Computer-Aided Design of a Flash Smelting Installation

By M. A. T. COCQUEREL*, Ph.D., C.Eng., A.M.I.Chem.E., R. T. GATES,† B.A.Sc., M.A., and C. A. GREEN,‡ B.Soc.Sc.

SYNOPSIS

Engineering studies by Selection Trust, Limited, initially in connection with the development of a copper and nickel deposit for Bamangwato Concessions, Limited, and subsequently for several other clients, have required a large number of metallurgical design calculations. The flash smelting process, developed by Outokumpu Oy in Finland, has been selected as the most suitable method for these projects and the computer programs described in this paper have been developed to facilitate the computation.

The data required by the programs are the chemical and mineralogical analyses of the concentrate, gangue and flux materials and the specification of possible fuels. The required grade of furnace matte is set as the main design parameter and the programs calculate detailed heat and material balances for the smelting process.

INTRODUCTION

In 1967 investigations by the RST Group led to the choice of the Outokumpu flash smelting process for treating nickel/copper concentrates from deposits in Botswana. The Engineering Division of Selection Trust, Limited, were commissioned to carry out the engineering design studies in conjunction with Outokumpu Oy for this project. Since 1967 Selection Trust Engineering Division have had further requests by other clients to prepare engineering studies for smelters to process both nickel and copper concentrates.

The initial metallurgical design calculations were based on scientific principles and were the subject of much detailed discussion with Outokumpu Oy. These calculations, which were lengthy, were intended for use in basic engineering design work. However, as it became necessary to vary the parameters to investigate the effects of changing factors such as concentrate analysis and treatment rates and, furthermore, as other projects arose, it became apparent that computerization of the routine calculations could result in savings in time and avoidance of errors. An initial program ('SMELT') was written at the RCM laboratories in Kalulushi, Zambia, to calculate heat and mass balances for the flash furnace only.

Further development of the program, renamed 'FLASH I' was carried out in London from mid-1969. A second program, 'FLASH II', was written in early 1970 to incorporate the flash smelting of nickel concentrates. The scope of the program has been widened to include heat balances for each section of the flash furnace, converter mass balances, slag cleaning by either electric furnace or milling and flotation, and the treatment of the waste gases for sulphuric acid or elemental sulphur production.

The programs have two main functions, namely,

(i) to compute heat and mass balances in order to determine tonnages of matte and slag, and the volume and composition of waste gases, so that the size of furnace, waste heat boiler and associated equipment required to treat the design tonnage of concentrate can be determined, and

(ii) to assess the effects of changes in certain operating parameters on the initial design.

In the future the existing programs could be used as basic mathematical models for production control and the development of operating strategies. This paper describes the flash smelting process, the major design considerations, and the existing computer program.

THE FLASH SMELTING PROCESS

The flash smelting process for sulphide concentrates was developed by the Finnish mining company, Outokumpu Oy, from 1948 onwards. By mid-1971, a number of mining companies had negotiated licences and installed plants for using this process. Several other installations for both copper and nickel concentrates are in the design and construction stages.

In contrast to the reverberatory furnace smelter, in which most of the sulphide oxidation occurs in the converters and the matte grade is dictated by the concentrate analysis, sulphide oxidation can be carried out to a predetermined degree in the flash furnace. The heat of the oxidation reactions is used to help maintain the furnace heat balance. In some instances the iron and sulphur contents of the concentrate may be sufficiently high as to make the smelting process autogenous.

The equipment required in a flash furnace is illustrated in two Outokumpu publications. Figure 1 shows a schematic representation of a proposed copper/nickel installation. The heart of the process is the flash furnace itself which consists of a horizontal settler section with vertical reaction and gas offtake shafts at opposite ends. The furnace is constructed of steel platework lined with refractories.

Dry concentrates and flux material are fed to specially designed burners at the top of the reaction shaft, together with preheated air. Additional fuel may be burned in the reaction shaft if required.

