L \times N \times Q^{-0.788} \times Q \times R \text{ (dollars or Sterling/Pounds}$$

where L = operating labour in man-hours/ton

DLC = direct labour or operating labour cost in dollars or Pound/Sterling

K_L = labour constant = 463

N = number of modular equipment steps

Q = process capacity in tons/annum

R = direct labour rate in dollar or pound/hour

8.2.4 Utilities Sub-program

The computer calculates utilities cost by the cost model derived in Chapter 6 (sub-section 6.1.1.4) as follows:-

$$UC = K_U \times M^c \times Q \times N \times \frac{PPI}{378.4} \times ER$$

where UC = utilities cost in dollar or pound/annum

K_U = utilities constant

M = concentrate assay

Q = process capacity in tons/annum

N = number of modular equipment steps

c = exponential factor for M

PPI = producer price index, fuels and related products, and power (= 378.4 at base year of 1980)

Note that exchange rate, ER is included in the utilities cost model to convert dollar into Pound Sterling.

Since the utilities constant, K_U and the exponential factor, c are not the same for each process, the computer will select the appropriate ones. Their values are summarized below:-

Process	K_U	c
Copper	4	-0.275
Zinc	4	-0.293
Lead	21	-0.774
Tin	1703	-1.511

8.3 CFA Program Description

The CFA program predicts profitability (see section 7.4) of the venture in terms of cash flows for N years. It is a flexible and useful tool in project analysis because it saves time, standardizes computational procedures and provides a uniform manner of presenting results to management. It requires first three such inputs as fixed capital investment, tax rate, discounted cash-flow rate of return, and then sales income and total product cost less depreciation for N years.

The structure of the CFA program is depicted in detail diagramatically in Figure 8.2.Similarly, the program statement number in the figure corresponds each stage of the flowchart with the program listing given in Appendix D-2, which is self-explanatory. An example of computer result is shown in Appendix D-4.

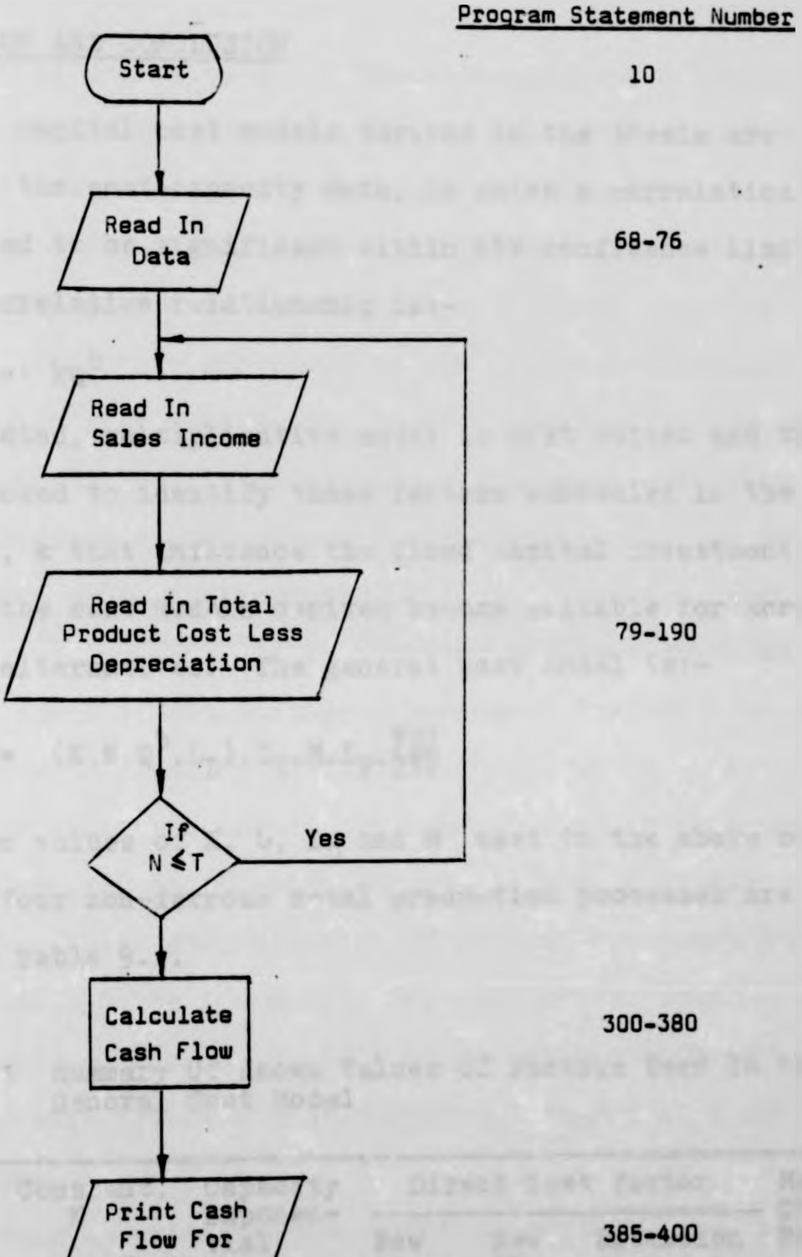


Figure 8.2
Flowchart For
Cash Flow
Analysis

CHAPTER NINE

DISCUSSION AND CONCLUSION

The capital cost models derived in the thesis are based on the cost-capacity data, in which a correlation was proved to be significant within 95% confidence limit. Their correlation relationship is:-

$$C = kQ^b$$

As indicated, multiplicative model is best suited and theory was proposed to identify those factors concealed in the constant, k that influence the fixed capital investment, C so that the cost models derived become suitable for screening project alternatives. The general cost model is:-

$$C = (K.N.Q^b.L_D).L_I.M.L_F.\frac{PEI}{219}$$

The known values of K, b, L_D and M used in the above model for the four non-ferrous metal production processes are given in Table 9.1.

Table 9.1 Summary Of Known Values Of Factors Used In The General Cost Model

Process	Constant, K	Capacity Exponential Factor, b	Direct Cost Factor			Material Of Construction Factor, M
			New Plant On New Site	New Plant On Existing Site	Extension On Existing Site	
Copper	63	0.82	2.54	1.99	1.54	1.2
Zinc	11	0.95	2.54	1.99	1.54	1.2
Lead	13	0.96	2.54	1.99	1.54	1.2
Tin	22	0.93	2.54	1.99	1.54	1.2

The factors in the general cost model are summarized below:-

(a) Process Capacity, Q - The cost-capacity relationship was shown to be a very powerful cost predictor with good accuracies being obtained with the source data. It is always known right from the conceptual design development stage and therefore it is on this that the simplicity and speed of the technique depends.

(b) Modular Equipment Steps, N - As defined, N does not depend on individual pieces of equipment but rather on identified blocks of equipment serving the same function in the process stream and it is designated as modular equipment steps. It is also on this that the simplicity and speed of the technique depends. However, the main source of error in estimating the fixed capital investment for a specified smelter is likely to arise from personal differences as to what constitutes a modular equipment step. Therefore, the list of modular equipment steps given in Table 2.1 and 3.1 is intended to familiarize oneself with the type of modular equipment steps, so that this personal factor need not represent a sizeable error.

(c) Process Materials of Construction Factor, M - It is a significant cost predictor. The materials of construction for non-ferrous metal production processes including Cu, Zn, Pb and Sn are mostly stainless steel, in which process materials of construction factor was calculated to be 1.2. It is considered the factor 1.2 is a good approximation for the capital estimation.

(d) Lang Factors, L_D & L_I - Lang factors are conveniently divided into direct and indirect cost factors. It has been shown that indirect cost factor is not a constant factor, but varies inversely with direct costs. The indirect cost factor, L_I can only be determined soon after direct costs, DC have been known from the equation:- $L_I = 2.354 - 0.0543 \times \ln DC$. The direct cost factors, L_D for three types of investment in a smelter are given in Table 9.1. There is already evidence that by separating Lang factors into direct and indirect cost factors, it would improve estimate accuracies. This view is supported by John Cran (7).

(e) Location Factors, L_F - These were clearly shown to improve estimate accuracies in the test results. However, complications exist, which need to be considered before using any published location factor. Because the major factors, such as productivity, exchange rates, inflation and labour cost which influence location factors, are constantly changing relative to each other with time. Then, it is expected that location factors will also change with time and thus they are applicable for short terms only, say two to three years after their publication. Bridgwater has published a list of location factors for a total of 34 countries (see Table 5.5).

(f) Model Constant, K - This is a possible weak point in the research and its accuracy depends very much on the data source.

(g) Cost Index, PEI - As indicated, the capital cost model was developed on the basis of updated cost to Mid-1980. Process Economics International (PEI) cost index was used to update costs. Though it is not the most sophisticated index available, it does not show any significant variation with comparable indices and as such it was considered satisfactory for use in the research. However, an index problem does exist because of the defects in their derivation, such that:-

- It completely ignores the magnitude and effect of market forces, eg. supply and demand
- It reflects no technological change or breakthrough
- It does not account for learning curve, improvement in construction technique and major productivity change

Thus, error can result in the cost estimation. It is recommended that by revising and updating the base year every two years, the error will be minimised.

