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Promax2100: A Computer Programme for Design and Optimization of Mineral Processing Plant

Ajaka, E. O. and Chukwuma O. C.

Department of Mining Engineering, Federal University of Technology, Akure, Nigeria

A B S T R A C T

This article presents the development of a software programme ProMax2100 for design of an efficient mineral processing plant. In developing this software package, flowsheets designed for concentration of some metallic minerals were used. A complete plant design criteria document which contains detailed information on process engineering including large volume of numeric and non-numeric data on ore properties, capacity or scale of operation, results of comminution tests, bench scale and pilot scale recovery tests, process and equipment selection, scheduling and proportioning, materials handling and analysis, waste treatment and disposal among others was developed. An entire plant was divided into stages and all information and input data required for each stage were compiled, sorted and converted (where necessary) to a programme developer's language for programme code development. The Visual Basic Programme was used with C-Sharp and other language editors to develop the package. The individual programmes for all stages were then linked to form a continuous string that can simulate an entire plant in part or whole. The results of simulations carried out with the package show that the programme mimics the plants flowsheets used for simulation close to 100%..

1. Introduction

A mineral processing plant consists of sections and units developed separately following careful mineral identification, mineralogical design and economic evaluation. They are systematically integrated to produce a single simple flowsheet by which mineral concentrates and other products (Shoemaker, 2003). Designing an efficient mineral processing plant requires that a complete design criteria document be developed. Such document usually contains detailed information about the characteristics of the ore, mining plans, capacity or scale of operation, results of comminution tests, bench scale and pilot scale recovery tests, process and equipment selection schedule and proportioning, and materials handling and analysis among others (Scott, 2002; Laplante and Spiller, 2002). Most of the information mentioned above relate to process engineering only whereas a complete plant design document also contains another set of information that relate to construction engineering which deal with such non-process information as civil, structure, architectural, electrical, mechanical, seismic conditions, climatic conditions, altitude and other environmental constrains.. These set of information though partly related to process efficiency are not emphasized in the design of ProMax Optimizer since they have little or no effects on recovery. Thus a large amount of numeric and

each unit of the processing plant. In the view of Scott (2002), the criteria document so developed which evolves through preliminary studies and conceptual evaluation of the project then forms the basis for any assumptions, the governing codes and standards, plant assembly, process flow and overall representation of the plant. Although plant details and process parameters for a mineral type from different deposits differ because no two deposits of the same mineral are exactly the same, a general plant format can be developed that is adaptable to processing any kind of ore from any deposit by substitution and or variation of point or position factors in such a way that the materials still flows in the system in a manner that satisfies all programmed details (Scott, 2002; Onyemaobi, 2002, 2001). For example, the flowsheets in Appendix A may be used for other minerals by replacing the process techniques, change the recovery criteria, or eliminate a process stage.

The design criteria document should also specify the life of the plant, annual throughput capacity and operating schedule for equipment, the quality of feed to be processed as well as the grade or quality of products expected (Scott, 2002). Sometimes, a mineral processing plant is designed to process ores imported from other lands in which case the plant's life is not tied to the life of a mine. In such a case, provision for blending is very essential if the designed feed quality is to be maintained.

However, since the process design criteria which contains plant's dynamics and recovery are based on interpretation of metallurgical test works carried out on the ore such that the project details parallel the test works on completion, it is possible to simulate

Correspondence:

E-mail address: deleajaka@futa.edu.ng, akdenezer@gmail.com

plant behaviour based on conceptual design using models that exactly mimic the real or intended plant (Laplante and Spiller, 2002; Herbst et al., 2002; Dean, 2002).

$$W = 10w_i[1/\sqrt{P_{so}} - 1/\sqrt{F_{so}}] = P/T \dots\dots\dots\dots 1$$

where

w_i = work index (Kwh/t)

P_{80} = 80% passing size of the products ()

F_{80} = 80% passing size of feed ()

P = power drawn (Kw)

T = mass processed (tonnes per hour)

This equation has been used to design many ball and rod mill circuits for many years and it is still been used as the basis for most ball mill design work but it has limitations in terms of details required in process analysis and optimization work. These limitations are overcome in modern circuit design through the introduction of several efficiency factors in ore milling .

The result of application of modeling and simulation to mineral processing plant design through research over some years is now such that various numerical models have been developed leading to the availability of efficient simulators which are used with laboratory tests results and field data to simulate plant response.

An example is shown in Figures 1 and 2 which represent a user interface and output from USIM PAC. Some of these simulators are designed to simulate plant responses in part. For instance, the JKSimFloat simulator was produced by Julius kruttschnitt Mineral Research Center in Australia for simulating floatation processes (Harris, et al. 2002; Herbst, et al., 2002; Salama, 2001); and there are many of such partial plant simulators especially in the areas of comminution and particle sizing. Some like the USIM PAC Series, however are designed to simulate plant responses from crushing to refining but this require a large array of data (Brochot et al., 2002; Herbst and Lawrence, 2002).

