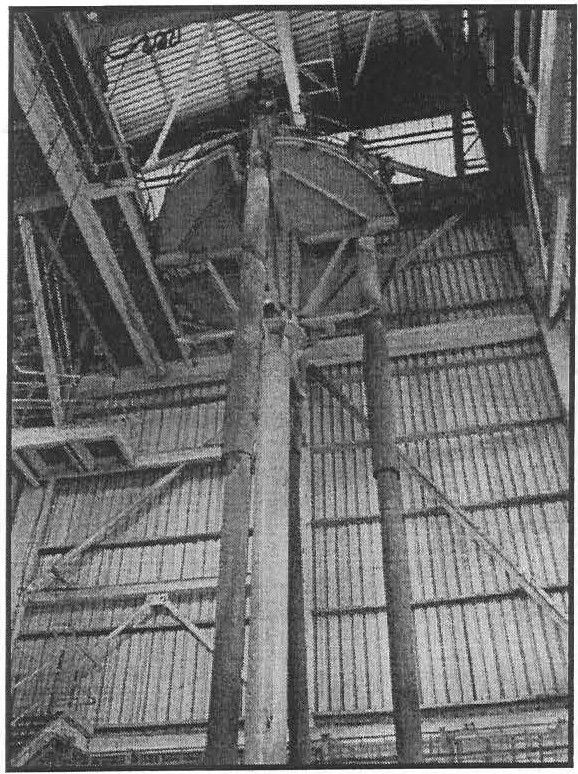
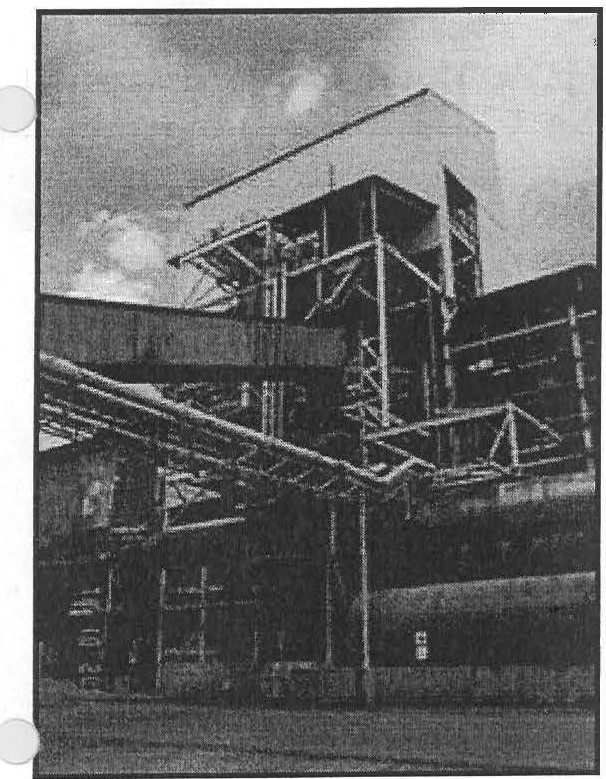
**ONG0P0L0 MINING LIMITED**

7TH JANUARY 2007

**ZINC FUMING PROJECT INITIAL MASS AND ENERGY BALANCE**



*LEAD SMELTER FURNACE LANCI;S*



**STIRLING PROCESS ENGINEERING**

PROCESS ENGINEERING RISKANALYSIS STUDY MANAGEMENT STRATEGIC PLANNING DETAILED DESIGN

**DISCLAIMER**

This document has been prepared for Ongopolo Mining ltd (Ongopolo) by Stirling Process Engineering Ltd (Stirling Process Engineering), based on assumptions as identified throughout the text and upon information and data supplied by others. Stirling Process Engineering is not in a position to, and does not, verify the accuracy of, or adopt as its own, the information and data supplied by others.

Stirling Process Engineering does not accept any legal responsibility to any person, organisation or company for any loss or damage suffered resulting from reliance on this report however caused, and whether by breach of contract, negligence or otherwise.

#### ONG0P0L0 MINING

#### ZINC FUMING MASS AND ENERGY BALANCE TABLE OF CONTENTS

1. [CONCLUSIONS AND RECOMMENDATIONS 7](#_TOC_250004)
2. [OBJECTIVES AND CALCULATION METHODOLOGY 11](#_TOC_250003)
3. [DESIGN CRITERIA 24](#_TOC_250002)
4. [MASS AND ENERGY BALANCE OUTPUTS 33](#_TOC_250001)
5. [DISCUSSION OF MODEL OUTCOMES 36](#_TOC_250000)

## CONCLUSIONS AND RECOMMENDATIONS

* A first pass energy balance has been developed to describe the performance of the existing Tsumeb lead Ausmelt furnace converted to zinc fuming duty. Whilst this model should be regarded as a first pass it does appear to be generating reasonably sensible data with respect to air requirements and off-gas flowrates on the basis of parametric checks against other projects and the Korea Zinc proposal for treating the Tsumeb lead slag.
* Whilst the model simulates the overall mass and energy balance it does not simulate the smelter reaction kinetics or the reactivity (free energy) of the system. It is therefore assumed that there is sufficient residence time in the furnace to treat slag at the base case rate of 55,000 tpa and achieve 75% recovery of Zn. The recovery value in practice will depend on the oxygen partial pressure in the furnace, the reductant addition rate and the smelting temperature adopted,.
* Other assumptions that have been made include the split the between fuel oil and reductant coal and there is potential to reduce costs by optimising this split and by utilising pulverised coal as a fuel rather than oil. This is an enhancement that can be made to the system once it is back in operation. The off-gas temperature is also assumed at 1,300°C and the stoichiometric ratio of CO:CO2 is a further assumption albeit one that can be varied within the model.
* It is proposed that the spreadsheet and the accompanying design criteria should form the basis of a more comprehensive model to be developed by the CSIRO. It is understood that the CSIRO model can simulate reaction kinetics and determine the reaction equilibrium condition. To this effect a specification has been drafted for a definitive mass/energy balance to be performed by this organisation.
* The system examined is a single step continuous system. This is done on the basis of preliminary recommendations that such an operation can handle higher throughputs of slag feed albeit at somewhat lower recoveries than a batch system operated in two stages (smelting followed by reduction). It is recommended that future system modelling by the CSIRO should examine a batch operation with an initial smelting step followed by reduction and slag tapping. This would achieve higher zinc recoveries albeit within a system tht requires greater operator intervention and attention.
* It is concluded that the existing Ausmelt furnace has the capacity to treat in excess of 55,000-tpa of blast furnace slag for zinc recovery. This is on the basis that the off-gas flowrate is within the volumetric capability of the existing cooling tower. The gas space velocity and residence times within the cooler are compared with those of other projects. The off gas flow could be reduced by the use of oxygen enrichment but the use of this technique is limited in a single stage furnace situation in that an increase in the oxygen partial pressure will reduce the recovery rate of zinc metal within the bath.

The KZ proposal adopts the use of a membrane gas heat exchanger and waste heat boiler as a means of recovering energy and reducing gas flowrates to the cooler. This would be costly and difficult retrofit for the existing Tsumeb smelter.

- The outcomes of the current model have been benchmarked against available project and study data. The key comparisons are with those stated within the KZ proposal ie:

Slag Feedrate Air Required Gas to Cooler Cooler Velocity

Cooler Residence Time

Current Exercise 55,000 tpa

26,100 Nm3/h

28,151 Nm3/h

2.8 *mis*

5.2 sec

KZ Proposal 100,000 tpa

44,000 Nm3/h (assuming air, no 02)

55,000 Nm3/h (assuming air not 02)

4.2 m/s

2.9

Further work clearly needs to be done downstream of the cooler in terms of establishing the target temperatures ahead of the bag filter, sizing of the bag filter and establishing the capacities of the main air fan and other process ancillaries.

## OBJECTIVES AND CALCULATION METHODOLOGY

#### OBJECTIVES

The aim of this case study is to develop a first pass mass and energy balance for the Ongopolo zinc fuming project. The objectives can be defined as follows:

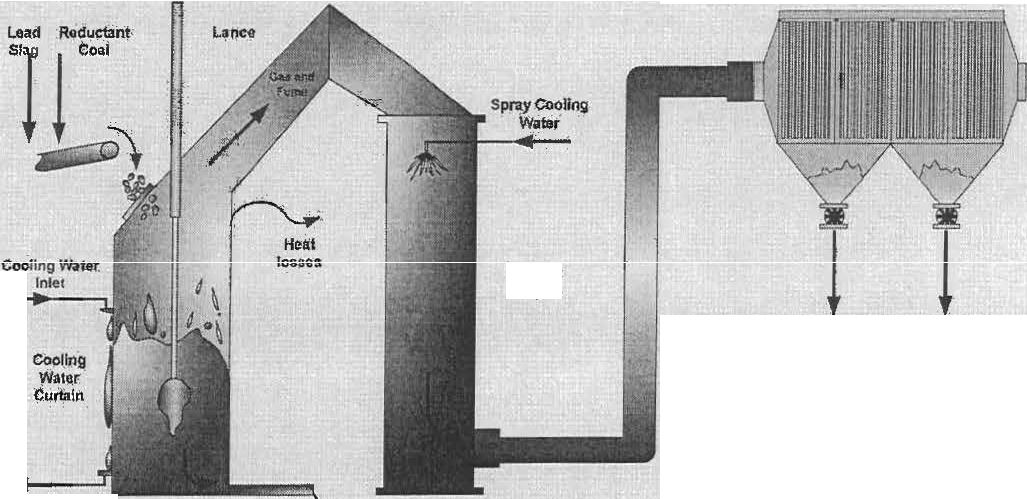
To determine the potential throughput of the system in terms of lead slag input and ·gas flowrates.

* + - To understand the constraints and bottlenecks within the existing plant and equipment.
    - To form a basis for ongoing detailed mass and energy balances to be undertaken by the CSIRO.

#### CALCULATION ASSUMPTIONS

The flowsheet for the existing plant is shown schematically in Figure 2.1. It comprises the following key equipment items:

**FIGURE 2.1 PROCESS BLOCK DIAGRAM**



- ... """Prl<J!ii"""',:..,..!)!'"'"·' -,,l,,L

Cqrni><l>tipn,Air **ff**

..

**Ba** Filtpr

**Gas to**

S14ck

Coo!Tng towvr"

Zinc

6 1de

Zin•·

Oxide

' .CPG,l\_lngWator

.Rilum

**Slag**

\

Slag feed system i.e. bins, feeders and conveyor.

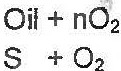
* + - Ausmelt furnace 4.4 m inside diameter complete with ancillaries.

Gas cooler Bag filter.

Whilst most of the existing system is capable of rehabilitation, site staff advise that the bag filter will need replacing in its entirety.

The basis of the mass and energy balance calculation is as follows:

* Adopt as a base case the continuous or 'single step' smelter operating mode using the existing furnace. The 'single step' mode can handle higher throughputs of feed slag than 'two-step' operation Le. batch smelting followed by reduction. However, because the residence time in the furnace is lower ih- the single step process the zinc recovery is lower than for two-step smelting. It is estimated that a furnace of this **size** should achieve about 75% zinc recovery. This equates to 3% Zn in the residual slag. The recovery value in practice will also depend on the oxygen partial pressure in the furnace, the reductant addition rate and the smelting temperature adopted. The basic rationale for adopting the single step process is to maximise the throughput of slag in order to get zinc fume onto the market quickly.
* The calculations assume that the furnace system is operating in steady state with respect to the mass and energy balance. In practice, time would be required to heat the furnace and contents from a cold start using the start-up burner.
* The initial slag feedrate adopted is 55,000 tpa based on initial calculations undertaken by others. The intent is to determine the furnace off-gas flowrate and ascertain the compatibility of this flowrate with the design and sizing of the off-gas cooling system. At an availability of 85% (7446 hours/a) this equates to a design feedrate of 7.4 tph of lead slag.
* ft is assumed that the heat input to the furnace via the lance is supplied by heavy fuel oil (as for the original lead smelter). The burning of fuel oil follows the reactions:

= a CO2 (gas) + b H2O

= SO2

The combustion reaction air requirement, off-gas flowrate and off-gas composition are given in the design criteria (Section 3) and in the heat and mass balance spreadsheet.