In paralled with the research on developing capital cost model, an overall general total product cost model, TPC was also derived:-

$$TPC = RMC + (K_1 \times DLC) + UC + (K_2 \times C) + (K_3 \times AS)$$

The above equation takes typical, minimum and maximum values for the total product cost according to the circumstances that could affect the cost (section 5.5). They are summarized below:-

Total Product Cost	K_1	K_2	K_3
Typical value	2.75	0.27	0.015
Minium value	2.25	0.119	0
Maximum value	3.25	0.39	0.03

The total product cost model was based on the contribution of individual costs to the total product cost. Methods for estimating these individual costs are based on certain percentage of either direct labour cost, capital cost or sales, with the exception of raw-materials, direct labour and utilities costs. And, they are estimated from the following equations:-

(a) $RMC = 0.224 \times Q \times M^2(S-TSC)/(M-L)$

(b) $DLC = K_L \times N \times Q^{0.212} \times R$

(c) $UC = K_U \times M^c \times Q \times N \times \frac{PPI}{378.4}$

Two computer programs called EVAL and CFA were written in BASIC. Their main purpose is to generate economic evaluation in a fraction of a minute, and thereby allow the evaluator to concentrate upon his primary functions of analysis and interpretation.

In conclusion, the research has achieved its objectives, which are summarized as follows:-

- Quick and simple to use - This objective is fully met as the estimating method is based on multiplicative type of model, which can produce not only quick but cheap estimates just by substituting the known values of relevant factors

- Capable of utilizing a minimum information - In the early design, or investigative stage of a project, a minimum amount of process information usually exists. Therefore, cost models were derived based on the minimum information that is likely to be available during screening study activities, i.e. process capacity, number of process steps, materials of construction, together with the non-process data, such as plant location and planned-construction completion date of the plant, so that the cost models derived have no obvious information constraints during application
- Accurate to within +30% to -25% - Test results for four primary processes of copper, zinc, lead and tin and one secondary recovery of lead were proved to be accurate within +20% to -21%, which are considered to be very satisfactory for screening alternatives
- Successfully incorporated into computer programs for the purpose of economic evaluation - The cost models derived are incorporated into computer programs written in BASIC, which can generate the necessary analytical information in a fraction of a minute instead of a day normally required and thereby allow the evaluator to concentrate upon his primary functions of analysis and interpretation
- Successful achievement of the overall general product cost model - The general model is only applicable to the primary production of non-ferrous metal smelting processes

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- Successful achievement of the overall general product cost model - The general model is only applicable to the primary production of non-ferrous metal smelting processes

CHAPTER TEN

SUGGESTIONS FOR FUTURE WORK

The suggestions for future work are as follows:-

Cost Data Standardisation

Although the stated research objectives (summarized in the last chapter) have been largely achieved, there is no doubt room for improvement. One important point that need to be emphasized again is that this research work was based on limited amount data. Thus for future work in this area of cost-estimating, this major problem must be overcome and the following data from number of plants, must be obtained:-

1) Cost Data - (a) Equipment costs (which are then built up to give delivered equipment cost, see Table 4.14)
    - (b) Direct costs (which are derived from delivered equipment cost factored for installation, instrumentation, building, etc., see Table 4.12)
    - (c) Indirect costs (see Table 4.12)
    - (d) Capital cost for three types of investment

2) Process Data - (a) Process size or capacity
    - (b) Modular equipment steps
    - (c) Materials of construction
    - (d) Mass balance data

3) Non-process Data - (a) Location of the plant.
(b) Completion date of construction.

The above cost data obtained from different locations and time must be brought to a common base by an appropriate cost index. The data can be obtained from the following two sources:-

1) Industrial source data of known reliability should be obtained from various interested parties, particularly the contracting firms who possess the most abundant data. Unfortunately, individual firm's confidentiality of data and their reluctance to provide the necessary cost data for academic purposes thus makes this data source unlikely to materialise. This view towards academic research work should be challenged for the work done by research students do contribute very much to the company (even national) economy and her progress.

2) As the industrial source data is difficult to obtain, this leads the academic researchers to depend on published cost data, which tends to be ill-defined and are not always reliable. In addition, the published cost data are widely scattered in the literature and often require considerable time to find. And even when cost data are found for the equipment one is interested in, for example, cost may not be given for units of the sizes one wants. Also, inflation rapidly renders cost data obsolete. Hence, considerable research effort must be required in searching, screening and standardising

cost data, and finally compiling a data base for future research. Furthermore, the research centres in this field should develop a centralised cost data management facility, so that resources can be pooled and information transferred.

Theory

With the above data now supplemented with the results of further analysis and investigation, the cost model derived in this thesis can be further refined by the following alternative approach:-

Firstly, the correlation between direct costs, DC and the process capacity, Q, and number of modular equipment steps N is performed and we obtain the following equation:-

$$DC = K_{xy}.Q^{x}.N^{y} \qquad ...(1)$$

A direct cost factor, L_D is introduced by multiplying L_D on both sides of equation (1). Therefore, we have:-

$$DC.L_D = K_{xy}.Q^{x}.N^{y}.L_D$$

or

$$DC = K.Q^{x}.N^{y}.L_D \qquad ...(2)$$

where

$$K = \frac{K_{xy}}{L_D}$$

The fixed capital investment, C is given by the following equation:-

$$C = \text{Direct costs} + \text{Indirect costs}$$

or

$$C = DC + IC \qquad ...(3)$$

There is a general relationship between indirect costs and direct costs. O'donnel (6) confirmed this relationship by plotting indirect costs versus plant cost (fixed capital investment). This phenomenon has been supported by Cran (7). He replotted indirect costs versus direct costs. For the purpose of multiplicative model, indirect cost factor, L_I is used instead in the relationship (see sub-section 5.2.4). Therefore, equation (3) becomes:-

$$C = DC \times L_I \qquad \ldots(4)$$

Since the direct costs are referred to carbon steel plants, the materials of construction factor, M must be incorporated into equation (4) for the use of alloys or other special materials of construction (its derivation is described in sub-section 5.2.5). Then, equation (4) becomes:-

$$C = DC.L_I.M \qquad \ldots(5)$$

By substituting the value of DC from equation (2) into (5), we obtain:-

$$C = K.Q^x.N^y.L_D.L_I.M \qquad \ldots(6)$$

Finally, location factor is also incorporated into equation (6):-

$$C = K.Q^x.N^y.L_D.L_I.M.L_F \qquad \ldots(7)$$

This chapter thus gives suggestions for future work to be done on this area of cost estimating on the condition that sufficient data is available. The resultant model does not only offer better accuracy, in addition, it can be applied to metallurgical and chemical processes.

APPENDIX A

CAPACITY EXPONENTIAL FACTOR DETERMINATION

The published cost-capacity data as shown in Table A-1 for the determination of capacity exponential factor are extracted from Engineering and Mining Journal Survey of Mine and Plant Expansion (1-8). Information in the survey was obtained both from published sources and by direct contact with the companies. Table A-1 summarizes the original cost-capacity data obtained which have varying base years and have been converted to the same based year, Mid-1980 by USA Process Economics Internationsl (PEI) plant cost index (see sub-section 4.48). For example, a copper plant of process capacity of 36,000 tons per annum at 1974 costs $22 x 10^6$, what is the capital cost in 1980?

Solution:

From Table 4.13 the USA PEI cost index at 1974 is 133 and at 1980 is 219.

Therefore, the same copper plant of same process capacity at 1980 would be:

$$\$22 \times 10^6 \times \frac{219}{133} = \underline{\underline{\$36.2 \times 10^6}}$$

It is possible to find the degree of correlation between sets of data analytically as indicated in Table A-1. The measure of correlation, termed the product moment coefficient of correlation, r assumes a linear relationship between pairs of data. When there is perfect correlation between

Table A-1 Original Cost Capacity Data With Updated Mid-1980 Costs

Copper Process

Year of Construction Completion	Process Capacity tpa x 10^3	Cost $\$x10^6$	Cost At 1980 $\$x10^6$
1974	36.0	22.0	36.2
1975	45.0	75.0	117.3
1982	53.0	140.7	116.3
1981	65.0	75.0	68.2
1981	65.0	200.0	181.7
1979	65.0	200.0	223.5
1978	118.0	200.0	247.5
1978	130.0	300.0	371.2
1976	150.0	100.0	148.0
1978	150.0	210.0	259.8
1980	163.4	210.0	210.0
1980	180.0	210.0	210.0

Zinc Process

Year of Construction Completion	Process Capacity tpa x 10^3	Cost $\$x10^6$	Cost At 1980 $\$x10^6$
1977	16.4	14.0	18.9
1975	16.4	14.0	21.9
1976	27.3	20.0	29.6
1975	27.3	29.0	45.4
1976	27.3	34.0	50.3
1976	27.3	44.0	65.1
1983	60.0	225.0	175.4
1977	72.7	25.0	33.8
1980	80.0	89.0	89.0
1980	80.0	89.0	89.0
1981	91.0	138.0	125.0
1980	120.0	260.0	260.0

Cont'd

Lead Process

Year of Construction Completion	Process Capacity tpa x 10^3	Cost $\$x10^6$	Cost At 1980 $\$x10^6$
1983	37.3	55.0	42.9
1975	28.0	31.0	48.5
1975	45.8	35.0	54.8
1975	54.5	70.0	109.5
1982	90.9	200.0	165.3
1972	100.0	40.0	79.6
1975	100.0	141.0	220.6

Tin Process

Year of Construction Completion	Process Capacity tpa x 10^3	Cost $\$x10^6$	Cost At 1980 $\$x10^6$
1980	1.82	3.45	3.45
1975	3.20	4.00	6.26
1980	3.60	8.00	8.00
1981	4.73	9.20	8.36
1980	5.20	9.20	9.20

pairs of data, the value of r will be 1 or -1 and when there is no correlation at all, the value of r will be zero. The following relationships are used to calculate r:

$$r = \frac{S_{xy}}{\sqrt{S_{xx}}\sqrt{S_{yy}}}$$

where $S_{xy} = \Sigma xy - \frac{\Sigma x \Sigma y}{n}$

$S_{xx} = \Sigma x^2 - \frac{(\Sigma x)^2}{n}$

$S = \Sigma y^2 - \frac{(\Sigma y)^2}{n}$

and n = number of pairs of values, x, y.