Most of the modern software are high fidelity simulators (HFS) employed not only for plant response simulation or plant design generally, but also for data integrity analyses. They are capable of producing graphical display of plant flowsheets, calculate recoveries and grades simultaneously, do mass balance, predict costs, incorporate maintenance routine and produce a computer printable output of all these parameters as shown in Figure 1 and 2. Modeling and simulation have also been the most viable tools in plant process control and instrumentation (Wills, 2006)
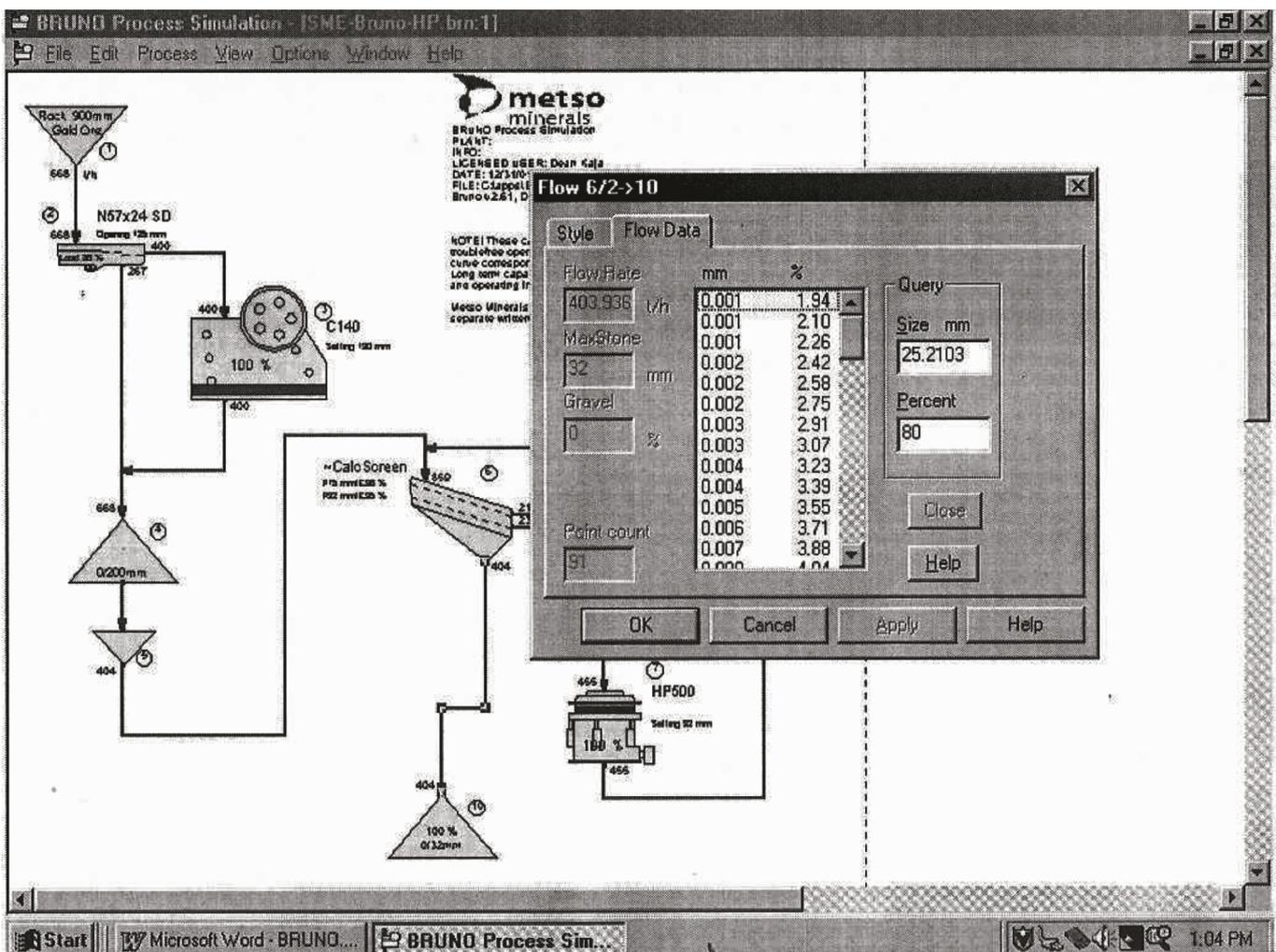

Figure 1: Graphical Display of Process Stages by Simulation (Produced by Metso Minerals)

#	Stream definition:	Target.up3 d80 of phase Gold ore (μm)	Target.up3 Mass flowrate of Gold (g/h)	Target.up3 Recovery of water (%)
1	Feed	4801	665	12.28
2	RM regulator feed	4801	665	12.28
3	Rod mill feed	4801	669.1	100
4	RM regulator add	?	0	11.71
5	Rod mill product	1038	669.1	100
6	Cyclone feed	427.1	1603	824.2
7	HC regulator add	?	0	23.42
8	OF	74.96	692.6	618.1
9	UF	800.1	910.1	206
10	Leached pulp	74.96	692.6	618.1
11	Unloaded carbon	?	8	0
12	Barren pulp	74.96	66.22	618.1
13	Loaded carbon	?	634.4	0
14	Recycled water	?	27.64	518.1
15	Tailings	74.96	38.58	100
16	HC regulator recycled	?	23.58	442.1
17	RM regulator recycled	?	4.054	76.01
18	Ball mill feed	800.1	910.1	258.6
19	BM regulator add	?	0	52.59
20	Ball mill product	122.7	910.1	258.6

Figure 2: Computer generated Output from a plant simulator

2.0 Methodology

2.1 The Promax2100 Concept

The initial concept of ProMax was to develop a software package for optimizing recovery of metallic minerals from their ores through effective process and process equipment selection and proportioning. However, it was discovered that maximizing recovery in a mineral processing plant is also dependent on the effectiveness of the comminution processes which are controlled by comminution equipment types, choice of circuits, feeds and products sizes. These parameters are also known to be the major determinants of comminution and indeed process costs. Effective post-concentration operations are also dependent on these factors. Thus ProMax-21 was designed to be able to simulate a mineral processing plant from comminution to concentrate stocking. The simulation may be done in stages or straight from the start to the end. Thus, the objective of this project is to develop a software package that can be used in simulating a mineral processing plant from comminution to concentrate storage by using flowsheets designed for concentration of metallic minerals such as Iron and lead-zinc minerals found in some Nigerian ores.