* It is assumed that the combustion of fuel oil is undertaken stoichiometrically with respect to oxygen supply. This may be a little ambitious but it should be possibie with a liquid fuel to operate with an excess oxygen content of <10%. In the event that a solid fuel, e.g. pulverised coal, is employed then the excess oxygen' requirement would be higher.
* The combustion of fuel oil generates the heat required to:

Maintain the operating temperature of the furnace i.e. raise the incoming slag feed from ambient to 1300 °C. This entails the addition of both sensible heat and heat of fusion.

Replace the furnace heat losses.

Provide the heat required for the furnace reactions.

* The reductant employed for the furnace reaction is crushed coal that is added to the feed slag on a ratio basis. Details of the coal available for purchase by Ongopolo are not presently available. At this time, therefore, a non-caking coal is assumed having properties as indicated in the Design Criteria and with a gross calorific value of 23.9 MJ/kg on an 'as-fired' basis.
* The smelting reactions are:

ZnO + C = Zn + CO (1)

With an endothermic heat of reaction of + 364 kJ/mol

In practice however it is likely that the reaction firstly proceeds with the partial combustion of coal to form CO within the molten slag bath that then reacts with the oxide to produce zinc according to:

ZnO + CO = Zn + CO2 PbO + CO = Pb + CO2

(2)

The reductant combustion would also generate excess CO to maintain reducing conditions within the furnace bath.

For the purposes of this study reaction (1) is taken.

Data for the lead reduction reaction is not to hand and hence the zinc heat of reaction is assumed.

In addition to the reductant usage above, it assumed that coal is also added to the furnace to maintain reducing conditions. This is done on the basis of achieving a targeted CO:CO2 ratio within the reducing zone. The target can be varied but has been set at 0.6:1 in the base case on the basis of information in the literature.

* The incoming coal and slag contain moisture that has to be evaporated. The sensible heat and latent heat of evaporation are allowed for in the heat balance.

ONG0P0L0 ZINC FUMING PAGE9

Above the lance bath, secondary air 1s introduced to combust the carbon monoxide and oxidise the metallic zinc fume to zinc oxide:

CO + 0.5 02 = CO2 -283 kJ/moi

Zn + 0.5 02 = ZnO -348 kJ/mol The reactions are exothermic.

* + No heat loss is assumed from Zone 2 (CO combustion zone). Sundry losses are covered by the overall 2% loss indicated previously.
  + Fluxing. It is taken that, as the slag exhibited sufficient liquidity within the original lead smelting operation, then it would behave satisfactorily within a zinc fuming reactor operating at higher temperatures. The addition of limestone as flux would g\_enerate carbon dioxide that would alter the CO/CO2 ratio and require the addition of more reductant. No flux additions of either limestone or silica are made in thi& mass balance. The SiO2and Cao contents of the feed do indicate that it would be self-fluxing and this has been found to be the case on other slag fuming, applications.
  + Furnace wall cooling. A protective layer of slag several centimetres thick is formed on the furnace walls to protect the chrome-magnesite brick lining. It is taken that the cooling water flowrate is sufficient to remove enough heat (by conductance and convection) from the shell to keep the slag solidified. The calculations of heat removal are based on the thermal conductivity of the slag and refractory layers.

#### CALCULATION METHODOLOGY:

The base case calculation spreadsheet is included as Appendix A of this case study. The following overall methodology is adopted:

* + - The spreadsheet is linked to the Design Criteria and any of the basic parameters given in the Design Criteria can be altered to gauge the impact on the balance.
    - For the purposes of calculation the furnace system is split into two zones i.e.:
      * Zone 1 - Smelting and reduction bath - the main zone
* Zone 2 - Coll')bustion zone above the bath in which excess c9 rs 'burned and zinc oxidised to ZnO
  + - The fuel oil consumption is computed based on the heat required to raise the feed slag·from ambient to 1300 °C, to melt the charge and to recover any heat losses. The heat generated by the burning of coal to generate reducing conditions is deducted from the heat load of the fuel oil. In more detailed work it would be

ONG0P0L0 ZINC FUMING **PAGE10**

useful to examine this calculation basis. The fuel oil consumption will presumably be dependent on the lance capacity (in turn based on velociries and pressure drops through the lance) and there would also be an optimal economic mix of fuel oil: coal.

Heat losses include those from:

* Molten slag discflarge from the furnace at 1300 °C.

Computed from the specific heat of solid and molten slag and the heat of fusion of fayalite slag.

* Hot combustion gases and water vapour exiting at 1300 °C.

The gas rate is computed from the fuel oil and coal additions and employing primary combustion air in the required quantities. It also accounts for the water evaporated from the feed slag and coal and the CO generated in the reduction reactions.

* Endothermic heat of reaction of zinc and lead reduction.

Computed from the heat of reductive reactions of Zn and Pb. These are endothermic and have been obtained from the literature.

* Cooling of the furnace shell to form the frozen slag layer.

Computed from guesstimates of the slag thickness and actual brick thicknesses and the thermal conductivity of these laminates plus the steel shell of the furnace.

* Evaporation of water present in the slag feed. A moisture content of 5% is assumed.
* Spurious heat losses from the furnace shell. Assumed to be 2% of the total heat input.
  + - The reductant addition is computed based on the straight reduction reactions. In addition coal is also burned to generate the desired ratio of CO:CO2 within the reducing gas. This ratio is taken in the base case to be 0.6. Along with the other design criteria it can be varied within the model.
    - The secondary air requirement is computed from the amount of CO in the gases leaving the smelting/reduction zone -of the furnace. Zinc is also oxidised from metallic zinc to zinc oxide. It is assumed that the CO is combusted to CO2 above the main furnace bath. It is further assumed, in the first instance, that none of the reaction heat in the secondary combustion zone is available as useful heat in the smelting process. This is probably a conservative approach. Data indicate that

perhaps as much as 20% *of* the heat energy released above the bath is converted to useful energy.

# DESIGN CRITERIA

The key design criteria that define the submerged lance reactor for zinc fuming are summarised as follows:

##### Criteria Units Value Comments Lead Slag Feed Properties

Lead slag feed rate Smelter availability Operating hours

*Ua* 55,000 First approximation for this examination

% 85 Experience on other units hours/a 7446 Calculated

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Solid slag specific heat | kcal/kgl°C | 0.2 | Perry's Chem Eng Handbook | |
| Slag heat of fusion | kcal/kg | 85.0 | Perry for fayalite slag | |
| Fusion point | °C | 1114 | Copper smelting calculation example | |
| Liquid slag specific heat | kcal/kgl°C | 0.4 | Copper smelting calculation example | |
| Solid slag density |  | 1.9 | Perry's Chem Eng Handbook | |
| Chemical Analysis of Slag: | |  |  |  |
| Element | | % | Element | % |
| Zn | | 9.5 | SiO2 | 26.0 |
| Ge | | 0.0375 | Al2O3 | 4.0 |
| Ga | | 0.02 | CaO | 22.0 |
| In | | 0.017 | MgO | 5.0 |
| Pb | | 2.2 | s | 0.5 |
| Cu | | 0.35 | F | 0.05 |
| As | | 0.3 | Cl | 0.10 |
| Mo | | 0.25 |  |  |
| Fe | | 17.1 |  |  |
| Moisture | | 5.0 |  |  |

**Criteria Units Value Comments**

|  |  |  |  |
| --- | --- | --- | --- |
| Size Analysis of Slag: | Size microns | % w/w retained | Analysed at site A Scholz |
|  | +4000 | 0.93 | Average of two tests |
|  | -4000 + 3350 | 0.50 |  |
|  | -3350 + 2800 | 1.17 |  |
|  | -2800 + 2000 | 4.55 |  |
|  | -2000 + 1400 | 11.06 |  |
|  | -1400 + 250 | 77.50 |  |
|  | -250 | 4.29 |  |

Slag bulk density - loose t/m3 1.6

Slag bulk density - packedt/m3 1.8

**Heavy Fuel Oil Properties** Density at 15°C Composition by mass:

|  |  |  |
| --- | --- | --- |
| g/cm3 | 0.96 |  |
| Species |  | %w/w |
| C |  | **85.4** |
| H |  | 11.4 |
| s |  | 2.8 |
| 0 |  | 0.4 |
| oc | 45 |  |
| oc | 60 | Typical practice |

ZincOx Resource Estimate, Sept 2003 ZincOx Resource Estimate, Sept 2003

Rose and Cooper, Technical Data on Fuel

Minimum handling temp. Normal handling temp.

Stoichiometric Combustion Air Requirement

m3 dry air/kg fuel (1 Atm, 0°C) 10.70 Calculated

Stoichiometric Waste Gas Volume:

m3 gas/kg fuel (1 Atm, 0°C) 11.33 Calculated CO2+SO2 1.61

H20 (assumes dry air) 1.27

N2 8.45

Stoichiometric Composition of Waste Gas (assuming dry air feed)

|  |  |
| --- | --- |
| CO2+SO2 | 14.2 |
| H20 (assumes dry air) | 11.2 |
| N2 | 74.6 |

Gross Calorific Value (15°C)

MJ/kg 42.9 Typical for heavy oil.

**ONG0P0LO ZINC FUMING PAGE14**

**Criteria Units Value Comments**

**Reductant Coal Properties** Crushed coal size mm Analysis as fired to furnace:

Species Moisture Ash

C H **N**

s

0

Total

+5.0-25.0 Typical

Data from Rose and Cooper

%w/w 18.0

8.0

59.0

3.7

1.2

1.7

8.4

99.3

Calorific value as fired: Gross

Net

MJ/kg MJ/kg

23.85

22.60

Coal Analysis:

Species %w/w

Moisture 18 Rose and Cooper Ash 8

C 59

H 3.7

**N** 1.2

s 1.7

0 8.4

Total 99.3

**Smelter Operation**

Mode of operation

Smelter operating temp °C

Continuous -Ausmelt recommendation. Preferred over batch smelting / reduction

1300 Typical for zinc fuming to achieve kinetics Recommendations from Ausmelt for continuous smelting.

Zinc recovery in smelter % Zinc in final slag

Lead recovery in smelter % Lead in final slag %

75

3.0

91

0.3

Suggested by Ausmelt and KZ for operation at 1300 °C and low 02 partial pressure.

Calculated

Typical Calculated

**Criteria Units Value Comments**

Slag thickness on wall mm 80 Assumed Avg. temp frozen slag oc 1,000 Assumed

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Inside diameter furnace | m | 4.4 | As built |  |
| Height of furnace cooled | m | 3.0 | Assumed, needs verification. | L |

Cooling water inlet oc 20

*�j*

Cooling water exit oc 50 Assumption *t .J*

Key reactions in the smelter:

For the purposes of the current review the following key reactions are assumed.

**Z(?ne 1 Smelting and Reduction.**

ZnO(c) + C(c) = Zn(g) + CO(g)

Heat of reaction kJ/mol 364 Kinetics of zinc fuming (Richardson)

Total reductant addition

kg coal/kgZn- kg/kg 1.0

Heat loss from reactor % (Excluding shell water curtain)

2.0

Based on experience

**Zone 2 Combustion and Oxidation**

CO + 0.502 = CO2

Heat of reaction

kJ/mol -283

Blast furnace iron making - Biswas

Zn + 0.502 = ZnO

Heat of reaction

kJ/mol -348

# MASS AND ENERGY BALANCE OUTPUTS

* 1. **MASS BALANCE**

The spreadsheet for the mass and energy balance is given in the Appendix. The key outputs for the base case at 55,000 tpa slag treatment are given in table 4.1.