Even with unrelated data, a certain degree of correlation may arise by chance. The significant value of r therefore needs to be considered. Tables are available that give the critical value of r at the 0.05 significance level. The null hypothesis is that r equals zero; if the value of r is found to be greater than the values in the table, then the result is significant and can be interpreted as indicating that correlation exists between the pairs of values.

In order to determine the capacity exponential factor, a regression line of logarithmn of investment cost on capacity has to be derived and is given by:-

$$y_i = a + bx_i$$

where $a = \bar{y} - b\bar{x}$ ($\bar{y}$ and $\bar{x}$ are the average values of y and x)

and $b = \frac{S_{xy}}{S_{xx}}$ = capacity exponential factor.

The results of cost-capacity correlation calculation are given in Table A-2 and the values of r for the cost-capacity data sets of all four non-ferrous metal production processes are found to be significant. Table A-2 shows the results of cost-capacity correlation : First row gives the number of data sets; second row, the correlation coefficients; third row, the constant terms; fourth row, the gradients (capacity exponential factors) and fifth row, the standard errors of estimation for the derived regression lines of non-ferrous metal production processes respectively. From the regression lines (see Table A-3), fixed investment and per annual ton costs at various process capacity can be calculated and their results are shown in Table A-4.

Table A-2 Results Of Cost-Capacity Correlation Calculation

	Copper Process	Zinc Process	Lead Process	Tin Process	Overall Processes
n	12	12	7	5	36
r	0.718	0.810	0.849	0.974	0.950
a	1.374	0.536	0.620	0.375	0.685
b	0.82	0.95	0.96	0.93	0.94
e	0.183	0.211	0.095	0.006	0.110

Table A-3 Regression Lines Of Cost-Capacity Correlation For Non-Ferrous Metal Production Processes

Process	Regression Lines
Copper	$Y = 0.82X + 1.374$
Zinc	$Y = 0.95X + 0.536$
Lead	$Y = 0.96X + 0.620$
Tin	$Y = 0.93X + 0.735$
Overall	$Y = 0.94X + 0.685$

Note: $Y = \text{Log } C$

$X = \text{Log } Q$

where C = fixed capital investment

Q = process capacity

Table A-4 Average Fixed Capital Investment And Per Annual Ton Costs At Various Process Capacity

cont'd

Process Capacity tpa x 10^3	Copper Process		Zinc Process		Lead Process	
	Cost $\$ \times 10^6$	Per Annual Ton $\$ \times 10^3$	Cost $\$ \times 10^6$	Per Annual Ton $\$ \times 10^3$	Cost $\$ \times 10^6$	Per Annual Ton $\$ \times 10^3$
50	97.7	1.952	70.3	1.406	79.5	1.590
100	172.5	1.725	135.8	1.358	154.6	1.546
150	240.5	1.603	200.0	1.330	228.2	1.521
200	304.5	1.522	262.3	1.311	300.8	1.504
250	365.6	1.462	324.2	1.297	372.6	1.491
300	424.5	1.415	385.5	1.285	443.9	1.480

cont'd

Process Capacity tpa x 10^3	Tin Process		Overall Processes	
	Cost $\$ \times 10^6$	Per Annual Ton $\$ \times 10^3$	Cost $\$ \times 10^6$	Per Annual Ton $\$ \times 10^3$
50	79.3	1.586	78.1	1.563
100	151.1	1.511	149.8	1.498
150	220.3	1.469	219.2	1.461
200	287.8	1.439	287.2	1.436
250	354.3	1.417	354.1	1.417
300	419.7	1.399	420.3	1.401

APPENDIX B

SELECTION OF MATERIALS OF CONSTRUCTION FOR NON-FERROUS METAL SMELTING PROCESSES (9,10,11)

Various options of materials of construction are available for use in non-ferrous metal production processes. Basically, it can be divided into three areas:-

1) Material handling and storage
2) Pyrometallurgical
3) Offgas handling systems

Each area is described in detail.

Material Handling And Storage

Carbon steel is the most common and cheapest metal used in material handling and storage system. For annealed steel with low carbon (0.20 percent C) where tensile strength can be 55,000 lb/sq. in, it is used to fabricate bins, conveyors, pelletizers, etc. For annealed high-carbon steel, it is used to fabricate crushers, screens, cape mills, etc.

The corrosion resistance of carbon steel depends upon the formation of an oxide surface film. However, its resistance to corrosion is somewhat limited and it should not be used in contact with concentrated acids.

Pyrometallurgical System

In pyrometallurgical operations, metallic structures in kilns, roasters and furnaces are subject to constant or fluctuating high temperatures, abrasion and possibly corrosion. Thus, heat-resistant alloys are selected on the basis of how well they resist these conditions. Alloy Casting Institute (ACI) nomenclature is employed to designate heat-resistant cast alloys. The prefix H indicated a heat-resistant alloy, and the second letter represents nickel content, increasing from A to X. Some of the most commonly used alloys are listed in Table B-1.

Temperature and strength considerations usually limit the use of carbon steels to applications below 455°C, wrought low-alloy steels to 538°C, and 300 series stainless steels to 815°C.

Offgas Handling System

Cleaning the hot offgas from a pyrometallurgical operation involves several stages: cooling the gas from a temperature that may be as high as 1,315°C, removing solids, scrubbing out unacceptable constituents and separating fume or mist from the gas.

Corrosion problems in handling sulphur dioxide-laden gases are often related to the pressence of a small amount of sulphur trioxide. If temperature falls below the dewpoint, then hot concentrated sulphuric acid condenses out. Other components in offgas that lead to corrosion problems are metallic ions, such as selenium and tellurium, and nonmetallic chlorides and fluorides.

Table B-2 shows options of materials of construction for offgas handling system.

Table 8-1 Some Of The Most Commonly Used Alloys Designated By Alloy Casting Institute

Material	Composition, % (Essential Element)	Tensile Strength 1000lb/sq in	Maximum Usable Temperature ^{o}C	Description
HE	29Cr-9Ni	90-95	1090	1) Excellent high-temperature corrosion resistance. 2) Recommended for service in high sulphur atmosphere.
HF	19Cr-9Ni	85-100	870	
HH-Type 1	25Cr-12Ni	80-86	1080	1) Type 1 is used where operating conditions are subject to changes in temperature and applied stress. 2) Type 2 is preferred in components that are subject relatively constant high-load conditions.
-Type 2	25Cr-12Ni	85-92	980	
HK	25Cr-20Ni	75-85	1150	1) HK provides an economical combination of strength and scaling resistance at temperature between 980°C and 1150°C.
HP	26Cr-35Ni		1000	1) The presence of carbonaceous materials in the pyrometallurgical feed may cause embrittlement of the above mentioned alloys due to carburization. In this case, heat-resistant castings with higher nickel contents such as HP,HT,HW and HX are used.
HT	17Cr-35Ni	70-75		
HW	12Cr-60Ni	68-84		
HX	17Cr-66Ni	65-73		

Table B-2 Options Of Materials Of Construction For Offgas Handling System

Offgas Handling	Function	Options Of Materials Of Construction	Usage Description
1) Uptake Hoods	To capture exhaust gas from furnaces.	1)Heat-resistance cast alloys	
		2)Carbon steel	2)Refractory-line or water-cooled
2) Offgas Ducting	To transport flue gases from one equipment to another.	1)Carbon steel	1)Refractory-line
		2)Low-alloy steel	2)Applicable up to 540°C
		3)Wrought stainless steels-types 316, 309 & 310	3)Applicable up to 815°C
		4)Incoloy alloy 802	4)For strength at temperature up to 1090°C
3) Heat Recovery System From Offgas	Useful heat is captured by recuperative or regenerative methods. The former utilizes a heat exchanger system. The latter involves heating incoming air, continuously or in batches, using the outgoing gas, eg the Ljungstrom air preheater.	1)300 series stainless steel	1)Used for baffle plate
		2)Carbon or low-alloy steels	2)Used for boiler tube
4) Expansion Joints	As the name implies	1)Fabric	1)Insulated fabric resist temperature up to 980°C. However, it can fail if moisture containing fluoride condenses.

cont'd

		2)Stainless steel-type 321	2)It can fail due to corrosion fatique if the gas temperature falls below the dewpoint resulting chlorine ions are soaked up.
		3)Inconel alloys 600,601 & 625	3)Offer improved resistance to above problems.
5) Cyclone Separators	This equipment removes particulates from high temperature gas stream.	1)Stainless steel-type 316L	1)To improve its abrasion resistance, it must be refractory-lined.
		2)Carbon steel	2)Refractory-lined for the same reason, but requires an extra insulating layer between itself and the abrasion resistance surfacing.
6) Dry Electrostatic Precipitators	Dust particles are attracted to the plates and rappers are used to remove them to the hoppers below.	1)Carbon steel	1)If the temperature falls below the acid dewpoint
7) Wet Electrostatic Precipitators		1)Stainless steel-type 316L	
		2)Incoloy 825 or Alloy G	2)Used if highly acidic conditions are present.
8) Gas Quenching	Gas quenchers, in which the hot gas typically enters the chamber through a cascade of water.	1)High-nickel alloy	1)Special refractory lining, eg. silicon carbide brick, is utilized in the throat of the quencher.
		2)Carbon steel	2)Rubber-lined.
		3)Stainless steel and higher stainless steel	

cont'd

9) Scrubber and Separator	1)Stainless steels-type 316L, 317L 2)Inconel alloy 625 3)Incoloy alloy 825	
10) Fan	1)Stainless steel-type 316L	
	2)High-nickel alloy	2)Used if halide ions are present.
	3)Fiberglass-reinforced plastic 4)Rubber-line carbon steel	3) and 4) are used for fan casing construction.
11) Stack	1)Carbon steel	1)Acid-proof monolithic mortar lining, acid-proof brick and mortar, and plastic lining on carbon steels require very careful preparation of carbon steel surface.
	2)Concrete	2)Require linings as above.