A predetermined proportion of the sulphides in the concentrate is oxidized in the reaction shaft and the smelted materials fall into the liquid in the settler section. Matte and slag separate into two layers in this section as in conventional reverberatory furnace smelting. Matte is tapped from the reaction shaft end of the furnace and slag from the opposite end.

Hot gases from the reaction shaft pass through the settler section and leave the furnace by way of the vertical gas offtake shaft. These gases are cooled in waste heat boilers in which steam is raised for power generation. Part of the dust burden is removed in the waste heat boilers and the remainder is normally removed from the gases by means of electrostatic precipitators. Flue dusts can be recycled to the flash smelting furnace, or treated separately.

*Selection Trust, Limited, London.
†Engineering Division, Selection Trust, Limited, London.
‡RCM Research and Development Department, Chibuluma Division, Zambia.

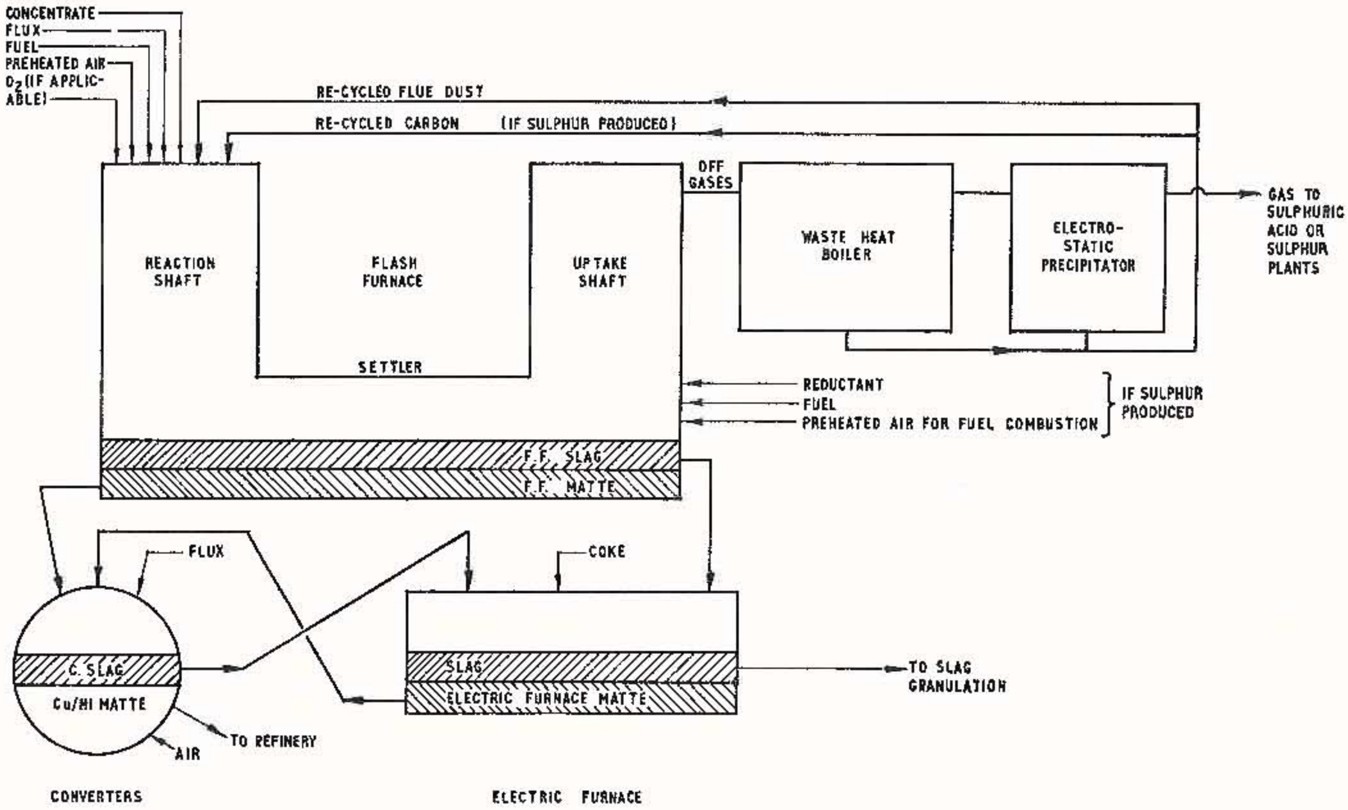

Fig. 1. Schematic diagram of a Cu/Ni smelter complex.