**TABLE 4.1 KEY PROCESS STREAMS**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Stream No.** | **Description** | Solid/Liquid/Gas | Hourly Flow | **Units** | **Annual Flow** |
| 1 | Dry Slag feed Moisture in feed  Zinc exit reduction zone Lead exit reduction zone Slag exit furnace Codling·water  Heavy Fuel 011  Gas exit due to oil burning Reductant coal - reaction Excess coal for CO Carbon in coal  Toatal coal  Air for oil combustion Air for coal combustion Air ingress  Total air to Zone 1  Total gas exit Zone 1  Secondary air  Total gas exit Zone 2 | Solid | 7.39 | t/h | 55000.00 |
| 2 | Liquid | 0.39 | tih |  |
| 3 | Solid | 0.53 | t/h | 3918.75 |
| 4 | Solid | 0.15 | t/h |  |
| 5 | Solid | 6.71 | t/h |  |
| 6 | Liquid | 15.59• | t/h |  |
| 7 | Liquid | 1.48 | t/h | 10992.52 |
| 8 | Gas | 16726.46 | Nm3/h |  |
| 9 | Solid | **0.14** | t/h |  |
| 10 | Solid | 1.73' | t/h |  |
| 11 | Solid | 1.02 | t/h |  |
| 12 | Solid | 1'.87• | t/h | 13916.05 |
| 13 | Gas | 15796.39 | Nm3/h |  |
| 14 | Gas | 4'527.31 | Nm% |  |
| 15 | Gas | 500.00 | Nm3/h |  |
| 16 | Gas | 20823.71 | Nm3/h |  |
| 17 | Gas | 23840.66 | Nm3/h |  |
| 18 | Gas | 5265.15 | Nm3/h |  |
| 19 | Gas | 28151.05 | Nm3/h |  |

All solid and liquid flows are in t/h and gas flows are in Nm3/h.

* 1. **ENERGY BALANCE**

The energy balance has been computed for the two main zones of the furnace i.e.: Zone 1 - the main smelting and reduction zone

Zone 2 - combustion zone where Zn and CO are reacted above the bath.

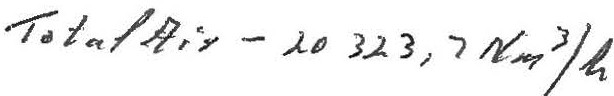
**Zone 1 Balance**

The energy inputs and outputs are given in Tables 4.2 and 4.3.

TABLE 4.2 HEA**TlNPUt**•**S**,

- **ZONE 1**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | Units | Temp.  oc | **Heat** Content  **kcal/h** | **Heat Content**  **kJ/h** | **Comments** |
| Slag Feed | 7.39 | *tlh* | 15 | 22,159.5 | 92,777.6 | Temperature datum o•c |
| Heavy Fuel Oil | 1,476.30 | kg/h | 15 | 15,126,874.7 | 63,333,199.0 | Stoichiometric combustion |
| Combustion Air for Oil Combustion Air for Coal | 15,796.39  4,527.31 | Nm3/h  Nm3/h | 15  15 | 0.0  a.a | a.a  0.0 | Stoichiometric combustion Sub-Stoichiometric |
| Coal Heat of Reaction | 1.73 | t/h | 1300 | 2,319,251.4 | 9,710,241.6 |  |
| Sundrv Air lnoress | 500.00 | Nm3/h | 15 | 0.0 | 0.0 |  |
| Total |  |  |  | 17,468,285.6 | 73,136.218.2 |  |



**TABLE 4.2 HEAT OUTPUTS** - **ZONE** 1

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | Flow | Units | Temp.  oc | Heat Content  kcal/h | Heat Content  **kJ/h** | Comments |
| Liquid Slag Exit Furnace | 6.71 | t/h | 1300 | 2,565,459.8 | 10,741,066.9 | Sensible heat plus fusion |
| Furnace Shell Cooling | 15.59 | t/h | 50 | 467,762.4 | 1,958,427.6 | Water cooled section |
| Moisture Evaporation from Feed Stag | 0.39 | t/h | 1300 | 386,182.7 | 1,616,869.5 |  |
| Moisture Evaporation from Coal | 1.87 | t/h | 1300 | 1,856,519.7 | 7,772,876.5 |  |
| Metal Reduction Heat of Reaction |  |  | 1300 | 896,619.9 | 3,753,968.4 | Endothermic |
| Heat in Gas Exiting Zone 1  Sundrv Heat Losses from Svstem | 23,840.7 | Nm3/h | 1300 | 10,924,216.0  349,365.7 | .fs;no/,so1.4  1,462 724.4 | ***,-5.. f...,,l',i. t.***  Assumed data |
| Total |  |  |  | 17,446,126.1 | 71,580,716.3 |  |

### Zone 2 Balance

The energy inputs and outputs are given in Tables 4.4 and 4.5.

**TABLE 4.4 HEAT INPUTS -"ZONE 2**

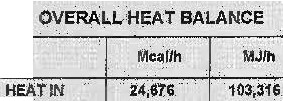
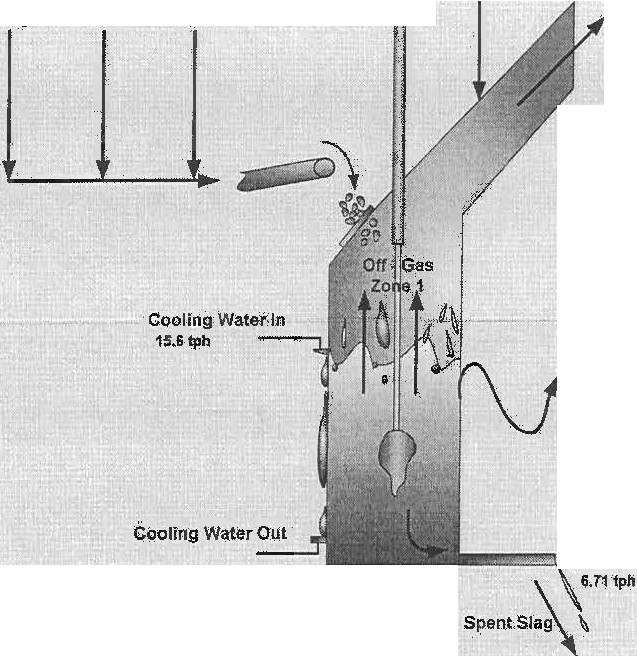
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | Units | Temp.  •c | Heat Content  kcal/h | **Heat** Content  kJ/h | Comments |
| Heat in Gas Entering Zone Heats of Reaction | 23840.66  - | Nm3/h  .  .  .  Nm3/h | 1300 | 10,924,216.0 | 45,737,507.4 |  |
| CO Combustion | - |  | 6,539,311.5 | 27,378,789.4 | CO + 0.502 == CO2 |
| Zn toZnO | - |  | 669,180.2 | 2,801,723.6 | Zn + 0.5 =*ZnO* |
| Secondary Combustion Air | 5265.15'4 | 15 | 0.0 | 0.0 |  |
| Total |  |  |  | 18,132,707.6 | 75,918,020.3 |  |

**TABLE 4.5 HEAT OUTPUTS'**- **ZONE 2**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | Units | Temp.  •c | **Heat Content**  kcal/h | Heat Content  kJ/h | Comments |
| Heat in Gas Exiting Zone Heat Losses |  |  |  | 18,132,707.6  nil | 75,918,020.3  nil | Neglect for this zone |
| Total |  |  |  | 18.132,707.6 | 75,918,020.3 |  |

## DISCUSSION OF MODEL OUTCOMES

FIGURE **5.1 SUMMARY** OF BASE MODEL OUTCOMES



Heav.y Fl,/ol OU o;sup ,

7,$lph U4 gl.11, t.Tlkg/h

Reductant Fvel

Slag • Ci:oai• Cpal

7

Primary Combustion Air 20,823Nm'lh

Seconda,ryCombustion S,265 Nm ih

Air

28,151Nm'lfl

,Clff-Gi!S

ToCooier

Extra epus HeatL<,ss, s

HEAT OUT 25,05. 101,,762

Figure 5.1 combines the heat inputs and outputs of Zones 1 and 2 for the base case of 55,000 tpa slag treatment. The balance lies within reasonable limits.

The mass/energy balance has been compared with that of other projects, data from which are available to Ongopolo Mining or in the public domain. The benchmarking is given in Table 5.1 below. Of particular interest is the volumetric flow of off-gas entering the cooler. It has been postulated that the capacity of this unit operation is probably the major factor determining the overall throughput of the Tsumeb zinc fuming project. From Table 5.1 and Figure 5.1 it can be seen that the off-gas flow for the base case is 28,151 Nm3/h.• Running the mass/energy balance with a slag input of 100,000 tpa gives an off-gas flow of 47,957 Nm3/h. These flowrates are in line with those estimated for the Silver Spur project and the Korea Zinc proposal for fuming Tsumeb lead slag. The latter project proposed to enrich the air entering the first furnace with oxygen. If the oxygen is converted to air at 21% 02 then the equivalent off-gas flow would be similar to that of the current base case.

0z

Cl

0

"0

r0

i! 0

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ZINC FUMING PROJECTS | | | | | | | | | | | | | | | | | |
| **Project** | Feed Type | Feedral•  **Ina** | Mode of  Operation | Feedrate  **tph**  for 1/balchl | No.of Stage& | Furmu;e  Di• m | Temp  •c | Zn Grade   * t.wfw | **Zn**  Recovery  % | PbG dit  •t.wtw | Product | **Fuol**  **Typo** | Reducta.nt  **Type** | Oxygen Level | Total *Air*  In  Nm3/h | TotalGas To Cooter  Nm1lh | T•mpGas To Cooler  •c |
| Tsumeb Current Case | SoHd Leadslaa | 55,000 | Contlnuou1 | 7.4 tph | 1 | **4.4** | 1,300 | 9.5 | 75 | 2.2 | ZnO/Pb Fume | HaavyOil | Co.al | 21%vlv | 26,088 | 28,151 | App 1300 |
| Tsumeb  *Kl* Proposal | **Solid**  Lead Slag | 100,000 | Continuou1 |  | 2 | St 1  St 2 |  | **9.5** | 75 | 2.2 | zno/Pb Fume |  |  | 35% Stage 1  21% Stage 2  Tollll | 354857  B,700 441B5 | 31,206  12,464  43670" | 700  700 |
| Sltver Spur Study | Solid LeadStag | 45,000 | Batch | 24.3 I/batch  3.75 h/batc:h  6.4 toh | 2  S\"l•Smelt St 2 Reduce | 2.74 | 1250  1350 | **17.6** | **9B** | 3,1 | 2n0/Pb f001e | **Pulv•rised**  Coal | Crushed Coal | 21¾ Stace 1 | 27,444 | 30,195 | ? |
| Korea Zinc·t  QSLFurner 1992 | SolidLead Slaa | 52,100  Aclual | CQ.fltinUOUS | 5.0 tph | 1 | 3.9 | 1300 | **14-18** | 7 | **5-8** | ZnOIPblume | Coal | Ccal | **35%** |  |  |  |
| Korea 2:lnc  Zinc Furner 1995 | EZ Residue | 120,000 | Continuous |  | 2  St 1•SmelURsd  St 2 Reduce | Sl "I - 3.9  St2-3.2 |  |  |  |  |  | Coal  **Coal** | Coal  Coal | 35% Stagi, 1  21%SUne2 |  |  |  |
| Kor•a Zinc Zir1cFumer | **Solid** | 100,000 | Ccntinuoua |  | 2  $11-Smett Sl2 Reduce | Stt -3.9  St 1 -3.9 |  |  |  |  | St 1 ?brume  512 Pb/lnO | Coal Coe\ | Coal Coal | 40%S!ago 1  21% Staoe 2 |  |  |  |
| lead Ta illg$ | |
|  |  |
| M sui-1993 Slao Furner | Liquid  ISF Slao | 80,000 | Continuous |  |  | **2.4** |  |  |  |  | ZnO rume | **Oi** | Oil/Coke | 21%v/v |  |  |  |
| Mitsui- 2002 Slaa Fumer | Liquid fumerSlaa | B0,000 | Conti01JOUS |  |  | 2.4 |  |  |  |  | ZnOfume | oa | OiVCoke | 21¾v/v |  |  |  |
| **Whyalla2000** | Solid EAF Dusi | 15,000 | Continuous |  |  | 5,0"3.0  Ellint.,al |  |  |  |  | ZoOfume  Pin Iron | **Coal** | Coal | 60% | |  |  |
|  |  |

r 0:, .z,,

m 0

01 C

:.., z

3:

m *G)*

Note:1t

., Based on operational data design was for100,000 tpaof llqutcl1lag feed

This furnace later 1upplimented W\lh a further unit al 3.9m dla and the sy,tem conv•n•d lo a continuous, lY.o stage operatlon.