APPENDIX C

SMELTER CONTRACT

Smelter contract over the last decade has been analysed for concentrates of the four major base metals - copper, zinc, lead and tin (12). The net payment of the gross value of metal contained in concentrates actually paid for by the smelter to the mine and the smelter charges are expressed in US¢/lb metal.

Smelter terms are complex: The value of a contract is determined not only by the processing charges but also by deductions for metal losses, differing arrangements for how the metal price ruling the contract is determined, provisions for the smelter's participation in metal price movements, and penalties and credits for deleterious materials and byproducts. However, all smelter terms for copper, zinc, lead and tin concentrates can be expressed in the same general form:-

$$M/100 \times (S-T-r-d) - (X+Y) = \text{net smelter value (NSV)}$$

or $$M/100 \times (S-TSC) - (X+Y) = \text{net smelter value} \quad ...(C.1)$$

where M = actual concentrate assay in percentage
S = <u>annual</u> average metal price in ¢
T = treatment charge in ¢/lb
r = refining charge in ¢/lb
d = deductions in ¢/lb
X = penalty payments in ¢/lb

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where M = actual concentrate assay in percentage

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T = treatment charge in ¢/lb

r = refining charge in ¢/lb

d = deductions in ¢/lb

X = penalty payments in ¢/lb

Y = credit payments in ¢/lb

TSC = total smelter charge in ¢/lb

The net value of the concentrates to the mine, or at mine revenue, is the net smelter value less realization costs. Realization costs cover such items as freight, insurance, sales agents' commission and representation at the smelter during weighing and sampling, and they depend greatly on the geographical location of each individual mine relative to the smelter. Therefore, net smelter value is the delivered raw materials cost to the smelter.

Penalties: There are certain impurities that any given smelting - depending on the technology of its particular process, on local environmental constraints, on the levels of impurities in the feed it already has, and on the requirements for its end products - will not tolerate to any great extent. Table C-1 summarizes the penalty schedules for copper, zinc, lead and tin, which carry penalties for concentrations of any of these above a certain level. The specific penalty charges vary widely from smelter to smelter, depending both on their tolerance for the impurity and the concentrate market. For these reasons, penalty payment will be omitted from the calculations of net smelter value.

Credits: The most commonly credited byproducts in copper, zinc, lead and tin concentrates are the precious metals - most commonly gold and silver in the case of copper and lead, and silver in the case of zinc. Lead smelters may

Table C-1 Penalty Elements In Copper, Zinc, Lead And Tin Concentrates

Element	Tolerance Level Below Which No Penalty Is Applied, %			
	Copper	Zinc	Lead	Tin
Antimony	0.2-1.0	0.1	0.5	0.01-0.1
Arsenic	0.4-1.0	0.1	0.1	0.01-0.1
Bismuth	0.05-0.25	n.a	0.01	0.01-0.1
Cobalt	0.5-2.3	0.01	-	n.a
Copper	n.a	-	n.a	0.02-0.1
Chlorine	0.5	0.1	0.01-0.1	-
Fluorine	n.a	0.1	0.2	0.5
Iron	-	9-10	n.a	4.5-6.5
Lead	2.0-7.0	n.a	-	0.02-0.1
Mercury	n.a	0.01	-	-
Nickel	0.03	0.01	n.a	n.a
Cu+Pb+Sb+Bi+Zn	-	-	-	0.1-0.25
Sulphur	-	-	20	0.1-4.0
Water	-	6-10	8-10	n.a
Size	-	3mm	3mm	-

also credit copper and zinc above certain amounts. Some zinc smelters will pay for a percentage of lead. Some copper smelter will pay for a percentage of lead or zinc above certain levels, or may penalize them. Unlike other base metals, credit payments for tin concentrates are rarely made, except very occasionally for silver, bismuth, iron and lead. Credit payments for copper, zinc and lead vary widely from smelter to smelter, but they can be summarized as in Table C-2 and C-3. For simplicity of the calculations, credit payment will also be omitted and the equation (C.1) becomes:-

$$M/100 \times (S - TSC) = \text{net smelter value} \qquad \ldots(C.2)$$

Note that equation (C.2) is expressed in cents per pound of metal, but when expressed in cents per pound of raw materials or concentrate, it then becomes:-

$$M^2/100^2 \times (S - TSC) = \text{net smelter value} \qquad \ldots(C.3)$$

The percentage payment is the percentage of the gross value of the metal contained in the concentrate actually paid for by the smelter, and can be expressed as follows:-

$$\text{Percentage payment} = \frac{NSV \times 100}{M \times S} \qquad \ldots(C.4)$$

Treatment And Refining Charges: In the case of copper, lead and tin, the treatment charge refers to the charges for smelting the materials. Copper, lead and tin undergo further refining steps, which carry on additional charge called refining charge. In the case of zinc, the treatment charge covers all processing costs from concentrate through

Table C-2 Credit Payments For Copper And Zinc Concentrates

Element		Level Below Which No Payment Is Made, %	Percent Of Metal Paid For Above Minimum Level	1977 Refining Charges
Copper -	Gold	1 g/t	90-100	up to $7.00/oz.
	Silver	30 or 35 g/t	90-100	10¢ - 25¢/oz.
Zinc -	Cadmium	0.09-0.20	50-80	
	Silver	30-155 g/t	60-100	
	Lead	1.0-6.0	50-100	
	Copper	1.3-2.5	50-100	

Table C-3 Credit Payment For Lead Concentrates

Element	Level Below Which No Payment Made	Percentage Of Remainder Paid For	Percentage Of Price Applied	1977 Refining Charges
Silver	30-155 g/t	90-100	95-100	15-25¢/oz.
Copper	1.3-2.5 %	75-100	99-100	23-37¢/lb
Gold	1 g/t	100	80-95	up to $1.00/oz
Zinc	6-8 %	50-100	100	-
Bismuth	0.05-0.1%	60-100	80-100	-

to refined metal. Typical ranges of treatment and refining charges for standard concentrates since 1970 to 1977 are shown in Table C-4. They are all expressed in ¢/lb.

Deductions: All of the metal contained in concentrate, as determined by the smelter's assay, is not paid for. This reflects the smelter's need to account for inevitable losses of metal in processing, as well as in some cases, providing another source of income. Deductions may take two forms. There is unit deduction, a certain fixed amount subtracted from the assayed content. Units are percentage points: a 1.2 unit deduction from material containing 30%, leaving 28.8% of each ton to be paid for. The other form of deduction is expressed in ¢/lb. Table C-4 shows deduction value since 1970 to 1977 in ¢/lb. By adding treatment and refining charges, and deductions, one arrives at the total charges for a contract.

Calculation Results: Table C-3 to C-6 show the results of net smelter worth and percentage payment for copper, zinc, lead and tin at various metal content ranging from 20% to 70%. They are calculated from equation (C.2) and (C.4) respectively.

Note that in Table C-3 to C-6, the total charges for 1978 to 1980 are estimated by means of the regression lines as shown in Table C-7, which are the results of correlation between data sets of year and total charges.

Table C-4 Charges For Copper, Zinc, Lead And Tin Concentrates Since 1970 In Current Money Terms (US¢/lb)

Year	1970	1971	1972	1973	1974	1975	1976	1977
Treatment And Refining Charges								
1) Copper, 30% concentrate								
Range - Minimum	4.5	5.1	4.5	6.9	9.4	9.6	10.6	10.2
Maximum	6.1	7.9	8.3	11.1	17.6	17.4	18.2	20.8
Annual average	5.4	6.3	6.3	8.4	14.0	14.5	16.0	16.0
2) Zinc, 50% concentrate								
Range - Minimum	3.9	4.3	4.9	5.8	10.0	11.4	11.2	10.1
Maximum	5.1	5.7	6.1	8.5	14.2	14.5	13.8	11.5
Annual average	4.4	4.7	5.4	6.8	11.2	12.0	12.0	10.8
3) Lead, 60% concentrate								
Range - Minimum	1.7	1.7	2.0	3.0	5.3	4.9	5.4	7.7
Maximum	2.3	2.8	2.5	6.7	9.1	6.4	9.2	11.9
Annual average	2.0	2.3	2.3	4.8	7.9	6.1	7.7	10.2
4) Tin, 70% concentrate								
Annual average	1.8	4.0	3.6	4.8	6.3	5.3	5.6	13.1
Deductions								
Annual average for:-								
1) 30% copper	2.3	1.8	1.8	2.9	3.4	2.0	2.3	2.1
2) 50% zinc	2.2	2.5	2.8	3.8	5.6	5.9	5.8	5.2
3) 60% lead	0.7	0.6	0.7	1.0	1.3	0.9	1.0	1.4
4) 70% tin	2.8	2.7	2.9	3.7	6.3	5.3	5.9	8.2
Total Charges								
Annual average for:-								
1) 30% copper	7.7	8.1	8.1	11.3	17.4	16.5	18.3	18.1
2) 50% zinc	6.6	7.2	8.3	10.6	16.9	17.9	17.7	16.0
3) 60% lead	2.7	2.9	3.0	5.8	9.2	7.0	8.7	11.6
4) 70% tin	4.6	6.7	6.5	8.5	12.6	10.6	11.5	21.3