The concentration of sulphur dioxide in the waste gases usually varies between 10 and 15 per cent, and is well suited to sulphuric acid or elemental sulphur production. Should it be required to produce elemental sulphur, a carbonaceous reductant is introduced into the furnace uptake, as shown in Fig. 1.

In both copper and copper/nickel smelting, matte from the flash furnace is processed further in conventional converters to produce blister copper or copper/nickel matte for subsequent refining.

Slag from the flash furnace usually contains a percentage of the valuable metal considerably higher than that found in conventional reverberatory or electric smelting furnace slags. The quantity of metal in the slag increases as the grade of matte being produced is increased. In all cases, smelter recoveries would be unacceptably low if the slag were to be discarded without further cleaning. In the nickel smelting process, slag is cleaned by reduction under coke in an electric furnace, while copper flash smelting furnace slags may be cleaned either in an electric furnace or by milling and flotation to produce a slag concentrate which is recycled to the flash furnace.

During the design stage of the initial furnace installation, the requirements of future extension and expansion must not be neglected. One of the modern techniques for increasing smelter throughput which is now being used successfully by a number of companies is to enrich the air fed to both primary smelting furnaces and converters with oxygen. Oxygen enrichment has been in use in a flash smelter in Japan for some time, Tsuromoto, *et al* (1970). In view of these developments, the computer program now permits heat and mass balance calculations to be made for any given set of operating conditions at various levels of oxygen enrichment of the air to the flash smelting furnace.

PROCESS CALCULATIONS

The task facing the designers of a smelting plant is considerable even when the process has been selected and the required scale of operations determined. In formulating the initial design of a flash furnace the physical dimensions are determined by average grade of the concentrate to be smelted and the grade of matte to be produced from the furnace. Once the physical dimensions of the furnace have been determined, it is often found necessary to make process calculations for a number of different operating cases.

A total of 10 convergences may be required to perform one set of calculations for the system illustrated in Fig. 1. However, as Fig. 2 illustrates, a number of these convergence loops fall within other loops making the total number of trial and error processes much larger than 10. Primarily, it is the facility of the computer for handling these convergence loops that has justified development of the programs.

PROGRAM DETAILS

The FLASH programs are written in standard FORTRAN for a UNIVAC 1108 computer owned by a London computer bureau. The programs have also been translated into FORTRAN IVG for use on an IBM system 360/40. Each of the two programs contains approximately 1 700 cards and is modularized, incorporating subroutines for optimum convergence, gas analysis calculations, fuel combustion, etc. This ensures that the program is readily amenable to extension. A logic diagram for the FLASH II program is shown in Fig. 3.