'2 Oxygen added lo F1 accounted as air ieoxyg1m flow• 100/21

"3 This va1ua woutd be higher if nitrogen were to be inltoduced with air

m**z**

0

:s:i::

)>

:n

"z

C)

0

"II

*Ch* C OJ

m3:

:n

G')

m

0

>**z**

0m

zN

0

"II

**s**C**:**:

z

C)

:-n0

0

c.. m 0

-I

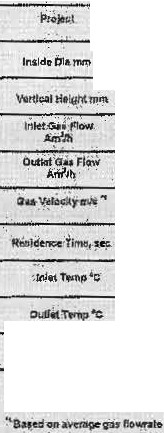
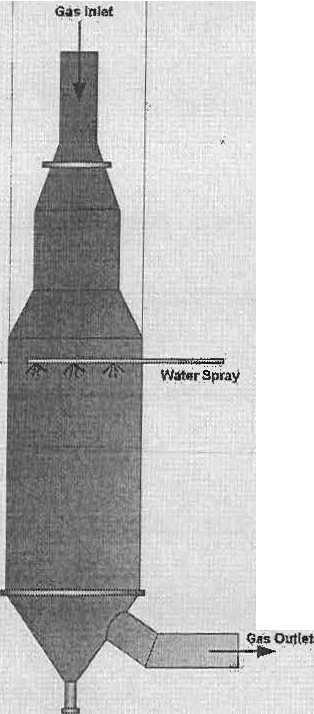
(/)

"'O

.m...

*ID*

**FIGURE 5.2 COMPARISON OF QUENCH COOLER SYSTEMS**



1, 0mm

BENCHMARKING O'li eooLlr\lG TOWi;RlJ

-Z:c,i,;c1J11g: -tqr.t:t•1ndLl 1. I. PL'osWOlblylll ·u•al'lffl!I"'

l:1i100¥fn 11---1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | .,...  ,.. | **12.0tO**  ,..  2.11  ,.. | ·UCO·      0v..:. !ifl1'dtor,,wrNI g'yrie\111  .".'. | **100** |
| ...,.W.::d..c..r.Ao•. | Lti  ,. - -· |  | u |  | 1UI |

Having derived an off-gas flowrate, it is possible to compare the flows of gas to the cooler with those of other projects. This is done in Figure 5.2 above and it is noted that, for the purposes of calculating gas velocities and residence times, the flows are given in Am3/h. It is noteworthy that the KZ proposal for Tsumeb included an off-gas heat recuperation system i.e. membrane heat exchanger and waste heat boiler to bring the off-gas temperature down to 700°C. This clearly reduces the volumetric flow of gas to the quench cooler. The technique also reduces the amount of quench cooling water to be added and this again lessens the volume of gas exiting the cooler. Without such a supplementary cooling system (waste heat boiler) the base case flowsheet exhibits a relatively high volumetric flow of gas at the discharge of the cooler i.e. 91,000 Am3/h.

However, the existing quench cooler at Tsumeb is relatively large in comparison with the cooler (F1) recommended in the KZ proposal. Hence the gas velocity through the existing unit is comparatively low and the retention time high compared with the KZ design. On • this parametric basis it is concluded that the existing quench cooler has sufficient volumetric capacity to handle the base case duty. Indeed it should be possible to increase ' the feedrate of lead slag to the existing smelter and accommodate the off-gas flowrate in the cooler. The capacity of the existing water injection system does, however, need to be checked (the PFD provided to Stirling Process Engineering is not legible).

**APPENDIX A**

Outputs of the Base Case spreadsheet.

Zone 1 Energy Balance Zone 2 Energy Balance Overall Mass Balance

PRIMARY SMELTIIILG AND REDUCTION ZONE

**HEAT INPUT**

*t5*

0,,

0

r0

0

**HEATOUTPUt**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | **Units** | **Temp.**  •c | **Heat Content**  **kcal/h** | **Heat Content**  kJ/h | **Commeiits** |
| **Lk:1uid Slag Exit Furnace** | 6.711/h |  | **1300** | **2,S6S,4S9.6** | 10,741,066.9 | **Sensible h.eat plus fusion** |
| **Furnace SheliCooling** | 15.591/h |  | 50 | 467,762.4 | 1 ,958,427.8 | **Water cooled section** |
| **Molslure Evaporation *from* Feedi Slag**  **Moisture EvapcraUon fromCoal Me1alReduction Heat ofReaction** | 0.39 1/h  1.87 Vh |  | 1300  **"1300**  1300 | **366,182.7**  I ,856,519.7  896,619.9 | 1,616,869.5  7,772,876.5  3,753,968.4 | **Endo1hem1ic.** |
| **Healin Gas Cxhlng Zone1** | 23,640.7 **N** | **m3Jh** | 1300 | 10,924,216.0 | **45,737,507.4** |  |
| **Sundrv Heat Losses from s t&m** |  |  |  | **349365.7** | **1 462124.4** | **Assumed data** |
| **Total** |  |  |  | **17 446 126.1** | 71 580 716,3 |  |

GAS COMPOSITION UITING ZONE 1

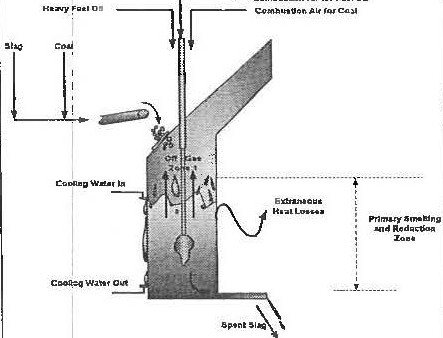
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Species** | Nm 1h  16 726.5 | **%vii/** | **Heat Capacity kJtmol**  1573'K | **Heat Content**  **kcalfh** | **Heat Content**  kJ/b | **Gas Flow**  MoUh |
| co, | 2,378.B | 10.0 | 59.15 | 1.499,003,3 | 6,276,027.0 | 106108.94 |
| H,O | 2,745.4 | 11.5 | **48,66** | **1,424,497.6** | 5.964,086.7 | 122564.03 |
| N, | 16,446.3 | 69.0 | **40.08** | **7.028,768.0** | **29,428,049.S** | 734209.81 |
| co  o, | 2,167.1  105.0 | 9.1 | **40.05**  **41.63** | **925,333.8**  46,612.4 | 3,874,187.4  195,158.8 | 96744.64  4887.50 |
| **Totallnc!udina feedmoisture** | 23 840.7 | 99,6 |  | 10 924 216.0 | 45 73 507.4 | 1064315.12 |

sron

7

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | **Units** | **Temp.**  ·c | **Heat Content**  **kcaUh** | **Heat Content**  kJ/h | **comments-** |
| **S>ag Feed**  **Heavy FuelOH Combostton Air for OH**  **Combustion Air for Coa1 Coal Heat of Reacllon**  **Sundrv Air lnoress** | **7.39**  **1,475.30**  15,796.39  4.527.31  1.73  500.00 | **t/h** kglh **Nnl/h Nml/h** un  **Nm /h** | 15  15  15  15  1300  15 | 22,159.5  15,126.874.7  0.0  0.0  2,319,251.4  0.0 | 92,777.6  **63.333.199.D** | **Ternperatme datum O"C Stoichiometriccombustion** |
| **0.0 Stoichiamelrlc comtlusllon** | |
| 0.0  9,710,241.6  0.0 | Sub-Slolchlometriccombu |
| **Total** |  |  |  | 17 468 285.6 | 73 136 218,2 |  |

**z**



.**m**...

**mz**

**m**

**:;o**

**G)**

-<

**r­**

)>

**z**

**0**

**m**

**z**

0

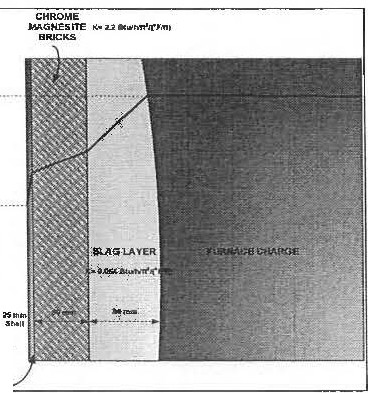
**"Tl**

C

**3zl:**

G)

**Ca1cu a1ion of bit Gas Molat Heat Capacify**



**1)00 c** .

**1'1•11.1 Wl('<"m;i**

***siui.1***

**FUAHACESHEU.**

**rOella. T-**-**1573 27J**-**-1300°K\**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Gas | T | • | **b** | C | d | **aT** | **bT2/2.** | cT'/3 | **DT'/4** | **Q kJlmoi** |
| N2 | **1300** | 27.32 | 0.006226 | ·0.00000095 | 0 | **35516** | 5260.97 | **-895.7167** | 0 | 40.081253 |
| 02  H20  co  CO2 | 1300  1300  1300  1300 | 25.46  32.22  27.11  22.24 | 0.01519  **0\_00192**  **0\_00655**  **0.05979** | -0.00000715  **0.00001054**  **-0.000DDi**  -0.00003498 | **1.311E-D9**  -3.594E-09  0  7.464E•09 | **33098**  **41886**  **35243**  28912 | **12835.S5**  **1622-4**  **5S34.75**  50522.55 | **-5236.183"**  **7716.793**  **-732.3333**  -25517.02 | 936.0866  -2566.206  0  5329.483 | **41.633453**  48.660987  **40.045417**  59.147013 |

**Cp.::Jlmolft< Q = aT + bT2/2 + GT3J3 + dT4/4**

"ti

>

G)

m

N N

HEAT **INPUT**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | **Units** | **Te.mp.**  •c | **Haat content**  **kcal/h** | **HutContenl**  k.Jlh | **Comments,** |
| **HeatIn Gas Entering Zone** | **23840.66** | **Nm1111** | **1300** | **10,924,216.0** | **45,737,507.4** |  |
| **Heats of Reaction** |  |  |  |  |  |  |
| **CO Combustion** |  |  |  | **6,539,311.5** | 27,378,789.4 | **CO+ 0.502 "' CO1** |
| **Znto ZnO** |  |  |  | **669JaD.2** | 2.801,723.6 | **Zn+ 0.5O .. ZnO** |
| **Seicondaiy Combl.l$60n Air** | **5265.153578** | **Nm,/h** | 15 | 0.0 | 0.0 |  |
| **Total** |  |  |  | **18132707.6** | **75 918 020.3** |  |

SECONDARY GASCOMBUSTION ZONE

0z

G)