Table C-5 Calculation Results For 20, 30 And 40% Copper Concentrate Since 1970 In Current Money Terms (US ¢/lb)

Metal Content	Year	Total Smelter Charges, ¢/lb	Metal Price, ¢/lb	Net Smelter Value, ¢/lb	Percentage Payment, %
20%	1970	10.7	62.8	10.4	83.0
	1971	10.7	48.5	7.6	77.9
	1972	11.0	47.8	7.4	77.0
	1973	19.9	79.6	11.9	75.0
	1974	16.5	91.5	15.0	82.0
	1975	20.4	55.2	7.0	63.0
	1976	22.7	63.1	8.1	64.0
	1977	21.0	58.2	7.4	63.9
	1978	25.3 (e)	60.9	7.1	58.5
	1979	27.2 (e)	88.7	12.3	69.3
	1980	29.0 (e)	94.1	13.0	69.2
30%	1970	7.7	62.8	16.5	87.7
	1971	8.1	48.5	12.1	83.3
	1972	8.1	47.8	11.9	83.1
	1973	11.3	79.6	20.5	85.8
	1974	17.4	91.5	22.2	81.0
	1975	16.5	55.2	11.6	70.1
	1976	18.3	63.1	13.4	71.0
	1977	18.1	58.2	12.0	69.0
	1978	20.7 (e)	60.9	12.1	66.0
	1979	22.5 (e)	88.7	19.9	74.6
	1980	24.4 (e)	94.1	20.9	74.1
40%	1970	6.3	62.8	22.6	90.0
	1971	6.8	48.5	16.7	86.0
	1972	6.7	47.8	16.4	86.0
	1973	9.6	79.6	28.0	88.0
	1974	17.4	91.5	29.6	81.0

cont'd

40%	1975	15.5	55.2	15.9	72.0
	1976	16.4	63.1	18.7	74.0
	1977	16.3	58.2	16.8	72.0
	1978	20.2 (e)	60.9	16.3	66.8
	1979	22.0 (e)	88.7	26.7	75.2
	1980	23.9 (e)	94.1	28.1	74.6

Note: (e) = estimates

Table C-6 Calculation Results For 50 And 60% Zinc Concentrate Since 1970 In Current Money Terms (US ¢/lb)

Metal Content	Year	Total Smelter Charges, ¢/lb	Metal Price ¢/lb	Net Smelter Value, ¢/lb	Percentage Payment, %
50%	1970	7.0	15.1	4.1	53.6
	1971	7.3	15.9	4.3	54.1
	1972	8.4	17.5	4.6	52.0
	1973	8.9	20.3	5.7	56.2
	1974	17.2	35.4	19.1	51.1
	1975	18.8	38.3	9.8	50.9
	1976	18.2	36.4	9.1	50.0
	1977	17.0	33.9	8.5	49.9
	1978	22.5 (e)	30.5	4.0	26.2
	1979	24.5 (e)	36.7	6.1	33.2
	1980	26.4 (e)	33.8	3.7	21.9
60%	1970	6.2	15.1	5.3	58.9
	1971	6.4	15.9	5.7	59.7
	1972	7.0	17.5	6.3	60.0
	1973	7.9	20.3	7.4	61.1
	1974	15.9	35.4	11.7	55.1
	1975	17.6	38.3	12.4	54.0
	1976	17.8	36.4	11.2	51.1
	1977	16.3	33.9	10.6	51.9
	1978	20.7 (e)	30.5	5.9	32.1
	1979	22.7 (e)	36.7	8.4	38.1
	1980	24.7 (e)	33.8	5.5	26.9

Table C-7 Calculation Results For 50, 60 And 70% Lead Concentrate Since 1970 In Current Money Terms (US ¢/lb)

Metal Content	Year	Total Smelter Charge, ¢/lb	Metal Price, ¢/lb	Net Smelter Value, ¢/lb	Percentage Payment, %
50%	1970	3.5	15.4	60.0	77.3
	1971	3.9	13.6	4.9	71.3
	1972	3.7	14.8	5.6	75.0
	1973	5.6	16.0	5.2	65.0
	1974	9.1	22.2	6.6	59.0
	1975	9.5	21.2	5.9	55.2
	1976	11.4	22.7	5.7	49.8
	1977	14.5	30.2	7.9	52.0
	1978	15.1 (e)	33.1	9.0	54.4
	1979	16.7 (e)	51.8	17.6	67.8
	1980	18.4 (e)	40.6	11.1	54.7
60%	1970	3.1	15.4	7.4	79.9
	1971	3.4	13.6	6.1	75.0
	1972	3.4	14.8	6.9	77.0
	1973	4.8	16.0	6.7	70.0
	1974	7.5	22.2	8.8	66.2
	1975	8.1	21.2	7.9	61.8
	1976	9.6	22.2	7.9	57.7
	1977	12.5	30.2	10.6	58.6
	1978	11.9 (e)	33.1	12.7	64.0
	1979	13.2 (e)	51.8	23.2	74.5
	1980	14.6 (e)	40.6	15.6	64.0
70%	1970	2.9	15.4	8.8	81.2
	1971	3.1	13.6	7.4	77.2
	1972	3.0	14.8	8.3	79.7
	1973	4.5	16.0	8.1	71.9
	1974	6.7	22.2	10.9	69.8

cont'd

70%	1975	7.2	21.2	9.8	66.0
	1976	8.9	22.7	9.7	60.8
	1977	11.8	30.2	12.9	60.9
	1978	11.5 (e)	33.1	15.1	65.3
	1979	12.8 (e)	51.8	27.3	75.3
	1980	14.0 (e)	40.6	18.6	65.5

Table C-8 Calculation Results For 20, 35, 50 And 70% Tin Concentrate Since 1970 In Current Money Terms (US ¢/lb)

Metal Content	Year	Total Smelter Charges, ¢/lb	Metal Price, ¢/lb	Net Smelter Value, ¢/lb	Percentage Payment, %
20%	1970	39.3	160.0	24.1	75.4
	1971	43.2	155.1	22.4	72.2
	1972	45.0	165.7	24.1	72.8
	1973	56.7	208.3	30.3	72.8
	1974	70.7	349.8	55.8	79.8
	1975	98.8	297.5	39.7	66.8
	1976	99.7	334.2	46.1	70.2
	1977	118.7	477.5	71.8	75.1
	1978	126.1 (e)	556.9	86.2	77.4
	1979	138.2 (e)	663.0	105.0	79.2
	1980	150.2 (e)	751.4	120.2	80.0
35%	1970	21.5	160.0	48.5	86.6
	1971	23.2	155.1	46.2	85.0
	1972	26.1	165.7	48.9	84.2
	1973	34.5	208.3	60.8	83.4
	1974	48.1	349.8	105.6	86.2
	1975	72.3	297.5	78.8	75.7
	1976	61.0	334.2	95.6	81.7
	1977	75.1	477.5	140.8	84.3
	1978	84.5 (e)	556.9	165.3	84.8
	1979	93.0 (e)	663.0	199.5	86.0
	1980	101.5 (e)	751.4	227.5	86.5
50%	1970	12.3	160.0	73.9	92.3
	1971	13.8	155.1	70.7	91.1
	1972	15.7	165.7	75.0	90.5
	1973	19.9	208.3	94.2	90.5
	1974	30.0	349.8	159.9	91.4

cont'd

50%	1975	31.2	297.5	133.2	89.5
	1976	30.0	334.2	152.1	91.0
	1977	40.2	477.5	218.7	91.6
	1978	41.8 (e)	556.9	257.6	92.5
	1979	45.8 (e)	663.0	308.6	93.1
	1980	49.7 (e)	751.4	350.9	93.4
70%	1970	4.6	160.0	108.8	97.1
	1971	6.7	155.1	103.9	95.7
	1972	6.5	165.7	111.4	96.1
	1973	8.5	208.3	139.9	95.9
	1974	12.6	349.8	236.0	96.4
	1975	10.6	297.5	200.8	96.4
	1976	11.5	334.2	225.9	96.6
	1977	21.3	477.5	391.3	95.5
	1978	19.5 (e)	556.9	376.2	96.5
	1979	21.4 (e)	663.0	449.1	96.8
	1980	23.2 (e)	751.4	509.7	96.9

Table C-9 Regression Lines For Projecting Total Smelter Charges, TSC

Metal		Regression Line
Copper,	20% concentrate	TSC = 1.868Y - 3669.6
	30% concentrate	TSC = 1.846Y - 3630.7
	40% concentrate	TSC = 1.812Y - 3563.9
Zinc,	50% concentrate	TSC = 1.954Y - 3842.5
	60% concentrate	TSC = 1.994Y - 3923.4
Lead,	50% concentrate	TSC = 1.612Y - 3173.4
	60% concentrate	TSC = 1.352Y - 2662.4
	70% concentrate	TSC = 1.263Y - 2486.7
Tin,	20% concentrate	TSC = 12.068Y - 23744.4
	35% concentrate	TSC = 8.529Y - 16785.9
	50% concentrate	TSC = 3.963Y - 7797.0
	70% concentrate	TSC = 1.873Y - 3685.3