2.1.1 Development of ProMax2100

In developing this software package, flowsheets designed for concentration of some metallic minerals were used as standard plant procedure for optimum recovery (Some of the flowsheets used are shown in Appendix A). An entire plant is divided into stages and all required information and input data for each stage compiled, sorted and converted (where necessary) to a programme developer's language for programme code development. The number of process stages in some of the flowsheets has been increased deliberately to ensure that the cleanest concentrates are obtained before the maximum number of process stages in the plant is reached. The complete programmes for all stages were then linked to form a continuous string that can simulate an entire plant in part or whole from start to finish. Some of the criteria data required for decision making by the software package were coded for internal use only and some coded for both internal and external uses. The package is therefore made flexible to accommodate new innovations and improvements such that the recovery or separation criteria can be entered as input data for new output. For example, the programme
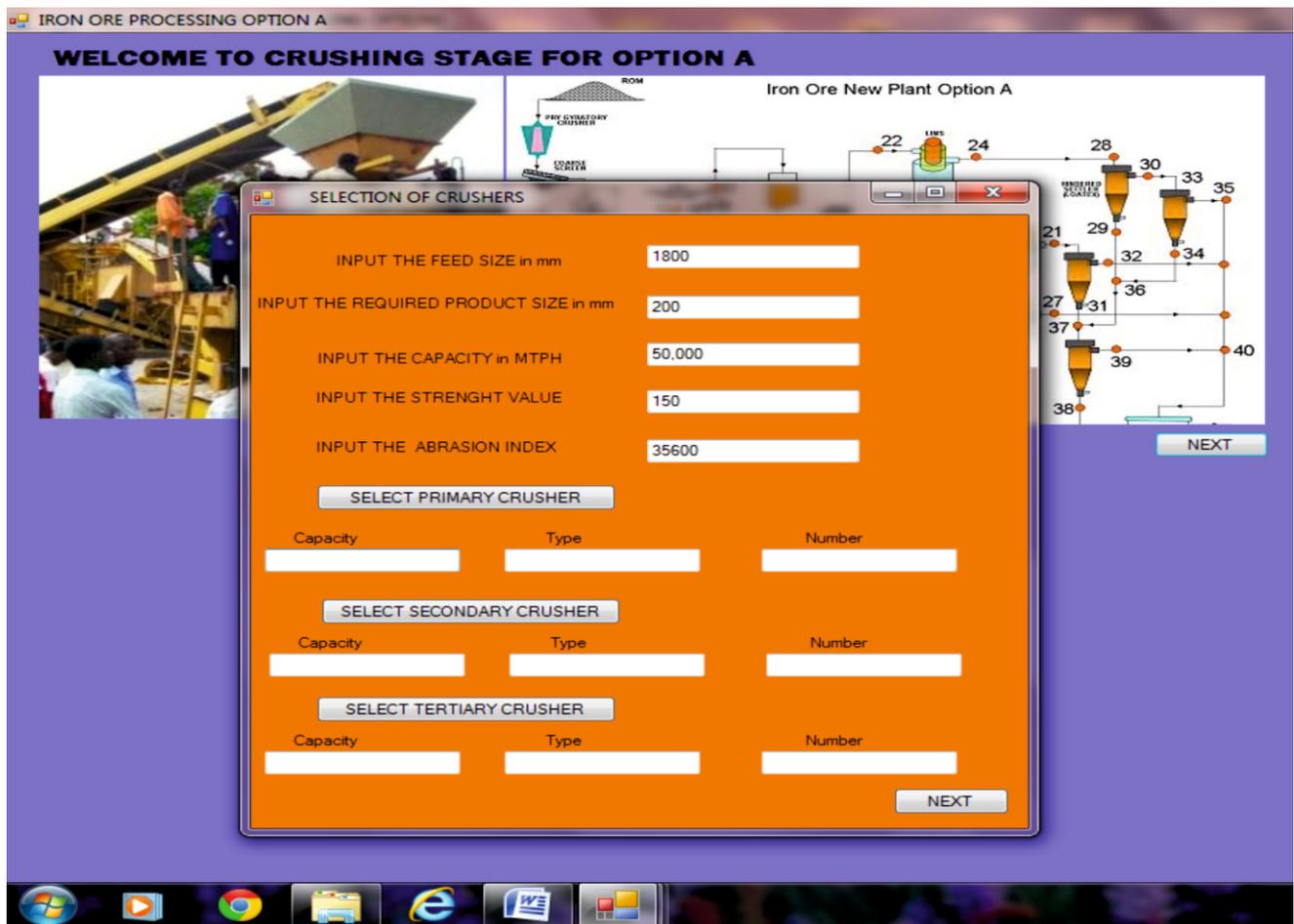
Figure 3: Crusher Selection Interface using Ore Properties and Plant Requirements as input Data.

programme uses in-built criteria data for selection of primary crusher when ore properties are inputted (Figure 9) but it may also use inputted crushers characteristics if user so desires to select the most appropriate crusher for a plant (see Figure 3).

2.2   Input Data Types And Sources

Comminution data, data for process type selection, equipment selection criteria, recovery, mass balance, cost estimation, and other important input data were gathered from results of laboratory experiments and various trusted sources and prepared for the software programme using the Visual Basic development environment. The summary of each data type used for development of the software are shown here.