0

5

z

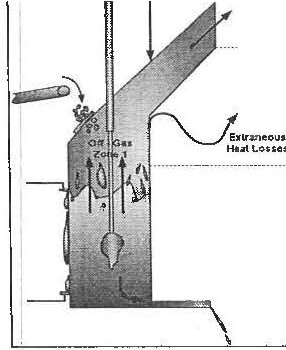
0

"Tl

C**s:**

z

**ncoml1n0GasA**n**alvsisf**rom ***ZJ:J***ne**1** G)



**0**

**N**

**z**

**m**

**m**

**N**

**z**

**;;o**

**m**

-<

**Ci)**

**0**

**z**

**m**

**OH.G,1ala Coaling** To-

**Stconda'"I'**

**Co,i,.txullort** -

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Nr11'1ti**  16.726.5 | | **%v/V** | **Heat Capacity J<J/mot**  **1573"K** | **Heat Content**  **kcaUh** | **Heat Content**  kJ/h | | **Gas Flow**  MoUh | |
| co, | 2,376.8 | | 10.0 | 59.15 | 1,499,003.3 | 6,276,027.0 | | **106108.94** | |
| H,O | 2,745.4 | | 11.5 | **48.66** | 1,424,497.6 | 5,964,086.7 | | 122564.03 | |
| **N,** | **16,4-46.l** | | **69.0** | **40.08** | 7,028,768.9 | 29,428,049.5 | | 734209.81 | |
| co  o, | 2,167.1  **105.0** | | **9.1** | 40.05  41.63 | 925,33"3.8  46,612.4 | **3,874.187.4** | | **967.44.84** | |
| 195,156.8 4687.50 | | | |
| **Totalillcludino feed moisttH** | | 23 840.7 | 99.6 |  | **10924216.0** | **4'5 542** | **350.6** | | 1064315.12 |

HEAT OUTPUT

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stream** | **Flow** | **U11its** | **T1m1p,**  oc | **Heat Content kcal/h** | **Heat Content**  kJlh | **Comments** |
| **Heal InGas Exiting Zone**  **Heat lesses** |  |  |  | 18,132,707.6  **nil** | 75,918,020.3 |  |
| **nii Neglect r0rlhls zone** | |
| **Total** |  |  |  | 18132707.6 | 75 918020.3 |  |

**Exitinn Gas Anal sis from ZonR2**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Nm1/h**  0.0 | **v.vN** | **HealCapaeily**  **kJ/mol**  **1573 •K** | **He t ConteQt**  **kcal/h** | **Heat Content**  kJ/h | **Gas Flow**  MoUh |
| co, | 4,543.9 | 16.1 |  |  |  | 20285"3.78 |
| H,O | 2,745.4 | 9.8 | 122564.03 |
| N, | 20,851.7 | 74.1 | 931325.66 |
| co | 0.0 | 0.0 | 0.00 |
| o, | 105.0 | 0.4 | **4687.50** |
| **Tota,Iincludina feedmois!ur** | **28151.1** | **100.0** |  | 18 132707.5 | 75 918020.3 | 1261430.97 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Heat Removal in Coolina** | Delta T= 473-273=200°K | |  | | | | | | | |
| Gas | T | • | **b** | **C** | **d** | **aT** | bT /2 | **cl'"/3** | **or14** | **Q,kJfmol** |
| **N2** 02 H20  co  CO2 | 200  200  200  200  200 | 27.32  25.46  32.22  27.11  **22.24** | 0.006226  **0.01519**  0.00192  0.00655  **0.05979** | ·0.00000095  **-0.00000715**  0.00001054  **0.000001**  **--0.00003498** | 0  **1.3111::•09**  -3.594E-09  **0**  **7.464E-09** | 5464  5092  **6444**  5422  4448 | **124.52**  303.8  3M  131  1195.8 | -2.533333  -19.06667  2810667  -2.666687  -93.28 | 0  0.5244  **-1.-4378**  0  2.9856 | 5.S85987  5.3TT258  **6.509069**  5.5S0333  5.553506 |

**Heat removal**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Nm.)/h** | **•J.ivlv** | **Heat Capacity**  **kJ/mol**  **1.573 "'K** | **Meat Cor1tenl**  **kca.1/h** | **lie.at Content**  kJ/h | **Gas Flow Mol/11** |
| co, | **4,543.9** | 8.7 | 5.55 |  | 1,126,549.6 | 202853.78 |
| H,O | **27,105.5** | 51.5 | **6.51** | 14,955,058.5 | 2297572.57 |
| N, | 20,861.7 | 39.7 | **5.59** | **5,202,372.7** | 931325.66 |
| co  o, | 0.0  105.0 | 0.n  0.2 | 5.55  5.38 | 0.0  **25,205.9** | 0.00  **4687.S0** |
| **Tclaliocludinn feed moistur** | **52 511.1** | **100.0** |  |  | 21 283,960.9 | 3436439.51 |

**Steam entalpy 2DOoC**

**Water Row**

**Waler flow**

54,634.039.S kJ/h

2791 kJ/kg

**19575.0768-4 kg/h**

**1087504.269 tnol/h**

**24360.09562 m3frl**

**"lJ**

);>

G)

m

wN

ONG0P0L0 ZINC FUMING PAGE 24

MASS BALMCE SUMMARY

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **St am No.** | **Oescr1ptton** | Solld/LlqukfJGas | **HourtyFlow** | Units | **Annu.al FJow** | **Comments** |
| 1  2 | OrySl3!1feed  **Moisture In feed** | **Solid**  Liquid Solid Solid Solid Liquid Llqold Gas  **Solid**  **Solid Solld** Solid  Gas Gas Gas  Gas  Gas  Gas Gas | 7.39  0.39 | 1/h  1/h | **55000.00** |  |
| 3 | **Zilc exitreduction zone** | 0.53 | 1/h | 3918.75 |  |
| **4** | **Lead eidt reducuon zone** | O.t5 | 1/h |  |  |
| 5  **6** | **Slag exit tumace**  **Cooingwater** | 6.71  15.59 | Vh  **1/h** |  | **Raquired to maintain a layer cf.slag on furnace** |
| 7 | **Heavy Fuel Oil** | 1.48 | tlh | 10992.52 | Assume slag thlclrneu 80mm |
| **8** | **Gas cxil due to ol1bumi"lg** | 16728.46 | **Nm3/h** |  |  |
| 9 | **Reductant coal. reaction** | **0,14** | 1/h |  | **Based onthereactklns giVen In tha designcril.er1a.** |
| 10 | **Ex.cu, coal for CO** | 1.73 | Uh |  |  |
| 11 | **Cart>on incoal** | 1.02 | 1/h |  |  |
| 12  13 | **Toatal coal**  *IJt tor* **ol** combustion | 1,87  15796,39 | *Uh*  Nm'lh | 13916.0S |  |
| 14 | **Air for coat combus1km** | 4527.31 | **Nm3/h** |  |  |
| 15  16 | **Air ingress**  **Tota a!rto Zono 1** | 500.00  =3,71 | Nm'lh  **N,n3n,** |  |  |
| 17 | **Tola1ga., exit Zone 1** | 23840,66 | **Nmllh** |  |  |
| 18 | **Sec:ond;al')' air** | 5265.15 | **Nm3/h** |  |  |
| 19 | **Total qas exit Zone 2** | 28151,05 | **Nm3/h** |  |  |

**Gas Exiting Zone 1 Due to Oil CombusUon**

|  |  |
| --- | --- |
| I Soeclos | **Nm,J"1** |
| **otal gasoil Ct>mbus** | 18,726.5 |
| co, | 2.376.8 |
| **-H:iO** | 1,874.9 |
| N, | 12,474.7 |
| Total | 16.726.5 |

**Gas Exiting Zone 1 Due *to* Coal Combu$tlon**

|  |  |
| --- | --- |
| I **Species** | Nm /h |
| **eta,gasoiS combustion** | |
| CO2 | nll |
| co | 1,901.5 |
| H,O | 386.7 |
| N, | 3,576.6 |
| Total | **5 864.8** |

T

**Gas Exltlnt Zona 1 Due to Sundry Air Ingress**

|  |  |
| --- | --- |
| **Scecle.s** | **Nm.1/h** |
| 0, | 105.0 |
| N, | 395.0 |
| Total | 500.0 |

**GasEx!tlng zone 1 from all Sources**

|  |  |
| --- | --- |
| **Soecte.s:** | **Nm /h** |
| CO,•SO, | 2.376.8 |
| H,O | 2,745.4 |
| N, | **16,446.3** |
| co | 2167.1 |
| To4al | 23,840.7 |

c:\documents and setlings\h.nolte\localsettings\!emporary internet flles\ol1<18\reportrev3.doc

**Hans Nolte**

compressors, oil pumps, lances etc. Appreciate your thoughts - I won't start work until you agree.

With best regards

**From: Sent: To: Subject:**

Dave Lunt [[lunt1@bigpond.net.au]](mailto:lunt1@bigpond.net.au) Saturday, January 13, 2007 2:14 PM Hans Nolte

RE: Invoice

Dave

Invoice

•6-021doc.doc **(40 K**

Hans

Please find attached my invoice up to the 7th

January.

This includes for the generation of the mass and

energy balance, the report and the scope document sent to CSIRO.

I still await the proposal from CSIRO.

I have a few concerns about this. I was under the impression from Keith Ramus that they had already developed an energy balance based on their early work in this field. From the e-mails we're receiving it appears that they are having to develop it from scratch and that it will take some weeks to complete. The price for the work is quite high as well. I wouldn't mind discussing your thoughts on this - maybe after we've received their proposal next week. I might start to quietly ask around in Perth if anyone has the SMELT model and can run a balance to check ours.

I've been thinking about what we can do in the meantime. I have reasonable confidence in the current models prediction of smelter off-gas flow and composition then I could start to look at the gas train ie cooler, drop box and bag house in more detail. Also we should start examining the capacity of existing equipment in a bit more detail ie air

1 2

**Table 4.** Smelting of moist slag at 7.78 t h-1 (55000 tpa -dry basis) with fuel oil and air to match estimated furnace heat losses (3.4 GJ h-1)

Lance Oil LanceAir Reduction Oil Zn Recovery Discard slag Off as1 pZn pPbspecies pCO2 pH2O CO/CO2 pOz Oil/Zn

(t h-1) (Nm3h-1) (t h-1) (wt%) (%) (t h-1) (Nm h- ) (atm) (atm) (atm) (atm) (atm) fumed(t/t)

*1 5 l,,*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0.83 | 8916 | 0.07 | 4.65 | 58 | 6.67 | 10295 | 0.014 | 0.0018 | 0.128 | 0.154 | 0.09 | 2.5x10:a | 2.10 |
| 0.90 | 9638 | 0.10 | 3.55 | 68.5 | 6.56 | 11179 | 0.016 | 0.0017 | 0.126 | 0.15 | 0.13 | 1.1x10-s | 1.98 |
| 0.94 | 10053 | 0.12 | 3.00 | 73.6 | 6.51 | 11692 | 0.016 | 0.0016 | 0.124 | 0.149 | 0.16 | 7.2x10-9 | 1.95 |
| 0.97 | 10323 | 0.13 | 2.68 | 76.5 | 6.48 | 12027 | 0.016 | 0.0015 | 0.123 | 0.147 | 0.19 | 5.6x10-9 | 1.95 |
| 1.03 | 10975 | 0.17 | 2.04 | 82.3 | 6.42 | 12843 | 0.016 | 0.0014 | 0.119 | 0.144 | 0.25 | 3.0x10-9 | 1.97 |
| *N/---<-).* | *] 2 o e,* |  |  |  |  |  |  |  |  |  |  |  |  |

**Table 5.** Smelting of liquid (1300°C) slag at 7.78 t h-1 (55000 tpa -dry basis) with;fuel oil and air to match heat losses (3.4 GJ h-1)

Lance Oil LanceAir Reduction Oil Zn Recovery Discard slag Off as pZn• pPbspecies pCO2 pH2O *COlC02* pO2 (t h-1) (Nm3h-1) (t h-1) (wt%) (%) (t h-1) (Nm h-1) (atm) (atm) (atm) (atm) (atm)

0.36 3825 0.107 3.05 73.1 6.50 4572 0.041 0.0041 0.044 0.014 0.37 1.6x10-9

*I JJ 'j I dJ; t'*

*f-* • *J* '7·-, ***6*** ):C

Oil/Zn fumed(t/t) 0.87

**Table 6.** Smelting of moist slag at 7.78 t h-1 {55000 tpa -dry basis) with fuel oil, air and reductant coal to match heat losses (3.4 GJ h-1)