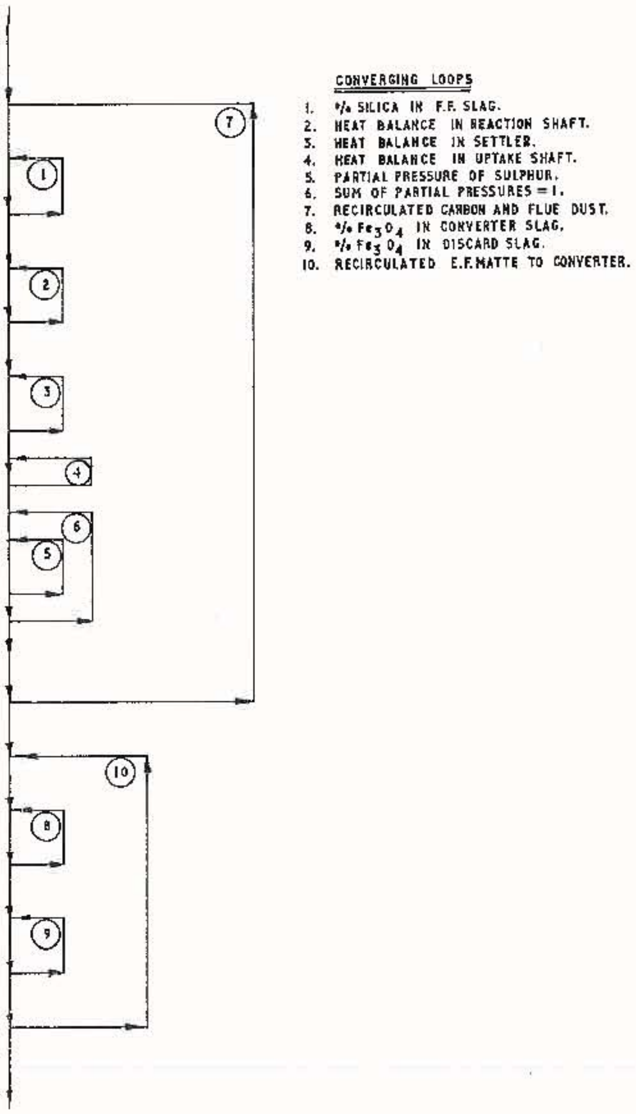

Fig. 2. Illustration of convergence loops.

Input to the program consists of approximately 100 design parameters or ambient conditions. Each of these variables is given a unique number and each initialized at its most probable final setting. To change any variable, the design engineer enters, as input data, the variable number and the new value to which this variable is to be set. Any number of variables may be changed for a particular run and any number of runs may be processed at one time.

The design variables include:

(i) concentrate composition (11 components),

(ii) gangue analysis (5 components),

(iii) flux analysis (7 components),

(iv) fuel analysis (12 components),

(v) reductant analysis (12 components),

(vi) temperatures (6 components),

(vii) non-controllable parameters (e.g. relative humidity, heat efficiencies) (20 components), and

(viii) major design parameters or operating conditions (e.g. matte grade, level of oxygen enrichment) (20 components.)

Output from the FLASH program has been designed so that it may be photocopied on to report-sized paper without necessitating photoreduction. Information generated includes:

(i) a complete summary of design variable settings,

(ii) a reconstituted concentrate assay,

(iii) matte compositions for the flash furnace and the electric furnace,

(vi) heat balances across the reaction shaft, settler and uptake shaft,

(v) gas analyses in each part of the furnace,

(vi) summary of fuel, flux and air requirements for the system,

(vii) circulating loads, and

(viii) slag analyses for the flash furnace, converters and electric furnace.

FUTURE DEVELOPMENTS

Work is in progress to produce an extended version, called FLASH III, which will incorporate all facilities of I and II with more sophisticated sulphur reduction calculations. Subroutines have also been proposed to calculate waste heat power generation, smelter utilities consumption, sulphuric acid and elemental sulphur production. Eventually optimization techniques may be introduced. Future developments will be as optional modules which will be selected by the user by means of a simple control program.

BENEFITS

Apart from the obvious savings in computation time and the inherent accuracy of the machine, the development and use of the program has enabled far wider studies of the effects of changes in process variables to be made than would otherwise have been possible. These studies have brought to light areas where savings both in initial capital and in future operating costs may be made. In addition to this, the program forms a basic mathematical model and as such has given those engineers working with it a better 'feel' for the smelting process.

CONCLUSIONS

The development of this program to aid in smelter design has been a success. It was found that the time required to write and prove the program was in fact longer than was first envisaged, but subsequent benefits, which were not initially expected, have more than justified the time spent.

ACKNOWLEDGEMENT

The authors wish to acknowledge the permission of the executive managements of Selection Trust, Limited, Bamangwato Concessions, Limited, RCM, Limited and Outokumpu Oy to publish this paper. They would also like to acknowledge the extensive co-operation of Outokumpu in the preparation of metallurgical calculations.

REFERENCE

TSURUMOTO, *et al* (1970). Development of copper smelting at Saganoseki Smelter. *Copper Metallurgy*. R. P. Ehlrich (Ed.), p. 117.