2.2.1   Comminution Data

Comminution data are size reduction data and equipment performance criteria required for coding as inbuilt or input data so that ProMax could select crushers and mills for all stages of the comminution circuits and proportion such equipment for cost estimation. ProMax can also be used to design comminution circuits for quarrying operations. The data includes types of crushing circuit, crusher's characteristics, capacity ranges and costs for common primary, secondary and tertiary crushers and mills including their characteristics, capacity range, cost and circuit. Some of the data

were obtained from manufacturers' catalog. For instance, the in-built data used as criteria for selection of primary crushers by ProMax include crusher's feed (run-off-mine) and product sizes, abrasive index value of ore, hardness, crusher capacity and clay content of ore (Utley, 2002). These were compiled for the eight commonly applied crushers in the mineral industry as shown by the following summary and the example in Figure 4. The criteria data with a question (?) mark will have their values entered as input while the size dependent selection criteria use an appropriate in-built equation for decision. For instance, power requirement for ball mill in the mill selection criteria data employs Equation 2.

$$KW_b = 4.879D^{0.3} \ 3.2 - 3V_p \big)C_s \left(1 - \frac{0,1}{2^{9-10cs}}\right) + S......2$$

2.2.1.1   Summary of Crushers' Characteristics for Selection

Gyratory Crusher

Capacity Range	$= 1500$ to $12,000$MTPH
Feed Size Range	$= 300$ to 1800mm
Product size Range	$= 150$ to 300mm
Abrasion index Range	$= 0$ to 600MPA
Material with clay content	$=$ Poor
Underground service	$=$ Good/ Very good

Power Requirement = Size dependent

Average Acquisition Price   =   ?
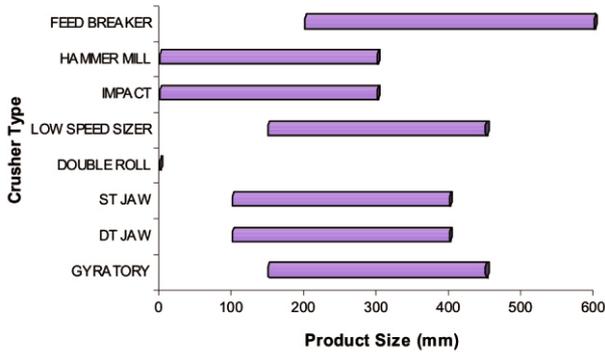
Annual Maintenance Cost   =   ?

Figure 4: Primary Crusher Selection Based on Product Size (Drawn from Utley, 2002)

2.2.1.2   Summary of Mills' Characteristics for Selection

For the selection of mills, the following summary of mills characteristics were used in programme coding. The efficiency factor equations are built in such that they can be used selectively and only numeric values for the variables such as wi (work index), F (feed size), F0 (optimum feed size), Rr (reduction ratio) and others are inputted. Autogenous (AG) and semi-autogenous mills are selected by changing the media charge value for the two common mills i.e. ball and rod mills. Since rod mills are seldom used in recent time, ProMax is designed for an efficient ball and autogenous milling.

2.2.1.3 Summary of Data Type for Selection of Ball Mill

Feed Size Range = 80% Passing 8 -10mm

Product Size Range = 80% finer than 0.5mm

Grinding Conditions   = Wet

Autogenous Competency = Very good

Mill Media Charge   = 35- 45% mill volume

Media Size   =   ?

Mill Feed Charge   = 50-55% mill volume

Power requirements   =

$$KW_b = 4.879 D^{0.3} \left(3.2 - 3V_p \right) C_s \left(1 - \frac{0,1}{2^{9-10cs}} \right) + S ....2$$

Acquisition Price Range   =   ?

Annual Maintenance Cost   =   ?

Mill Size   =   ?

Inefficiency Factor Equations

Dry Grinding $= 13 W_c = 13 W_i \left(P^{-0.5} - F^{-0.5} \right) ....3$

Open Circuit   =   Circuit dependent

Diameter $= \left[\dfrac{2.44}{D} \right]^{0.2} ....ى$

Oversize $= \dfrac{R_r + W_i - 7}{R_r} \left(\dfrac{F - F_o}{F} \right) ....5$

Fine Grinding $= \dfrac{P + 10.3}{1.145 P} ....ى$

Low Reduction Ratio $= \dfrac{2 \left(R_r - 1.35 \right) + 0.26}{2 \left(R_r - 1.35 \right)} ....7$

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2.2.2   Input Data for Process Selection

The principles of operation of the various mineral concentration techniques were compiled and coded for process selection in ProMax based on some rules of thumb, established results of industrial applications of some concentration processes as obtained in literature, process equipment types and results of experimental runs with the particular recovery process. For example a summary of gravity concentration processes whose recovery data are used in ProMax is shown in Table 1. But the applicability of a gravity technique may be determined first by applying the gravity concentration criterion (Wills, 2006) given in Equation 9.

$$\Psi \quad = \quad \frac{\ell_{HM} - \ell_{FM}}{\ell_{LM} - \ell_{FM}} ....ۍ$$

Where, Ψ = concentration criterion

ℓ_{HM}= specific gravity of heavier mineral

ℓ_{LM}= specific gravity of lighter mineral

ℓ_{FM}= specific gravity of the fluid medium

According to Wills, 2006, gravity concentration is applicable at commercial level if the value of this criterion is greater 2.5.

2.2.2.1 Summary of Criteria for Selection of Some Gravity Equipment

Some details about the data type used by ProMax for selection of gravity equipment are shown in the following example. Similar inbuilt data were made for jigging, shaking table, hindered settler, cyclone and centrifuge and common gravitational sedimentation.