Lance Oil Lance Air Reduction Coal Zn101a1 Recovery Discard Off as pZn pPbspecies pCO2 pH2O CO/CO2 pO2 Oil/Zn (t h-1) (Nm3 h-1) **(t** h-1) {wt%) (%) slag(t h-1) (Nm h-1) (atm) (atm) (atm) (atm) (atm) fumed(t/t)

0.83 8916 0.148 4.64 58 6.68 10310 0.014 0.0018 0.132 0.15 0.09 2.5x10"8 2.28

0.9 9638 0.211 3.55 68.4 6.58 11200 O.Q16 0.0017 0.131 0.146 0.13 1.1x10-8 2.2

0.94 10053 0.255 2.99 73.6 6.53 11720 0.016 0.0016 0.13 0.144 0.16 7.1x10-9 2.2

0.97 10323 0.275 2.69 76.3 6.50 12056 0.016 0.0015 0.129 0.142 0.19 5.6x10-9 2.21

1.03 10975 0.362 2.04 82.1 6.45 12883 0.016 0.0014 0.126 0.138 0.25 3.1x10-9 2.3

*I* ***-3"il li.JIJ***

*-r*

**1·77 .l.).r**

Table 7. Smelting of moist slag at 7.78 t h-1 (55000 tpa -dry basis) with fuel coal, air and reductant coal to match heat losses (3.4 GJ h"1) Lance Coal Lance Air Reduction Coal Zn Recovery Discard slag Off as pZn' pPbspecies pCO2 pH2O CO/CO2 pO2 Coal/Zn

(t h-1

)

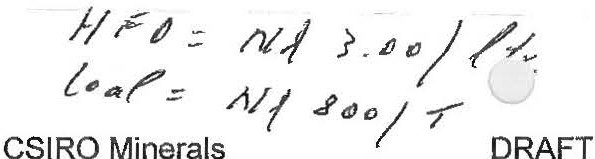
(Nm3 h-1

(t h-1

(wt%) (%) (t h-1

(Nm h"1

(atm) (atm) (atm) (atm) (atm) fumed(t/t)

1.725 8850 0.155 4.60 57.3 6.85 10409 0.014 0.0018 0.176 0.112 0.09 2.3x10-8 4.44

)

)

)

)

1.87 9595 0.23 3.57 67.3 6.76 11345 0.015 0.0016 0.174 0.109 0.13 1.1x10-9 4.23

1.965 10080 0.285 3.00 72.8 6.72 11961 0.016 0.0016 0.172 0.106 0.17 7.0x10·9 4.19

2.023 10379 0.327 2.64 76 6.69 12351 0.016 0.0015 0.17 0.105 0.19 5.3x10·9 4.19

*2,.* 2.181 11190 0.419 2.05 81.5 6.66 13370 0.016 0.0014 0.166 0.102 0.24 3.2x10-9 4.32

* *i, 't,-f'f?II*

*Iii/* / 72 *c,"o* CONFIDENTIAL 8

**Table 8.** Smeltin9 of moist sla9 at various rates with fuel oil, air and reductant coal to match heat losses (3.4 GJ h-1)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Annual Lance  rate Oil | Lance  Air | Reduction  Coal | Zn in  slag | Discard  sla | Zn  Recovery | Off gas  volume | pZn | pPbspecies | pC02 | pH20 | CO/CO | p02 | Oil/Zn fumed(t/t) |
| (k tpa} {t h"1}  100 1.56 | (Nm3 h-1}  16700 | (t h-1)  0.47 | {wt%}  2.99 | (th- }  11.87 | {%}  73.6 | (Nm3h-1)  19794 | (atm}  0.017 | (atm)  0.0017 | (atm}  0.128 | (atm}  0.152 | 0.18 | (atm)  6.7x10-9 | 2.06 |
| 100 1.72 | 18400 | 0.68 | 2.03 | 11.72 | 82.2 | 21941 | 0.017 | 0.0015 | 0.125 | 0.146 | 0.26 | 4.2x10·9 | 2.18 |
| 80 1.27  80 1.40 | 13600  14966 | 0.37  0.53 | 3.03  2.05 | 9.5  9.38 | 73.1  82.1 | 15958  17684 | 0.017  0.017 | 0.0017  0.0015 | 0.129  0.126 | 0.146  0.14 | 0.17  0.26 | 6.7x10·9  4.2x10-9 | 2.09  2.2 |

70 1.14 12186 0.32 3.02 8.31 73.3 14268 0.017 0.0017 0.129 0.145 0.17 6.7x10-9 2.12

70 1.25 13380 0.47 2.05 8.21 82 15773 0.01,7 0.0015 0.126 0.14 0.25 4.2x10-9 2.23

60 1.01 10797 0.28 2.96 7.12 73.8 12613 0.01'6 0.0016 0.129 0.144 0.17 6.7x10-9 2.17

60 1.11 11800 0.40 2 7.03 82.5 13886 0.01;7 0.0015 0.126 0.139 0.26 4.2x10-9 2.27

55 0.94 10053 0.25 2.99 6.53 73.6 11720 0.016 0.0016 0.13 0.144 0.16 6.7x10·9 2.2

55 1.03 10975 0.36 2.04 6.45 82.1 12883 o.01'6 0.0014 0.126 0.138 0.25 4.2x10"9 2.3

*'t, >* ***(f.., fe*9(s 8'** of moist sla9 at various rates with coal and airto match heat losses *pA* GJ h-1)

Annual ratelance Coallance AirReduction CoalZn in slagDiscard slagZn RecoveryOff gas volume pZn pPbspeciesPC02pH20pCO/pC02 p02 Coal/Zn (k tpa) (th-1) (Nm3 h"1) (t h-1) (wt%) (t h"1) (%) (Nm3 h"1) fumed(t/t)

(atm) (atm) (atm) {atm) (atm)

100 3.24 16700 0.52 3.07 12.19 72.1 20123 0.017 0.0017 0.17 0.116 0.17 6.5x10-9 3.89

100 3.57 18400 0.74 2.17 12.08 80.5 22307 0.017 0.0015 0.1650.111 0.25 3.2x10-9 3.99

80 2.64 13600 0.415 3.06 9.75 72.2 16239 0.017 0.0017 0.1710.109 0.17 6.6x10-9 3.94

80 2.9 14950 0.59 2.17 9.67 80.4 17970 0.017 0.0015 0.1660.105 0.24 3.2x10-9 4.05

70 2.37 12186 0.36 3.05 8.54 72.2 14519 0.016 0.0016 0.1710.108 0.17 6.8x10·9 4.03

70 2.6 13380 0.515 2.16 8.46 80.5 16051 0.016 0.0015 0.1660.104 0.24 3.3x10·9 4.12

60 2.1 10800 0.315 3.01 7.32 72.7 12837 0.016 0.0016 0.1720.107 0.17 6.9x10-9 4.13

60 2.29 11800 0.45 2.14 7.26 80.7 14124 I 0.016 0.0014 0.1670.103 0.24 3.4x10·9 4.22

55 1.965 10080 0.285 3.00 6.72 72.8 11961 0.016 0.0016 0.1720.106 0.17 7.0x10·9 4.19

55 2.181 11190 0.419 2.05 6.6 81.5 13370 0.016 0.0014 0.1660.102 0.24 3.2x10"9 4.32



**4.2 Modelling of Zone 2 Combustion of zinc and CO containing gases**

A series of calculations were performed to estimate the volume of gas required to fully combust the offgases from the Zone 1 calculations, including the zinc and lead in the offgas, and then to determine the flame temperature of the gas phase. The calculations were perfomed assuming gas temperatures close to that of the expected flame temperature. The input quantity of air was varied until the partial pressure of CO2 attained a maximum and this was used as the input quantity of air to determine

the flame temperature. The input temperature of the secondary air was assumed to

**be 25°C.**

The calculated volumes of secondary air, flame temperatures and gas volumes are given in Tables 10 to 13, corresponding to the simulations in Table 4 to Table 8.

Comparison of the flame temperatures in Table 10 where only fuel oil was used and Table 12 where only smelting with coal was simulated show that the flame temperatures are very similar.

**Table 10.** Calculated secondary air quantities and flame temperatures assuming no tertiary ingress air for the simulations with fuel oil from Table 4.

Lance Lance Red'n Recovery Zone 1 pZn pCO 2nd air Flame Oil Air Oil (%) Off aas (atm) pC02 (Nm h-1) Temp (t h-1) (Nm3 h-1) (t h-1) (Nm:rh"1) (°C)

0.83 8916 0.07 58 10295 0.014 0.09 1353 1416

0.9 9638 0.1 68.5 11179 0.016 0.13 1677 1440

0.94 10053 0.12 73.6 11692 0.016 0.16 1988 1455

0.97 10323 0.13 76.5 12027 0.016 0.19 2165 1463

1.03 10975 0.17 82.3 12843 0.016 0.25 2697 1479

Zone2 off aas

{Nrri3'h-1)

11648

12856

13680

14192

15540

*0.36# 3825 0.107 73.1 4572 0.041 0.37 1600 1566 6172*

# Liquid slag feed simulation conditions from

Table 5.

**Table 11.** Calculated secondary air quantities and flame temperatures assuming no tertiary ingress air for the simulations with fuel oil and coal from

Table **6.**

Lance Oil

(t h"1)

0.83

0.9

0.94

0.97

1.03

Lance

Air (Nm3 h-1) 8916

9638

10053

10323

10975

Red'n Coal

(t h"1)

0.148

0.211

0.255

0.275

0.362

Recovery Zone 1 pZn pCO 2" air Flame Off as pC02 (Nm h-1} Temp

(%) (Nm h-1) (atm) (0C)

58 10310 0.014 0.09 1340 1417

68.4 11200 0.016 0.13 1792 1439

73.6 11720 0.016 0.16 1992 1456

76.3 12056 0.016 0.19 2291 1459

82.1 12883 0.016 0.25 2834 1477

Zone 2 off qas

(Nm:rh-1)

11650

12992

13712

14347

15717

**Table 12.** Calculated secondary air quantities and flame temperatures assuming no tertiary ingress air for the simulations with coal from

Table **7.**

Lance Lance Red'n Recovery Zone 1 pZn pCO 2nd air Flame Zone 2

Coal Air Coal Off as pC02 (Nm h-1) Temp off as

(t h"1) (Nm3 h"1) (t h-1) (%) (Nm h-1) (atm) ,·c) (Nm h"1)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 1.725 | 8850 | 0.155 | 57.3 | 10409 0.014 0.09 1457 | 1422 | 11866 |
| 1.87 | 9595 | 0.23 | 67.3 | 11345 0.015 0.13 2042 | 1440 | 13387 |
| 1.965 | 10080 | 0.285 | 72.8 | 11961 0.016 0.17 2392 | 1455 | 14353 |
| 2.023 | 10379 | 0.327 | 76 | 12351 O.D16 0.19 2594 | 1467 | 14945 |
| 2.181 | 11190 | 0.419 | 81.5 | 13370 0.016 0.24 3343 | 1478 | 16713 |

**Table 13.** Calculated secondary air quantities and flame temperatures assuming no tertia!l'. in2ress air for the simulations with fuel oil and coal from Table 8.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Annual | | Lance | Lance air | Red'n | Recovery | Off gas | pZn | pCO | 2ndry air | Flame | Zone 2 |  |
| rate  {k tea} | | Oil  {t h-1} | (Nm3h-1) | Coal  {t h-1} | {%} | {Nm3h'1} | {atm} | pC02 | {Nm3 h-1} | Temp  {•C} | off as |  |
|  | 1!)0  100 | 1. 6  1.72 | 16700  18400 | 0.47  0.68 | 73.6  tf2.2 | 19794  21941 | 0.017  -0:0H | 0.18  0.26 | 3563  5099 | 1468  1488 | 23357 |  |
|  | 80 | 1.27 | 13600 | 0.37 | 73.1 | 15958 | 0.017 | 0.17 |  |  |  |  |
|  | 80 | 1.40 | 14966 | 0.53 | 82.1 | 17684 | 0.017 | 0.26 |  |  |  |  |
|  | 70 | 1.14 | 12186 | 0.32 | 73.3 | 14268 | 0.017 | 0.17 | 2568 | 1458 | 16836 |  |
|  | 70 | 1.25 | 13380 | 0.47 | 82 | 15773 | 0.017 | 0.25 | 3485 | 1484 | 19258 |  |
|  | 60 | 1.01 | 10797 | 0.28 | 73.8 | 12613 | 0.016 | 0.17 |  |  |  |  |
|  | 60 | 1.11 | 11800 | 0.40 | 82.5 | 13886 | 0.017 | 0.26 |  |  |  |  |
|  | 55 | 0.94 | 10053 | 0.25 | 73.6 | 11720 | 0.016 | 0.16 | 2392 | 1456 | 14353 |  |
|  | 55 | 1.03 | 10975 | 0.36 | 82.1 | 12883 | 0.016 | 0.25 | 2834 | 1477 | 15717 |  |

{Nm h-1}

'27040

Generally, the flame temperatures predicted by these calculations are lower than that would be predicted for the offgases of the previous work[1], where the furnace gases were richer in CO. The furnace off gas containing 6% CO, 10% CO2 and 1.5% Zn, would have a flame temperature of 1530°C when reacting with cold secondary air.