Note: Y = Year

APPENDIX D-1 EVAL COMPUTER PROGRAM LISTING

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Ready




LIST
EVAL        27-JUL-1982 15:32

10 REM  ECONOMIC EVALUATION OF NON-FERROUS METAL SMELTING PROCESSES
11 REM
12 REM  S=METAL PRICE                      SA=ANNUAL SALES
13 REM  M=CONC.ASSAY                       P$=PROCESS STRING
14 REM  N=NUMBER OF PROCESS STEPS          KU=UTILITIES CONSTANT
15 REM  Q=PROCESS CAPACITY                 PP=UTILITIES INDEX
16 REM  L=LOCATION FACTOR                  BC=BYPRODUCT(S) CREDIT
17 REM  Y=YEAR                             II=INFLATION INDEX
18 REM  R=EXCHANGE RATE                    DC=DIRECT COSTS
19 REM  B=CAPACITY EXPONENTIAL FACTOR      DP=DEPRECIATION
20 REM  K=CAPITAL COST CONSTANT            LT=TAXES
21 REM  A=ASSAY EXPONENTIAL FACTOR         FC=FIXED CHARGES
22 REM  I=INDIRECT COST FACTOR             AC=ADMINISTRATION
23 REM  C=FIXED CAPITAL INVESTMENT         GE=GENERAL EXPENSES
24 REM  H=THOUSAND UNITS                   AR=ACCOUNT RECEIVABLE
25 REM  J=CONVERSION CONSTANT              CA=CASH AVAILABLE
26 REM  P=CONVERSION CONSTANT              WC=WORKING CAPITAL
27 REM  DLC=DIRECT LABOUR COST             TR=TAX RATE
28 REM  BAS=BASE YEAR                      NAS=NET PROFIT BEFORE TAX
29 REM  RMC=RAW MATERIALS COST             INS=INSURANCE
30 REM  TSC=TOTAL SMELTER COST             POC=PAYROLL OVERHEAD
31 REM  MLC=MAINTENANCE COST               GOC=GENERAL OVERHEAD
32 REM  SPC=SUPERVISION COST               RDC=RESEARCH & DEVELOPMENT
33 REM  OSC=OPERATING SUPPLIES              FCC=FINANCING
34 REM  LCC=LABORATORY CHARGES             MUC=MANUFACTURING COSTS
35 REM  RPC=ROYALTIES                      RMI=RAW MATERIALS INVENTORY
36 REM  DPC=DIRECT PRODUCTION COST         CTAX=CORPORATE TAX
37 REM  PIPI=PROCESS IN PROGRESS PLUS PRODUCT INVENTORY
39 REM  TPCLD=TOTAL PRODUCT COST LESS DEPRECIATION
40 REM  NASAT=NET ANNUAL PROFIT AFTER TAX
41 REM  TPC=TOTAL PRODUCT COST
42 REM  C$,L$,R$,U$,X$,Y$ OR Z$=STRING FOR YES OR NO
43 REM  MU=POUND STERLING
44 PRINT "INPUT COPPER,ZINC,LEAD OR TIN"
45 INPUT P$
50 PRINT "INPUT CONCENTRATE ASSAY"
55 INPUT M
60 PRINT "INPUT PROCESS CAPACITY IN TON/ANNUM"
70 INPUT Q
```

```
80 PRINT "INPUT NUMBER OF PROCESS STEPS"
90 INPUT N
0100 PRINT "INPUT LOCATION FACTOR"
0110 INPUT L
0120 PRINT "INPUT UHICH YEAR"
0130 INPUT Y
0140 PRINT "INPUT DIRECT LABOUR RATE IN $ OR POUND STERLING/HOUR"
0150 INPUT R
0152 PRINT "ARE THERE ANY BYPRODUCT(S) ?"
0153 INPUT X$
0154 IF X$="NO" THEN 0160
0155 PRINT "INPUT ANNUAL BYPRODUCT(S) CREDIT IN $ OR POUND STERLING"
0156 INPUT BC
0157 BC=BC/(Q*22.4)
0160 PRINT "INPUT AVERAGE ANNUAL METAL PRICE IN CENTS OR PENCE/POUND"
0170 INPUT S
0172 PRINT "INPUT TAX RATE IN %"
0174 INPUT TR
0180 PRINT "ARE THEY U.S. DATA?"
0190 INPUT Y$
0200 IF Y$= "YES" THEN GOTO 230
0210 PRINT "INPUT EXCHANGE RATE FOR DOLLAR"
0220 INPUT ER
0225 KL=463
0230 IF P$="COPPER" THEN GOTO 270
0240 IF P$="ZINC" THEN GOTO 320
0250 IF P$="LEAD" THEN GOTO 370
0260 IF P$="TIN" THEN GOTO 420
0270 B=0.82
0280 K=63
0295 KL=793
0290 KU=4
0300 A=-0.275
0302 IF M>=15 AND M<25 THEN TSC=1.968*Y-3669.6
0304 IF M>=25 AND M<35 THEN TSC=1.868*Y-3630.7
0306 IF M>=35 AND M<45 THEN TSC=1.812*Y-3563.9
0310 GOTO 460
0320 B=0.95
0330 K=11
0340 KU=4
0350 A=-0.293
0352 IF M>=45 AND M<55 THEN TSC=1.954*Y-3842.5
0354 IF M>=55 AND M<65 THEN TSC=1.994*Y-3923.4
0360 GOTO 460
0370 B=0.96
0380 K=13
0390 KU=21
0400 A=-0.774
```

```
0402 IF M>=45 AND M<55 THEN TSC=1.612*Y-3173.4
0404 IF M>=55 AND M<65 THEN TSC=1.352*Y-2662.4
0406 IF M>=65 AND M<75 THEN TSC=1.263*Y-2486.7
0410 GOTO 460
0420 B=0.93
0430 K=22
0440 KU=1703
0450 A=-1.511
0452 IF M>=15 AND M<28 THEN TSC=12.068*Y-23744.4
0454 IF M>=28 AND M<43 THEN TSC=8.529*Y-16785.9
0456 IF M>=43 AND M<60 THEN TSC=3.963*Y-7797
0458 IF M>=60 AND M<75 THEN TSC=1.873*Y-3685.3
0460 REM  INFLATION INDEX FOR UPDATING CAPITAL AND OPERATING COSTS
0470 PRINT "DO YOU PREFER INPUT YOUR OWN INFLATION INDEX?"
0480 INPUT Z$
0490 IF Z$="NO" THEN GOTO 0540
0500 PRINT"INPUT INFLATION INDEX FOR BASE YEAR AND THE YEAR FORECASTED"
0510 INPUT BAS
0520 INPUT II
0530 GOTO 0585
0540 IF Y$="YES" THEN GOTO 0570
0550 BAS=385
0560 II=35.424*Y-69754.7
0565 GOTO 0585
0570 BAS=219
0580 II=14.31*Y-28122.8
0585 PP=28.572*Y-56190.2
0590 REM  FIXED CAPITAL INVESTMENT CALCULATION
0592 PRINT "DO YOU PREFER INPUT FIXED CAPITAL INVESTMENT?"
0593 INPUT C$
0594 IF C$="NO" THEN GOTO 0600
0595 PRINT "INPUT FIXED CAPITAL INVESSTMENT IN $ OR POUND STERLING"
0596 INPUT C
0597 GOTO 0630
0600 DC=2.54*K*M*Q**B
0610 I=2.354-0.0543*LOG(DC)
0620 IF Y$="YES" THEN C=1.2*DC*I*L*II/BAS
0625 IF Y$="NO" THEN C=1.2*DC*I*L*ER*II/BAS
0630 REM  OPERATING COSTS CALCULATION
0635 REM
0640 REM  DIRECT PRODUCTION COSTS
0642 PRINT "DO YOU PREFER INPUT RAW-MATERIALS COST?"
0644 INPUT R$
0645 IF R$="NO" THEN GOTO 0655
0646 PRINT "INPUT ANNUAL RAW-MATERIALS COST IN $ OR POUND STERLING"
0648 INPUT RMC
0650 GOTO 0660
0655 IF Y$="NO" THEN TSC=TSC*ER
```

```
0660 IF X$="NO" THEN RMC=Q*22.4*(S-TSC)*(M/100)*M/(M-0.8)
0665 IF X$="YES" THEN RMC=0.5*BC+Q*22.4*(S-TSC)*(M/100)*M/(M-0.8)
0668 PRINT "DO YOU PREFER INPUT DIRECT LABOUR COST?"
0670 INPUT L$
0672 IF L$="NO" THEN GOTO 0682
0674 PRINT "INPUT ANNUAL DIRECT LABOUR COST IN $ OR POUND STERLING"
0676 INPUT DLC
0678 GOTO 0683
0682 DLC=KL*N*Q**0.212*R
0683 PRINT "DO YOU PREFER INPUT UTILITIES COST?"
0684 INPUT U$
0690 IF U$="NO" THEN GOTO 0698
0692 PRINT "INPUT ANNUAL UTILITIES COST IN $ OR POUND STERLING"
0694 INPUT UC
0696 GOTO 0700
0698 IF Y$="YES" THEN UC=KU*N*Q*M**A*(PP/382)
0699 IF Y$="NO" THEN UC=KU*N*Q*M**A*(PP/382)*ER
0700 MLC=0.04*C
0710 SPC=0.15*DLC
0720 OSC=0.03*C
0730 LCC=0.15*DLC
0740 RPC=0.01*S*Q*22.4
0750 DPC=RMC+DLC+UC+MLC+SPC+OSC+LCC+RPC
0760 REM  FIXED CHARGES
0770 DP=0.08*C
0780 LT=0.01*C
0790 INS=0.01*C
0800 FC=DP+LT+INS
0810 REM  PLANT-OVERHEAD COSTS
0820 POC=0.2*DLC
0830 GOC=0.75*DLC
0840 PLOC=POC+GOC
0850 REM  GENERAL EXPENSES
0860 AC=0.5*DLC
0870 RDC=0.005*S*Q*22.4
0880 FCC=0.1*C
0890 EE=AC+RDC+FCC
0900 REM  MANUFACTURING COSTS
0910 MUC=DPC+FC+PLOC
0922 TPC=MUC+EE
0924 TPCLD=TPC-DP
0930 REM  WORKING CAPITAL CALCULATION
0940 RMI=30*(RMC+UC)/330
0950 PIPI=30*TPCLD/330
0960 AR=30*TPCLD/330
0970 CA=30*(TPCLD-RMC)/330
0980 WC=RMI+PIPI+AR+CA
0990 REM  NET ANNUAL PROFIT BEFORE TAX CALCULATION
```