2.2.2.2 Sample Summary of Data Type for Selection of Spiral Separators

Effective concentration criterion   = > 2.5   Feed size range = > 1mm

Product size range = as in feed

Slurry density = 25-40% solid by volume

Recovery/Efficiency = 50-75% (see Table 1)

Usual No of Process Stages = ore and concentrate grade dependent

Low grade ores   = 4 process stages

Medium grade ores =   3 process stages

High grade ores   =   1 - 2 stages

Wash water Requirement =   optional and ore dependent

Power Requirements   =   None
Annual Maintenance Cost   =?
Acquisition Price Range =   ?
Capacity Range   =   6-7.5 tph

·3.2.3 Process Stages and Stream Iteration

Some of the flowsheets used in iteration of recovery are shown in Figures 5 to 8. The concentration portion of each flowsheet consists of a number of process stages which correspond to roughing, scavenging, cleaning and recleaning. Each process stage has three streams which are the feed, concentrate and tailing. All streams in a particular circuit are serially numbered numerically for identification and coding. The recovery criteria shown in Table 1 were coded with other necessary parameters and used in stepwise iteration by ProMax for effective determination of the properties (weight and grade) of these streams. Thus, the properties of the concentrate, as well as recovery and loss can be determined at each process stage.

3.2.4 Concentrate Blending and Dilution

The stream iteration process also allows for blending a number of streams or dilutes any stream with another to produce a concentrate of specified grade. Equations 16 and 17 (derived from first principles) are used respectively as inbuilt criteria in ProMax for blending and diluting streams.

$$X_{ng} = \frac{X_1 W_1 + X_2 W_2 + \dots\dots + X_n W_n}{W_1 + W_2 + \dots\dots + W_n} \dots\dots\dots\text{وي}$$

Where
X1, X2,…. Xn = grade of the different concentrate blended (%)
W1,W2,….Wn= weight or volume of each concentrate (tonnes)
Xng= new grade produced by the blend of the different on concentrate (%)

In mineral processing operations that are designed to supply concentrates of specified grades, the number of process stages may be increased so that the plant produces a final super-concentrate or concentrates whose grades are higher than the specified grade (McNulty, 2002). Thus there is sometimes the need to dilute the concentrate with the middling or washed gangue materials to obtain the specified or required grade especially when the end user may not pay for extra valuable content above specified grade. To determine the volume or weight of middling or washed gangue that will be required to dilute concentrate of a given grade to a new grade, Equation 17 is used.

$$W_M = \frac{X_d - X_c}{X_m - X_d} x \ W_C \dots\dots\dots\dots\dots \text{يو}$$

where
W_M = required weight of material for dilution (tonnes)

X_d = Targeted or new grade (%)

X_c = grade of concentrate to be diluted (%)

X_m = grade of material for dilution (%)

W_c = weight of concentrate to be diluted الله

3.2.5 Equipment Selection Criteria

As explained for comminution and process equipment, the characteristics of most mineral processing and ancillary equipment including their technical details as obtained from manufacturer's catalogue, process stage or unit requirements and recovery criteria based on ore and mineral properties as obtained from compositional analysis and laboratory or bench scale recovery tests, were required as in-build or external data for selection of various unit equipment by ProMax; while the plant capacity and volume of material at each stage or unit were used in proportioning the equipment.

3.2.6 Development Package/ Environment

The Microsoft Visual Basic developer was used with C-Sharp (C#) to design all features of ProMax 2100. C# in particular allows working with two types of data (value types and reference types) which enables some data to be coded as inbuilt data, while other data are input as external data. The environment also enables autoplots of results of internal analysis of numeric data and displays these graphically or in tabular format.

3.3 Cost Estimation With ProMax

Although many factors are required for accurate cost estimation for a mineral processing plant, the items shown in Table 2 and Equations 18 to 20 are usually sufficient for producing acceptable financial estimate and are thus used as inbuilt criteria for cost estimation in all versions of ProMax optimizer.

$$C_{TOTAL} = C_{ET} + C_{EA} + C_{PA} + C_{IN} + C_P + C_{OP} + C_{MK} + C_{LE} \dots \text{يو}$$

C_{ET} is the factored annual cost of acquiring and installing equipment, C_{EA} is fixed cost that must be set aside for equipment replacement in x years, C_{PA} is cost of process piping and related activities; factored annual instrumentation cost is CIN, cost of providing power is C_{PW}, C_{OP} is the operating cost, and C_{LE} represent legal cost.

Annual revenue from all products is estimated using Equation 19 and the annual profit GPA is calculated using Equation 20.

$$\sum F_i = \sum M_C f_i + \uparrow M_{bp} f_{bp} \dots\dots\dots\dots \text{ولا}$$

Where,

M_C =   volume of concentrate sold per annum
M_{bp}=   volume of by-products sold per annum
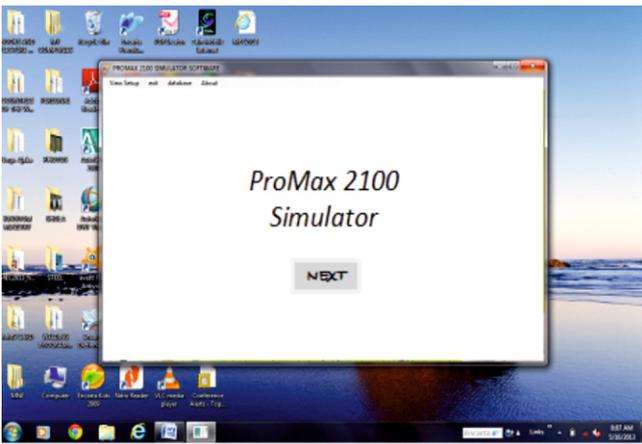
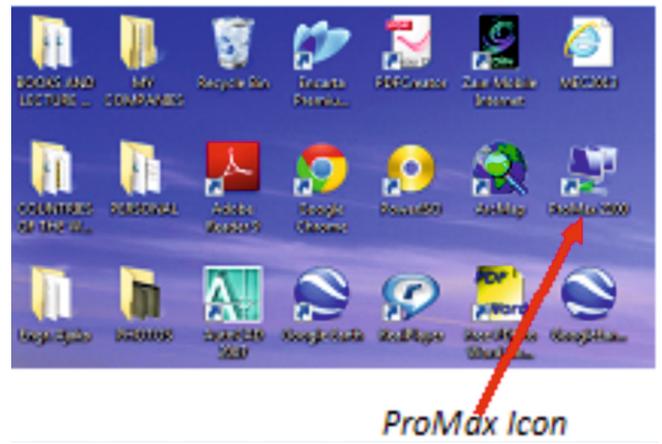**Figure 5: Screen Print of ProMax First User Interface**