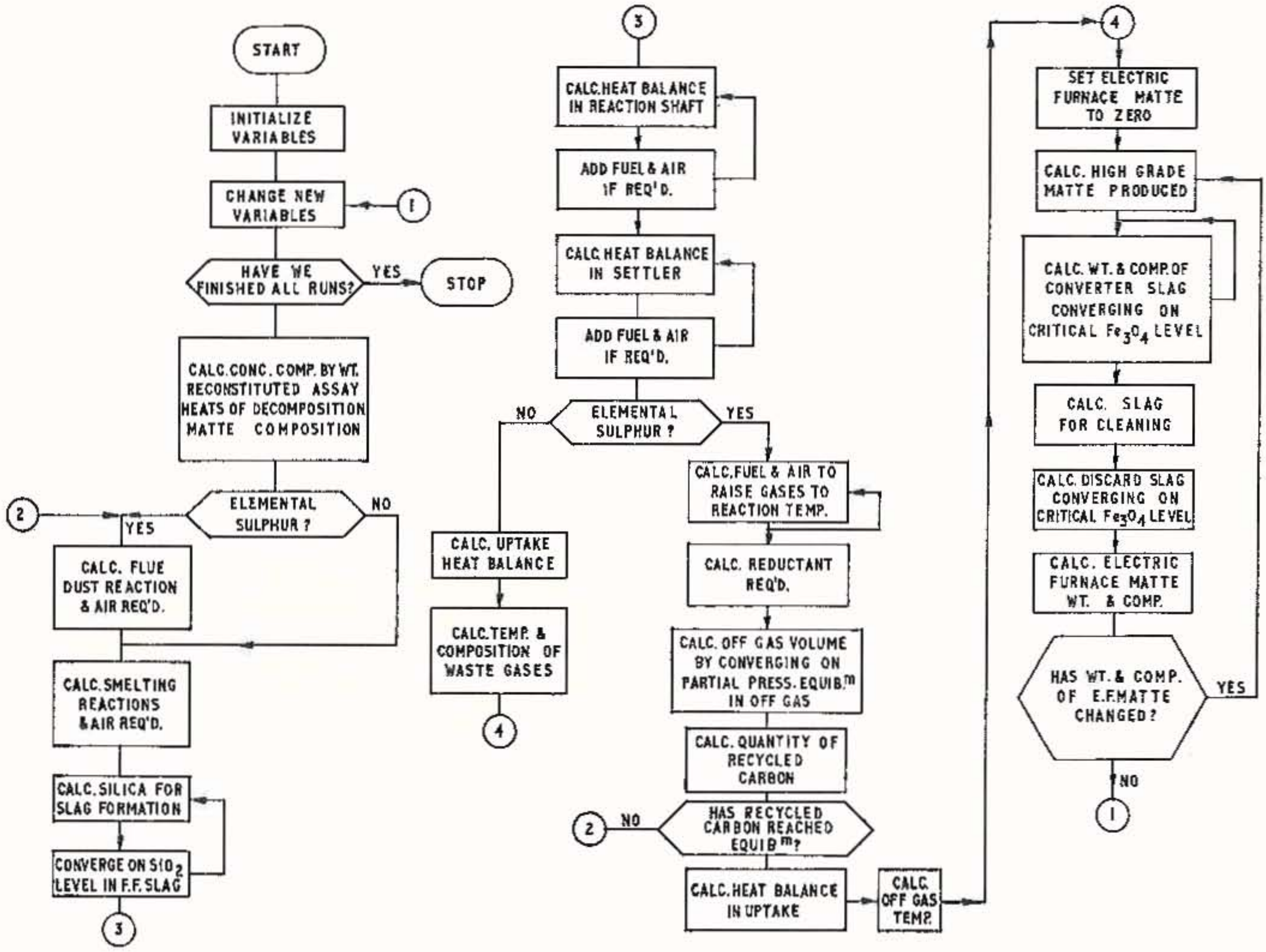

Fig. 3. Logic flowchart of FLASH program.