```
1000 IF X$="NO" THEN SA=S*Q*22.4
1005 IF X$="YES" THEN SA=(S+BC)*Q*22.4
1010 NAS=SA-TPC
1012 CTAX=NAS*TR/100
1014 NASAT=NAS-CTAX
1020 REM  CONVERSION FACTORS
1030 H=1000
1040 J=Q*22.4
1050 P=SA/100
1060 REM  PROFIT AND LOSS ACCOUNT CALCULATION
1070 PRINT "PROFIT AND LOSS ACCOUNT FOR A MATURE YEAR,";Q;" TON/ANNUM ";P$
1080 PRINT "***************************************************************"
1090 PRINT
1100 IF Y$="YES" THEN PRINT TAB(28%);"$(1000)"; TAB(38%);"CENTS/LB"; TAB(48%);"% SALES"
1110 IF Y$="NO" THEN PRINT TAB(28%);"1000 MU"; TAB(38%);"PENCE/LB"; TAB(48%);"% SALES"
1120 PRINT TAB(28%);"-------"; TAB(38%);"--------"; TAB(48%);"-------"
1130 PRINT "ANUAL SALES"; TAB(28%);INT (SA); TAB(38%);S; TAB(48%);SA/P
1140 PRINT
1150 PRINT "DIRECT PRODUCTION COSTS"; TAB(28%);INT (DPC/H); TAB(38%);DPC/J; TAB(48%);DPC/P
1160 PRINT "  RAW MATERIALS"; TAB(28%);INT (RMC/M); TAB(38%);RMC/J; TAB(48%);RMC/P
1170 PRINT "  DIRECT LABOUR"; TAB(28%);INT (DLC/H); TAB(38%);DLC/J; TAB(48%);DLC/P
1180 PRINT "  SUPERVISION"; TAB(28%);INT (SPC/H); TAB(38%);SPC/J; TAB(48%);SPC/P
1190 PRINT "  UTILITIES"; TAB(28%);INT (UC/H); TAB(38%);UC/J; TAB(48%);UC/P
1200 PRINT "  MAINTENANCE"; TAB(28%);INT (MLC/H); TAB(38%);MLC/J; TAB(48%);MLC/P
1210 PRINT "  OPERATING SUPPLIES"; TAB(28%);INT (OSC/H); TAB(38%);OSC/J; TAB(48%);OSC/P
1220 PRINT "  LABORATORIES CHARGES"; TAB(28%);INT (LCC/H); TAB(38%);LCC/J; TAB(48%);LCC/P
1230 PRINT "  ROYALTIES"; TAB(28%);INT (RPC/H); TAB(38%);RPC/J; TAB(48%);RPC/P
1240 PRINT
1250 PRINT "FIXED CHARGES"; TAB(28%);INT (FC/H); TAB(38%);FC/J; TAB(48%);FC/P
1260 PRINT "  DEPRECIATION"; TAB(28%);INT (DP/H); TAB(38%);DP/J; TAB(48%);DP/P
1270 PRINT "  TAXES"; TAB(28%);INT (LT/H); TAB(38%);LT/J; TAB(48%);LT/P
1280 PRINT "  INSURANCE"; TAB(28%);INT (INS/H); TAB(38%);INS/J; TAB(48%);INS/P
1290 PRINT
1300 PRINT "PLANT-OVERHEAD COSTS"; TAB(28%);INT (PLOC/H); TAB(38%);PLOC/J; TAB(48%);PLOC/P
1310 PRINT "  GENERAL OVERHEAD"; TAB(28%);INT (GOC/H); TAB(38%);GOC/J; TAB(48%);GOC/P
1320 PRINT "  PAYROLL OVERHEAD"; TAB(28%);INT (POC/H); TAB(38%);POC/J; TAB(48%);POC/P
1330 PRINT
1340 PRINT "MANUFACTURING COSTS"; TAB(28%);INT (MUC/H); TAB(38%);MUC/J; TAB(48%);MUC/P
1350 PRINT
1380 PRINT "GENERAL EXPENSES"; TAB(28%);INT (EE/H); TAB(38%);EE/J; TAB(48%);EE/P
1390 PRINT "  ADMINISTRATION"; TAB(28%);INT (AC/H); TAB(38%);AC/J; TAB(48%);AC/P
1400 PRINT "  RESEARCH AND DEVELOPMENT";TAB(28%);INT (RDC/H); TAB(38%);RDC/J; TAB(48%);RDC/P
1410 PRINT "  FINANCING"; TAB(28%);INT (FCC/H); TAB(38%);FCC/J; TAB(48%);FCC/P
1420 PRINT
1430 PRINT "TOTAL PRODUCT COST"; TAB(28%);INT (TPC/H); TAB(38%);TPC/J; TAB(48%);TPC/P
1435 PRINT
1440 PRINT "TPC LESS DEPRECIATION"; TAB(28%);INT (TPCLD/H); TAB(38%);TPCLD/J; TAB(48%);TPCLD/P
1445 PRINT
```

```
1450 PRINT "NET ANNUAL PROFIT BEFORE TAX"; TAB(28%);INT (NAS/H);
1455 PRINT TAB(38%);NAS/J; TAB(48%);NAS/P
1460 PRINT
1470 REM  RATE OF RETURN ON TOTAL CAPITAL INVESTMENT
1480 PRINT "TAXES AT ";TR;"%"; TAB(28%);INT (CTAX/H); TAB(38%);CTAX/J; TAB(48%);CTAX/P
1490 PRINT
1500 PRINT "NET ANNUAL PROFIT AFTER TAX"; TAB(29%);INT (NASAT/H);
1505 PRINT TAB(38%);NASAT/J; TAB(48%);NASAT/P
1510 PRINT
1520 PRINT "------------------------------------------------------------------------"
1530 PRINT
1540 PRINT "TOTAL CAPITAL INVESTMENT"; TAB(32%);INT ((C+WC))
1550 PRINT "  FIXED CAPITAL"; TAB(32%);INT (C)
1560 PRINT "  WORKING CAPITAL"; TAB(32%);INT (WC)
1570 PRINT
1580 PRINT "RETURN ON INVESTMENT AFTER TAX"; TAB(32%);INT (NASAT*100/(C+WC));"  %"
1590 STOP

Ready
```

APPENDIX D-2 CFA COMPUTER PROGRAM LISTING

```
OLD
Old file name--CFA
Ready

LIST
CFA          27-JUL-1982 15:38

10 REM PROJECT NET PRESENT VALUE
20 REM
30 REM  T=TIME IN YEAR                     DA=DEPRECIATION ALLOWANCE
40 REM  S=SALES INCOME                     DF=DISCOUNTED FACTOR
50 REM A,C=FIXED CAPITAL INVESTMENT        TP=TAX PAYABLE
60 REM  TCF=TAXABLE CASH FLOW              TR=TAX RATE
61 REM  P=TOTAL PRODUCT COST LESS DEPRECIATION
62 REM SPV=SUM OF  PRESENT VALUE
64 REM  NCFBT=NET CASH FLOW BEFORE TAX
66 REM  NCFAT=NET CASH FLOW AFTER TAX
68 PRINT "INPUT FIXED CAPITAL INVESTMENT"
69 INPUT A
70 PRINT "INPUT DISCOUNTED RATE OF RETURN"
71 INPUT I
72 PRINT "INPUT TAX RATE IN %"
73 INPUT TR
74 C=-A
75 PRINT "INPUT NUMBER OF YEARS FOR CASH FLOW ANALYSIS"
76 INPUT T
79 DIM S(20)
80 DIM P(20)
90 PRINT "INPUT SALES INCOME AND TOTAL PRODUCT COST LESS DEPRECIATION FOR ";T;" YEARS"
126 PRINT                 TAB(13%);"SALES
127 PRINT "END OF YEAR";TAB(13%);"-----INCOME"; TAB(26%);"TOTAL COST"
128 PRINT "-----------";          •"------------"; TAB(26%);"----------"
132 PRINT TAB(5%);"0"; TAB(26%);C
135 FOR N=1 TO T
140 INPUT S(T)
150 INPUT P(T)
160 PRINT N; TAB(13%);S(T); TAB(26%);P(T)
190 NEXT N
195 H=1000
200 DA=A/T
220 SPV=0
225 PRINT
```