Figure 6: Loading ProMax from the desktop
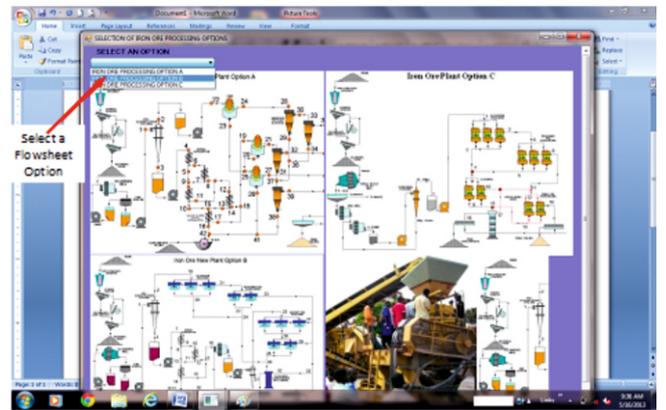

Figure 7:ProMax Simulator Interface

Figure 8: Selecting a Flowsheet Option

f_i= cost of selling a tonne of concentrate

f_{bp} = cost of selling a tonne of by-product

$\sum$= applies to the number of concentrate and by-products of different minerals or of different grades of the same mineral.

The actual annual profit margin G_{PA} putting capital cost offset into consideration is determined from equation 20.

$$ G_{PA} \quad = \quad \sum F_i - \quad C_{TOTAL} \quad \text{......................20} $$

2.3   ProMax2100 User's Interface

ProMax has the simple first contact user's interface shown in Figure 5. Subsequent interfaces are displayed based on the particular simulation being carried out and this follows the sequence of operation in a typical mineral processing plant. Figures 7 to 16 are examples

2.4   Future Development

In the future, ProMax will be able to produce a bankable feasibility report for new mineral projects using exploration and survey data and results of bench scale tests on ore samples; calculate equipment depreciation to alert for replacement and perform cash

flow analysis for plant operations. ProMax will also be available for online simulation with results of bench scale test data for any metallic mineral. Included in the programme for future development is for individual users to load a flowsheet of his own design and then assign inbuilt streams in ProMax to simulate it.

2.5   Simulation With ProMax 2100

Simulation follows a successful installation of a version of ProMax which operates in windows environment. ProMax icon on the desktop is double-clicked to load the software to windows (Figure 6). A simple user interface (Figure 5) is loaded for the user to explore or simulate with the programme. A set of numeric data from laboratory plant scale tests should be handy for simulation with ProMax.

To begin simulation, (1) simply click **NEXT** or (2) click *view setup* menu on the Taskbar (Figure 7) and ProMax automatically loads the interface shown in Figure 8 where the user can assess and select a flowsheet option from the inbuilt options

Once selected, the flowsheet is loaded to one side of windows with the rest of available space for display of tables and other numeric data (Figures 9). From this stage on, simulation
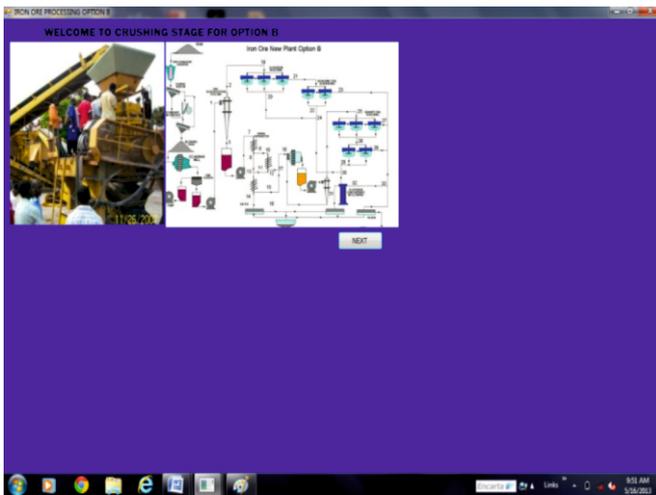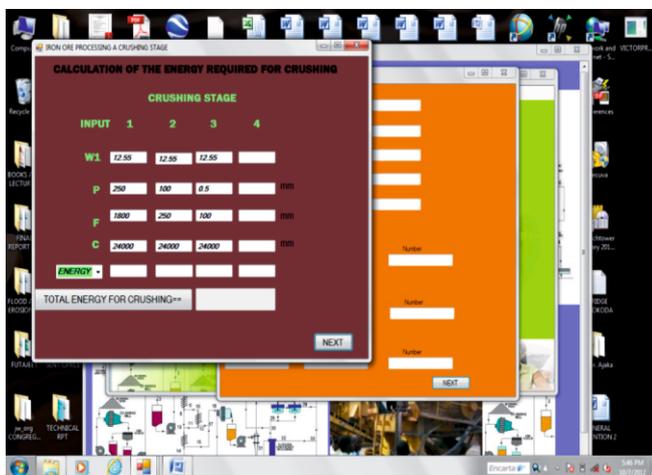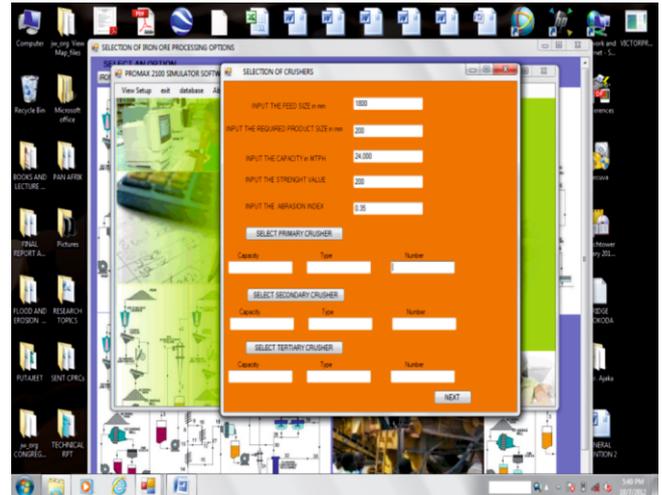
Figure 9: Simulation Page in ProMax