1. **SIMULATION OF THE BATCH ZINC FUMING**

Batch zinc fuming can be split into 3 parts:

* 1. Feeding and melting the cold slag
  2. Reduction
  3. Tapping

The tapping time is usually only a few minutes and can be neglected as its contribution to the fuming cycle is short. Steps 1 and 2 can take place at the same time, i.e., reduction can occur concurrently with melting. There is no literature available from the plant data to determine a suitable time interval to add and melt the cold slag. The time interval can be estimated from heat flux calculations. The reduction period can be evaluated from available plant data.

The feed rate at which dry granulated slag will fully melt was determined by heat flux calculations assuming the granulated slag is fully immersed in liquid slag and melts following shrinking core behaviour. The liquid was assumed to be isothermal and well mixed. The power input is from the combustion of the fuel oil and air down the

lance. Based on published lsasmelt Copper smelting plant data, where the furnace diameter and lance geometries and the Offgas volumes are given, the expected lance diameter should be less than 400 mm[4]. This would suggest a maximum air rate of 35,000 Nm3 h"1 (58% of total off gas) and assuming that the air stoichiometrically combusts an equivalent amount of fuel, the maximum heat input would be 25 MW (90 GJ h-1). The heat flux calculations assuming perfect melting with no heat losses to the injecting gas, derive a maximum feed rate of 60 t h"1, and assuming heat losses to the gas, the melting rate of the slag would be 37 t h"1•

Richards et al[5] examined the operation data of several zinc fuming plants. Although the zinc fuming furnace has a rectangular geometry and uses tuyeres rather than a lance, there is some useful information to help guide the batch fuming process. The slags used in zinc fumers have a density of 3.9 g cm-3 [5,6]. Assuming a furnace hearth area of 14.1 m2 (derived from n/4\*(4.4-0.16)2 {1]) and a furnace charge was 50 t, the bath depth would be 0.9 m, similar to that of many slag fuming furnaces [5]. The fuming rate of zinc from slag turners has been generally shown to be linear with time for Zn contents between 15 and 2 weight percent[5,7,8]. Fifty ton slag charges in zinc fuming plants can be reduced from initial11-14% Zn to a final level of 3 to 1 % zinc in 70 to 80 minutes[5,7]. Similarly a 100 ton charge can be reduced from 9% Zn to 1% Zn in 100 minutes, so the reduction time for a 501 charge containing 9% Zn may be as low as 50 minutes[8]. On the basis of the papers by Grant and Richards *et al,* it is assumed that the time to reduce 50t of slag from 9.5% Zn to 2% Zn is 60 minutes.

Work by the authors on zinc reduction from zinc fuming slags in small kilogram scales also showed that the decrease in Zn content in the slag was zeroth order until the zinc content was about 2%. The reduction rate then decreased sharply with time as the Zn content decreased below 1 wt% following first order behaviour. The results of the kilogram studies have been scaled to predict a possible scenario for reduction at the larger scale, and appear to be reasonable when compared with plant data after 80 to 100 minutes of zinc fuming[5]. The predicted reduction cycle time is shown in Figure 2.

12

10

8

**ti>**

**OI**

**'iii**

.5 6

**r::**

**N**

**Q**

4

2

0

0 0.5 1.5 2

**Time Predicted** (h)

Figure 2. Predicted reduction cycl time for fuming a 50 ton batch of Zn slag

The results of simulating the feeding of 50 ton of Zn slag followed by batch reduction for a period of 1-2 hr is presented in 'Table 14 using Fuel oil and air to provide the thermal energy and reductant. The simulations for Coal and air are presented in Table 15. The slag is assumed to be liquid and has no associated moisture. The first simulation treats the addition of all the inputs and outputs together, including heat losses, and the targeted Zn content in the slag is 2 wt%. The other time slice simulations assume intervals of 15 minutes for the first hour and the Zn content in the slag varies linearly with time, and uses the output slag chemistry as the input to the next simulation. After 1 hour the time slices are longer, 20 minutes and 40 minutes respectively to achieve 1% and 0.5% Zn in slag.

**Table 14.** Results of simulating melting 50 ton of cold slag and then batch reducing the hot slag with fuel oil and air assuming temperature is maintained at 1300°C. The first row represents the feeding/melting period, the second is for reduction for an interval of 1 hour, and the other simulations examine dividing the reduction period into **4** time slices of 15 minutes.

nme Lance Oil Lance Red'n Oil Zn Recovery Slag Off as pZn pCO CO/CO2 Oil/Zn

(h) (t h'1) Air (t h'1) (wt%) (%) mass(Nm h'1) (atm) (atm) fumed(t/t)

(Nm3 h"1) (t)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1.35 | 3.75 | 40000 |  | 12.5 | . 0 | 50.0 46300 | | 0.00020.004 | 0.035 |  |
| 1.0 | 2.07 | 22100 | 0.89 | 2.1 | 82 | 43.55 27755 | | 0.051 0.071 | 0.68 | 0.7 |
| 0.25 | 2.81 | 30000 | 0.50 | 8.1 | 23.2 | 47.5- | ·35568 | 0:047 0.023 | 0.18 | 0,7 |
| 0.5 | 2.50 | 26680 | 0.61 | 6.1 | 44.3 | 46.0 | 31742 | 0.046 0.029 | 0.22 | 0.7 |
| 0.45 | 2.27 | 24292 | 0.65 | 4 | 64.3 | 44.7 | 29224 | 0.047 0.041 | 0.34 | 0.7 |
| 1.0 | 2.11 | 22600 | 0.78 | 2.1 | 81.7 | 43.6 | 27604 0.043 0.063 0.57 0.8 | | | |
| *1* | *2.42* | *25893* | *0.64* |  |  |  | *31034* | | |  |
| 1.33 | 1.3 | 13950 | 0.57 | 0.93 | 92 | 42.9 | 5681 0.031 0.085 0.9 | | | 1.2 |
| 2.0 | 0.53 | 5700 | 0.15 | 0.50 | 95.7 42.7 4424 0.014 0.074 0.77 2.5 | | | | | |

#Average values from each 15 minute period

**Table 15.** Results of simulating melting 50 ton of cold slag and then batch reducing the hot slag with coal and air assuming temperature is maintained at 1300°C. The first row represents the feeding/melting period, the second is for reduction for an interval of 1 hour, and the other simulations examine dividing the reduction period into 4 time slices of 15 minutes.

TimeLance Coal Lance Red'n Coal Zn Recovery Slag Off @as pZn pCO CO/CO2 Coal/Zn

(h) (t h"1) Air (t h"1) (wt%) (%) mass(Nm h"1) (atm) (atm) (atm) fumed(t/t)

Nm3h

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1.35 | 7.74 | 40000 | 12.5 | | 0.0 | 50 | 46600 | 0.00020.004 0.0035 | | |
| 1 | 4.7 | 24300 | 2.3 | 2.01 | 82.3 | 44.17 31174 | | 0.046 0.094 | 0.63 | 1.7 |
| 1.25 | 6 | 30880 | 1.28 | 8 | 23.7 | 47.65 37376 | | 0.046 0.031 | 0.17 | 1.54 |
| 1.5 | 5.2 | 26720 | 1.4 | 6.01 | 44.3 | 46.32 32408 | | 0.044 0.039 | 0.21 | 1.6 |
| 1.75 | 4.8 | 24560 | 1.52 | 4.04 | 63.5 | 45.21 30128 | | 0.044 0.054 | 0.31 | 1.65 |
| 2.0 | 4.8 | 25400 | 2.28 | 2.02 | 82.1 | 44.16 31884 | | 0.04 0.085 | 0.55 | 1.9 |
| *1#* | *5.2* | *26890* | *1.62* |  |  | *32949* | |  |  | *1.67* |
| 1.33 | 2.4 | 11700 | 0.75 | 1.2 | 89.5 | 43.79 14310 | | 0.027 0.09 | 0.61 | 2.84 |
| 2 | 1.35 | 6900 | 0.525 | 0.6 | 94.8 | 43.56 8377.5 0.016 0.103 | | | 0.74 | 4.73 |

Average values from each 15 minute period

The simulations for both oil and coal show that the amount of fuel and reductant required to reduce the slag below 2 wt% increases substantially compared to the requirements at the higher zinc contents. The coal usage rate of Zn fuming furnaces can be calculated from the available plant data[5,7,8]. The coal rates per ton of Zn fumed average between 1 to 2.6 tit-Zn for a range of coal types. The average value was 1.6 *tit* and the predicted coal use rates shown in Table 15 are comparable with

this plant data. The average blast rate of air was 24,000 Nm3 h-1, also comparable with this study.

These simulations indicate that with a batch size of 50 t, a batch cycle of 3-4 hr can give zinc recovery well over 80%. The annual throughput at this processing rate is 100 kt assuming 15% down time. The heat loss through the furnace walls was not considered in the melting simulation. On the other hand, some reduction or fuming will also take place during the melting stage. These effects on the cycle time to some extent cancel each other.

While there is general agreement regarding the reaction kinetic behaviour, its impact on scale-up is not consistently established. The batch cycle time estimate presented above is more towards the conservative side.

##### 5.1 Modelling of Zone 2 Combustion of zinc and CO containing gases

The volume of secondary air and the flame temperature were calculated using the offgas compositions from Table 14 and Table 15 for fuel oil and coal reduction respectively.

**Table 16.** Secondary air quantities and flame temperatures of the batch simulation

assuming no tertiaryingress air for the simulationswith.fuel oil from-Table 8. Time Lance Lance Red'n Off gas pZn pCO 2ndry Air Flame Zone 2

(h) Oil Air Oil pC02 Temp off aas

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | (t h.1)  2.07 | (Nm3 h"1)  22100 | (t h"1)  0.89 | (Nm3h"1)  27755 | (atm)  0.051 | 0.68 | (Nm3 h"1).  13600 | (°C)  1610 | (Nm:rh"1)  41355 |
| 0.25 | 2.81 | 30000 | 0.504 | 35568 | 0.047 | 0.18 | 10670 | 1557 | 46238 |
| 0.5 | 2.5 | 26680 | 0.608 | 31724 | 0.046 | 0.22 | 9819 | 1560 | 41543 |
| 0.75 | 2.27 | 24292 | 0.652 | 29224 | 0.047 | 0.34 | 10521 | 1574 | 39745 |
| 1 | 2.11 | 22600 | 0.776 | 27604 | 0.043 | 0.57 | 11594 | 1570 | 39198 |
| 1.33 | 1.3 | 13950 | 0.57 | 5681 | 0.031 | 0.9 | 8116 | 1592 | 16772 |
| 1.66 | 0.53 | 5700 | 0.15 | 4424 | 0.014 | 0.77 | 2718 | 1540 | 9354 |

**Table 17.** Secondary air quantities and flame temperatures of the batch simulation assuming no tertiary ingress air for the simulations with coal from Table 15.