```
226 PRINT
227 PRINT "                     CASH FLOWS IN YEAR'S 1000 MONEY UNITS(MU)"
228 PRINT "---------------------------------------------------------------------------------------------"
230 PRINT "END OF"; TAB(6%);"NET CASH FLOW"; TAB(20%);"DEPRECIATION"; TAB(32%);
231 PRINT " TAXABLE"; TAB(44%);"  TAX"; TAB(55%);"NET CASH FLOW"; TAB(70%);"PRESENT VALUE"
240 PRINT " YEAR"; TAB(6%);" BEFORE TAX"; TAB(20%);" ALLOWANCE"; TAB(32%);
241 PRINT "CASH FLOW"; TAB(44%);"PAYABLE"; TAB(55%);"  AFTER TAX"; TAB(70%);"  IN YEAR 0"
260 PRINT "-----"; TAB(6%);"------------"; TAB(20%);"-----------"; TAB(32%);"---------"; TAB(44%);
261 PRINT "-------"; TAB(55%);"-------------"; TAB(70%);"-------------"
290 PRINT
300 PRINT "  0"; TAB(55%);C/H; TAB(70%);C/H
310 FOR N=1 TO T
320 DF=1/(1+(I/100))**N
330 NCFBT=S(T)-P(T)
340 TCF=NCFBT-DA
350 TP=TR*TCF/100
360 NCFAT=NCFBT-TP
370 PV=NCFAT*DF
380 SPV=SPV+PV
395 PRINT TAB(1%);N; TAB(6%);INT (NCFBT/H); TAB(20%);INT (DA/H); TAB(32%);INT (TCF/H);
390 PRINT TAB(44%);INT (TP/H); TAB(55%);INT (NCFAT/H); TAB(70%);INT (PV/H)
400 NEXT N
410 NPV=C+SPV
430 PRINT TAB(45%);"PROJECT NPV=";NPV
440 STOP

Ready
```

```
226 PRINT
227 PRINT "                   CASH FLOWS IN YEAR'S 1000 MONEY UNITS(MU)"
228 PRINT "--------------------------------------------------------------------------------"
230 PRINT "END OF"; TAB(6%);"NET CASH FLOW"; TAB(20%);"DEPRECIATION"; TAB(32%);
231 PRINT " TAXABLE"; TAB(44%);"  TAX"; TAB(55%);"NET CASH FLOW"; TAB(70%);"PRESENT VALUE"
240 PRINT " YEAR"; TAB(6%);" BEFORE TAX"; TAB(20%);" ALLOWANCE"; TAB(32%);
241 PRINT "CASH FLOW"; TAB(44%);"PAYABLE"; TAB(55%);"  AFTER TAX"; TAB(70%);"  IN YEAR 0"
260 PRINT "-----"; TAB(6%);"------------"; TAB(20%);"-----------"; TAB(32%);"---------"; TAB(44%);
261 PRINT "-------"; TAB(55%);"-------------"; TAB(70%);"-------------"
290 PRINT
300 PRINT "  0"; TAB(55%);C/H; TAB(70%);C/H
310 FOR N=1 TO T
320 DF=1/(1+(I/100))**N
330 NCFBT=S(T)-P(T)
340 TCF=NCFBT-DA
350 TP=TR*TCF/100
360 NCFAT=NCFBT-TP
370 PV=NCFAT*DF
380 SPV=SPV+PV
395 PRINT TAB(1%);N; TAB(6%);INT (NCFBT/H); TAB(20%);INT (DA/H); TAB(32%);INT (TCF/H);
390 PRINT TAB(44%);INT (TP/H); TAB(55%);INT (NCFAT/H); TAB(70%);INT (PV/H)
400 NEXT N
410 NPV=C+SPV
430 PRINT TAB(45%);"PROJECT NPV=";NPV
440 STOP

Ready
```

APPENDIX D-3 EVAL COMPUTER RESULT

```
RUN
EVAL          30-APR-1982 21:04

INPUT COPPER,ZINC,LEAD OR TIN
? COPPER
INPUT CONCENTRATE ASSAY
? 26
INPUT PROCESS CAPACITY IN TON/ANNUM
? 65000
INPUT NUMBER OF PROCESS STEPS
? 43
INPUT LOCATION FACTOR
? 1.15
INPUT WHICH YEAR
INP930DIRECT LABOUR RATE IN $ OR POUND STERLING/HOUR
? 9
ARE THERE ANY BYPRODUCT(S) ?
? NO
INPUT AVERAGE ANNUAL METAL PRICE IN CENTS OR PENCE/POUND
? 94.1
INPUT TAX RATE IN %
? 50
ARE THEY U.S. DATA?
? YES
DO YOU PREFER INPUT YOUR OWN INFLATION INDEX?
? NO
DO YOU PREFER INPUT FIXED CAPITAL INVESTMENT?
? YES
INPUT FIXED CAPITAL INVESTMENT IN $ OR POUND STERLING
? 149000000
DO YOU PREFER INPUT RAW-MATERIALS COST?
? YES
INPUT ANNUAL RAW-MATERIALS COST IN $ OR POUND STERLING
? 2589307
DO YOU PREFER INPUT DIRECT LABOUR COST?
? NO
DO YOU PREFER INPUT UTILITIES COST?
? YES
INPUT ANNUAL UTILITIES COST IN $ OR POUND STERLING
? 6800000
PROFIT AND LOSS ACCOUNT FOR A MATURE YEAR, 65000  TON/ANNUM COPPER
*************************************************************************

                                  $(1000)   CENTS/LB  % SALES
                                  -------   --------  -------
```

```
ANUAL SALES                  .13701E+09  94.1      100

DIRECT PRODUCTION COSTS      26593       18.2647   19.4099
  RAW MATERIALS              2589        1.77837   1.88987
  DIRECT LABOUR              4156        2.85503   3.03404
  SUPERVISION                623         .428255   .455106
  UTILITIES                  6800        4.67033   4.96316
  MAINTENANCE                5960        4.09341   4.35006
  OPERATING SUPPLIES         4470        3.07006   3.26255
  LABORATORIES CHARGES       623         .428255   .455106
  ROYALTIES                  1370        .941      1

FIXED CHARGES                14900       10.2335   10.8752
  DEPRECIATION               11920       8.18681   8.70012
  TAXES                      1490        1.02335   1.08751
  INSURANCE                  1490        1.02335   1.08751

PLANT-OVERHEAD COSTS         3949        2.71228   2.88234
  GENERAL OVERHEAD           3117        2.14127   2.27553
  PAYROLL OVERHEAD           831         .571007   .606808

MANUFACTURING COSTS          45442       31.2105   33.1674

GENERAL EXPENSES             17663       12.1315   12.8922
  ADMINISTRATION             2078        1.42752   1.51702
  RESEARCH AND DEVELOPMENT   685         .4705     .5
  FINANCING                  14900       10.2335   10.8752

TOTAL PRODUCT COST           63106       43.342    46.0595

TPC LESS DEPRECIATION        51186       35.1552   37.3594

NET ANNUAL PROFIT BEFORE TAX 73903       50.758    53.9405

TAXES AT  50 %               36951       25.379    26.9702

NET ANNUAL PROFIT AFTER TAX  36951       25.379    26.9702

------------------------------------------------------------------------

TOTAL CAPITAL INVESTMENT          .163578E+09
  FIXED CAPITAL                   .149E+09
  WORKING CAPITAL                 .14578E+08

RETURN ON INVESTMENT AFTER TAX   22   %
%BAS-I-STO, Stop
-BAS-I-FROLINMOD,  from line 1590 in module EVAL
Ready
```

APPENDIX D-4 CFA COMPUTER RESULT

```
RUN
CFA            1-MAY-1982 17:09

INPUT FIXED CAPITAL INVESTMENT
? 1\1\200000000
INPUT DISCOUNTED RATE OF RETURN
? 20
INPUT TAX RATE IN %
? 50
INPUT NUMBER OF YEARS FOR CASH FLOW ANALYSIS
? 10
INPUT SALES INCOME AND TOTAL PRODUCT COST LESS DEPRECIATION FOR  10  YEARS

END OF YEAR  SALES INCOME TOTAL COST
-----------  ------------ ----------
                           -.2E+09
    0
? 137000000
? 56700000
  1           .137E+09     .567E+08
? 137000000
? 56700000
  2           .137E+09     .567E+08
? 137000000
? 56700000
  3           .137E+09     .567E+08
? 137000000
? 56700000
  4           .137E+09     .567E+08
? 137000000
? 56700000
  5           .137E+09     .567E+08
? 137000000
? 56700000
  6           .137E+09     .567E+08
? 137000000
? 56700000
  7           .137E+09     .567E+08
? 137000000
? 56700000
  8           .137E+09     .567E+08
? 137000000
? 56700000
  9           .137E+09     .567E+08
? 137000000
```

```
? 56700000
 10         .137E+09    .567E+08

               CASH FLOWS IN YEAR'S 1000 MONEY UNITS(MU)
----------------------------------------------------------------------------
END OF NET CASH FLOW DEPRECIATION TAXABLE     TAX      NET CASH FLOW  PRESENT VALUE
 YEAR  BEFORE TAX    ALLOWANCE  CASH FLOW   PAYABLE      AFTER TAX     IN YEAR 0
----- -----------  ----------- ---------    -------    ------------  ------------

  0                                                      -200000        -200000
  1     80300         20000      60300       30150        50150          41791
  2     80300         20000      60300       30150        50150          34826
  3     80300         20000      60300       30150        50150          29021
  4     80300         20000      60300       30150        50150          24184
  5     80300         20000      60300       30150        50150          20154
  6     80300         20000      60300       30150        50150          16795
  7     80300         20000      60300       30150        50150          13995
  8     80300         20000      60300       30150        50150          11663
  9     80300         20000      60300       30150        50150           9719
 10     80300         20000      60300       30150        50150           8099
                                               PROJECT NPV= .102525E+08
%BAS-I-STO, Stop
-BAS-I-FROLINMOD, from line 440 in module CFA
Ready



EXIT
$ LO
  YLANG      logged out at  1-MAY-1982 17:12:25.90
```

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