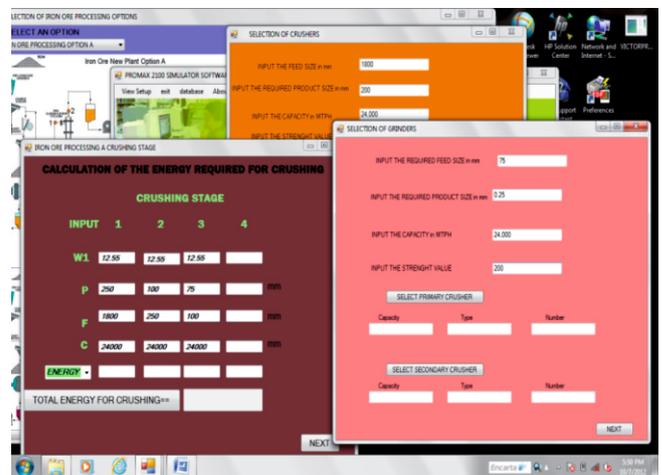Figure 11: Crushing Energy Determination interface

Figure 12: Mill Selection Menu

follows simple sequence of mineral processing operation beginning with crushing. Thus, clicking **NEXT** on this page displays the crusher selection menu automatically (Figure 10). Any of the stages can be skipped by simply clicking the **NEXT** button, and the results of previous iteration are automatically saved into a tabular file format or list within the system.

2.6.1   *Comminution Circuit Simulation*

The first interface in simulating comminution circuit prompts the user to select crushers by entering feed and product requirements and such ore properties as hardness, strength abrasiveness and others to select the most applicable crusher types. Part of the results are displayed on windows, but when the   botton **NEXT** is clicked, ProMax prompts the user to calculate the energy required for crushing by entering the number of crushing stages and the work index for the material (Figure 11) and automatically save the previous results. ProMax is also able to determine work index from results of grindability tests.

Clicking**NEXT** on the crushing energy menu calls the grinding mills selection menu (Figure 12) followed by a menu for the determination of the number of milling stages and calculation of the

energy required. The mill selection menu also incorporates some dialogue for application of some common inefficiency factors (Figure 13)

2.6.2   *Process and Process Equipment Selection*

When the last simulation in comminution is finished, ProMax welcomes the user to Process stream iteration (Figure 14) and one of the inbuilt flowsheet number is indicated on this welcome page but this can be changed by clicking on the button and selecting another option from the list.

Once the flowsheet is selected, ProMax displays a dialogue box prompting the user to enter ore properties and proposed plant capacity with which ProMax calculates and displays the weight of the valuable and gangue minerals in the input stream (Figure 15). This interface contains several other features whose dialogues are displayed only when activated (Figures 15 and 16). The purpose of the series of iteration steps built into this package is for mass balancing and metallurgical accounting. After all iterations have been done and properties of the final concentrates and tailings known, a number of streams may be blended to improve the properties of their blend or the final concentrate may be diluted with
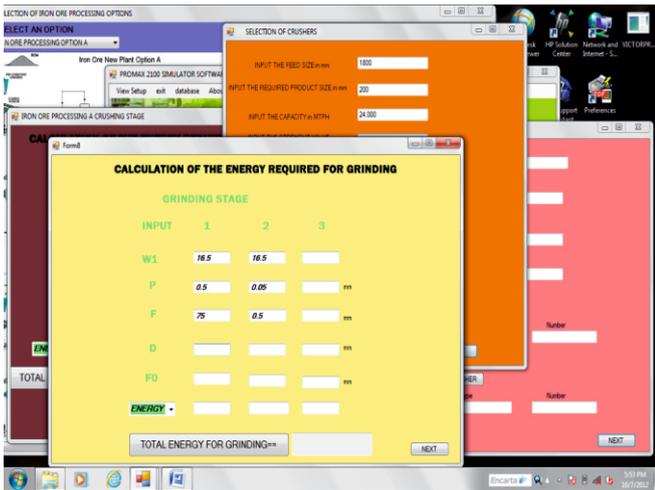
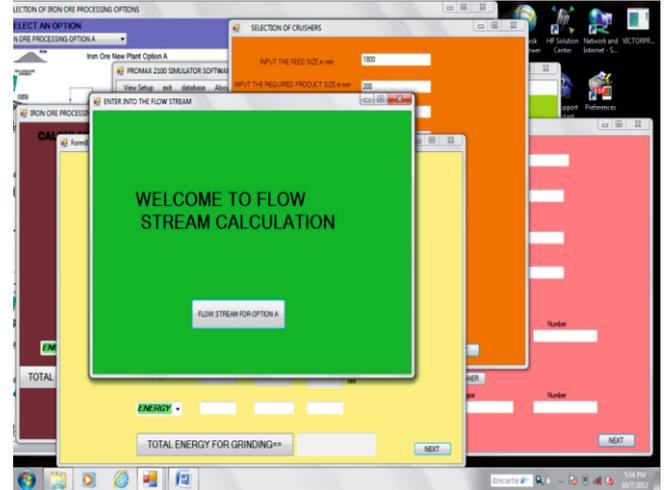**Figure 13: Milling Stages and Energy Determination Menu**

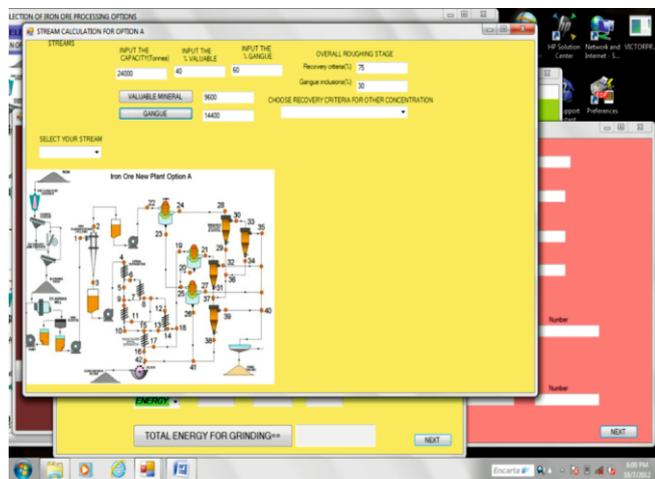**Figure 14: Flow Stream Iteration Selection Interface**

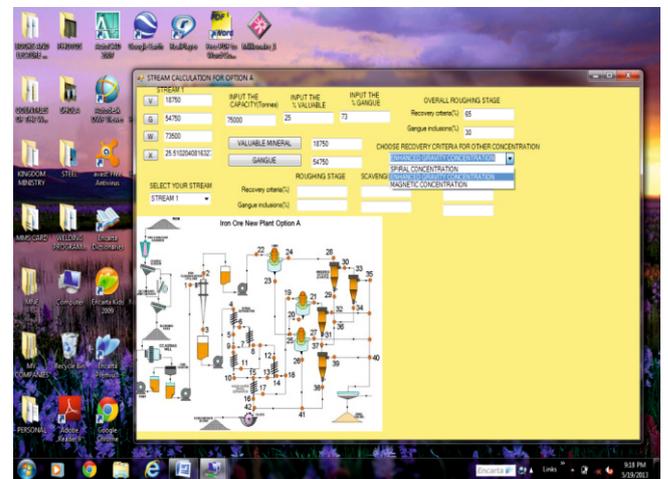**Figure 15: Ore Properties and Stream Balancing Interface**

Figure 16: Selecting a Gravity Concentration circuit in ProMax
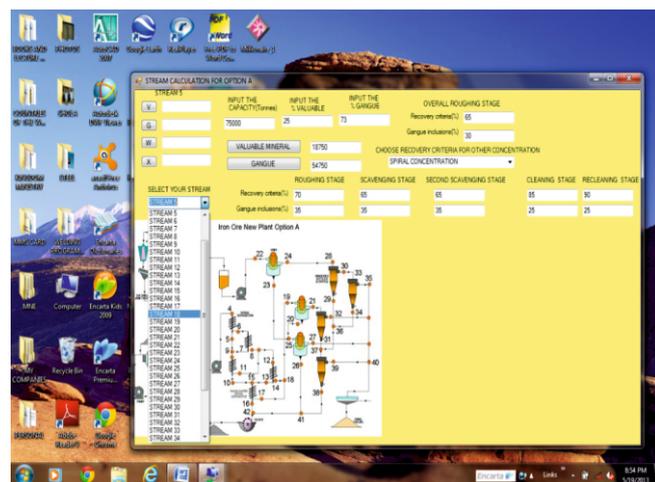

Figure 17: Other Features in the Stream iteration Interface
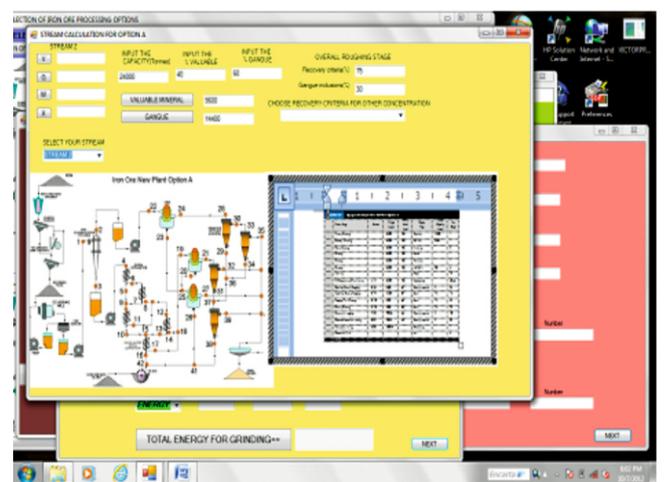

Figure 18: Results saved into Files within the Software can be copied

final tailing or any stream to increase the volume of final concentrate. This is done by simply selecting the desired streams for blending (Figure 17). Some of the results of simulation are displayed in windows on the interface for monitoring, all results are stored in files in the local disc and these can be copied and edited as appropriate (Figure 18). Although the software is still undergoing some improvements and innovation, the present version are versatile enough to perform most of the common calculations and selections in any mineral processing plant.

3.0   Conclusion

The successful development of ProMax software package to this stage shows that with more effort, a complete and all-inclusive software package can be developed for simulating every section or unit of any mineral processing and metallurgical plant. The continued research by the ProMax group into more programming possibilities in alpha-numeric and graphics information will ensure that ProMax attains an advanced stage in its next public edition.

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