Time Lance Lance Red'n Off gas pZn pCO 2ndry Alr Flame Zone 2

(h) Coal Air Coal pC02 Temp off aas

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | (t h-1)  4.7 | (Nm3 h"1)  24300 | (t h-1)  2.3 | (Nm3h-1)  31174 | (atm)  0.046 | 0.63 | (Nm3h-1) (°C)  16834 1603 | (Nmz-h-1)  48008 |
| 0.25 | 6 | 30880 | 1.28 | 37376 | 0.046 | 0.17 | 13455 1544 | 50831 |
| 0.5 | 5.2 | 26720 | 1.4 | 32408 | 0.044 | 0.21 | 11513 1547 | 43921 |
| 0.75 | 4.8 | 24560 | 1.52 | 30128 | 0.044 | 0.31 | 12051 1564 | 42179 |
| 1 | 4.8 | 25400 | 2.28 | 31884 | 0.04 | 0.55 | 15623 1588 | 47507 |
| 1.33 | 2.4 | 11700 | 0.75 | 14310 | 0.027 | 0.61 | 6726 1566 | 21036 |
| 1.66 | 1.35 | 6900 | 0.525 | 8377.5 | 0.016 | 0.74 | 4105 1553 | 12482 |

#### CONCLUSIONS AND RECOMMENDATIONS

Processes of fuming zinc from the specified feed slag have been simulated where the fuel requirement, gas volume and composition are calculated for various target slag compositions or levels of zinc recovery. •

For both the continuous and the batch processes

* To avoid melilite precipitation, therefore detrimental impact on slag fluidity, the operating temperature should be maintained no lower than 1300 °C.
* The fuel and coal requirements reflect the available calorific heat value of the fuel/reductant source. The coal requirements are roughly twice that of the fuel oil.
* The secondary air requirements and flame temperatures are predicted to be

similar for fuel oil and coal.

* Moisture associated with the slag and coal should be removed as much as possible because at 3% Zn in stag the equilibrium H2/H2O ratio is 0.08, ie 8% of H2O is reduced to "H{, placing an additional endothermic load on the process. At 1% Zn in the slag, the H2/H2O ratio is 0.28.
* Recovery of heat to preheat the lance air or dry and preheat the slag will decrease the fuel load on the process.

For the continuous process

* For a throughput of 55 ktpa to achieve a zinc recovery of 82% (target 2% Zn in discard slags), the feed rates are slag 7.4 t h·1(dry basis), fuel oil 1.2 t h-1, air 13700 Nm3.h·1, and the volume of the off gas is 15540 Nm3.h-1. The fuel and air rate is noticeably lower than results from the earlier study [1] mainly because of the difference in the CO/CO2 ratio of the reacted gas in the fuming zone. In this work the gas was setas·in equilibrium with the slag.
* Based on the kinetic behaviour of fuming reactions, a throughput of 100 ktpa may be achievable with sufficient (say 80%) recovery of zinc.
* The Zn content of the offgas is predicted to be around 2% when cold slag is fed continuously. If liquid slag is fed, the amount of fuel required is halved and the Zn content in the offgas is approximately doubled.

For the batch process

* The melting kinetics of the cold slag in the batch process needs to be evaluated. A model indicates that for a heat input of 90 GJ h-1, 37 t h"1 of slag may be melted.
* The kinetics of reduction down to 2% is expected to follow zero order

behaviour and is expected to slow down significantly and move from zeroth order to 1st order when the Zn content decreases below 2 wt%.

* For a batch size of 50 t, zinc recovery of over 80% may be achieved with total cycle time of 3-4 hours. This makes up a throughput of about 100 ktpa assuming 85% availability.
* In the reduction of the liquid slag, the coal usage per ton of Zn produced is predicted to be similar to that for Zinc fuming furnaces when the Zn content in the slag is above 2 %
* The coal usage per ton of Zn produced increases substantially when the Zn content decreases below 2 wt%.

1. **ACKNOWLEDGEMENTS**

Dr Y Pan's assistance in evaluating the heat transfer and slag melting rate is acknowledged.

1. **REFERENCES**
2. "Zinc fuming project initial mass and energy balance", Stirling Process Engineering Report, January 2007
3. H.J. Hurst, J.H. Patterson and A. Quintanar, *Proceedings of the 6th International Conference on Molten Slags, Fluxes and Salts,* 2000, Trita Met 85, June 2000.
4. G. Abrashev, "Slag fuming by the use of liquid fuel"pp. 317-326.
5. P. Arthur and P. Partington, Copper 2003, TMMMS, 2003. .
6. G.G. Richards, J.K. Brimacomb and G.W. Toop, Metallurgical Transactions B, 1985, vol. 16, pp. 515-527.
7. R.M Grant, Private communication.
8. R.M. Grant, *Australia Japan Extractive Metallurgy Symposium 1980,* pp.75- 93, **AuslMM,** Parkville, 1980.
9. T.Lehner and R. Lingren, *Zinc 85,* pp. 185-200, TMMS, Warrendale, 1985.

### Mass and Energy Balance for Zinc Fuming by Bath Smelting

Steven Wright, David Langberg and Shouyi Sun

### Executive Summary

Ongopolo Mining is evaluating the use of the submerged lance furnace for treating lead tail slags to recover the zinc by reductive fuming. To evaluate the feasibility of the process, a mass and energy balance analysis was reported by Stirling Process Engineering. CSIRO Minerals carried out an independent evaluation of the mass and heat balance for the proposed zinc fuming process and simulated key aspects of the equilibrium and the kinetics of the relevant reactions. Both continuous and batch processes are evaluated.

In general

* 1. To avoid melilite precipitation, therefore detrimental impact on slag fluidity, the operating temperature should be maintained no lower than 1300 °C.
  2. The fuel and coal requirements reflect the available calorific.heat value of the fuel/reductant source. The coal reqtiiremerits by weight~c:.ire roughly twice that of the fuel oil.
  3. Moisture associated with the slag and coal should be removed as much as possible because at 3% Zn in slag the equilibrium H2/H2O ratio is 0.08, ie 8% of H2O is reduced to "H2", placing an additional endothermic load on the process. At 1% Zn in the slag, the H2'H2O ratio is 0.28.

For the continuous process

* 1. For a throughput of 55 ktpa to achieve a zinc recovery of 82% (target 2% Zn in discard slags), the feed rates are: slag 7.4 t h·1(dry basis), fuel oil 1.2 t h·1, air 13700 Nm3Jf1, and the volume of the off gas is 15540 Nm3.h.1. The fuel and air rate is noticeably lower than results from the earlier study(1] mainly because of the difference in the assumed CO/CO2 ratio of the reacted gas in the fuming zone. In this work the gas was set as in equilibrium with the slag.
  2. Based on the kinetic behaviour of fuming reactions, a throughput of 100 ktpa

·may be achievable with sufficient (say 80%) recovery of zinc.

For the batch process

* 1. The melting kinetics of the cold slag in the batch process needs to be evaluated. A model indicates that for a heat input of 90 GJ h·1, 37 t h·1 of slag may be melted.
  2. For a batch size of 50 t, zinc recovery of over 80% may be achieved with total cycle time of 3-4 hours. This makes up a throughput of about 100 ktpa assuming 85% availability.

1. **Background**

Ongopolo Mining, a subsidiary of Weatherly International, owns a submerged lance lead smelting furnace located at its smelter complex in Tsumeb, Namibia. The unit has been used for varying short periods smelting lead concentri:ites to produce a bullion and copper sulphide concentrates to copper mattes. Recently, the company is evaluating the use of the submerged lance furnace for treating lead tail slags to recover the zinc by reductive fuming. To evaluate the feasibility of the process, a mass and energy balance analysis was carried out by Stirling Process Engineering. A confidential report has been generated[1J.

With in-house computational tools for simulating various slag reactions, CSIRO Minerals is commissioned to carry out an independent evaluation of the mass and heat balance for the proposed zinc fuming process and to review some of the equilibrium and kinetic issues. The work was covered under the agreement FT 2007010177 (CM Project code JB33B1). This report documents the outcome of this study.

1. **Objectives**

CSIRO Minerals is to.use its in-house models to perform.modelling and simulation studies (including mass/energy balance calculations, kinetics and thermodynamic modelling) of a proposed zinc fuming process with the aim of generating information on the process with regard to:

1. Zinc recovery;
2. Fuel and reductant requirements;
3. Air requirements for primary and secondary combustion;
4. Furnace off-gas composition; and
5. Furnace off-gas flowrate and temperature.

The above studies will be performed for two scenarios:

* 1. Single stage continuous with varied slag throughput generally within the range of 50 to 80 ktpa; and
  2. Two stage batch operation wiih batch size and smelting time to be determined.

1. **A Preliminary Evaluation of the Thermodynamic Limit for Reductive Fuming of Zinc from Ongopolo Pb Tail Slags**

As is recognised in the earlier study[1], the zinc recovery will depend on the slag oxidation state, or the prevailing oxygen potential in the slag bath. More reducing environment is obviously favourable for zinc fuming. However, condiiions too reducing can result in the reduction of iron oxide in the slag to form an iron alloy, which is to be avoided. This exercise evaluates the reduction limit and the slag properties at the target operating temperature.

The first thennodynamic simulations were to investigate the limit to slag reduction at 1300°C and at lower temperatures using the Pb slag. The dry tail slag was reduced with varying quantities of carbon (C) and nitrogen to the point where the slag was just saturated with solid iron. This occurs at pO2=5.2x10-12 atm (equivalent CO/CO2 ratio of 6). Although the zinc concentration in the slag could be reduced further, the point at which solid iron is formed could be regarded as the theoretical limit to Zn recovery. The equilibrium Zn content in the slag also depends on the partial pressure of other

gases such as nitrogen. These gases act as diluents and reduce the equilibrium partial pressure of Zn above the slag and the content of Zn in the slag. Figure 1 shows that the equilibrium Zn content in the slag and the Zn partial pressure are broadly in proportional relationship, the Zn content in the slag increases as the amount of diluting gases decreases, and the maximum possible Zn recovery decreases. In the smelter off gas, where air is used, the N2 partial pressure may be between 0.8 to 0.6 atm, depending upon the operating conditions. The Zn content in the slag could be between 0.5 to 1 wt% and the recoveries between 90 to 96 percent.

The equilibrium conditions near iron saturation were also calculated for temperatures between 1300 and 1260°C and the results are given in

Table 1. As the temperature decreased, the Zn content in the slag increased for a given partial pressure of zinc and the slag becomes saturated with a melilite phase (a solid solution of Ca2(Mg,Fe,Zn)Si2O7) which could substantially increase the viscosity of the slag phase.

0.8

2!

C.

C

**A**

'



'**A..** pN2

•

' '' '

'' '

'

'

',

#### A..

' ' '

' '

' \

**1300°C** •

C + N2<ol added pO2"s.2x10·12 atm CO/CO2 - 6.0

At Fe saturation

73

pZn

N 0.4 C.

0.2

' \

' '

'

90

' \

' \

\

'

\

\

' ' \

' \ '

' ' '

0 0.5 1.5

Zn in **slag (wt%)**

2 2.5 3

**Figure 1.** Concentration of zinc in the gas as a function of equilibrium zinc content in the lead slag under conditions near the onset of reduction of metallic iron from the slag. The numbers shown above the points on the Zn partial pressure line are the values for the Zn recovery as a percentage of the total zinc in the slag feed.

**Table 1.** Variation of Zn conent in gas and slag phases at equlibrium conditions near Fe saturation of the reduced Pb slag at varying temperatures with pN2 of ~0.8

Temp pCO/pCO2 pO2 pZn pPb Zn in Comments Viscosity (OC) (atm) (atm) (atm) slag (Pas)

{wt%)

1300 6.08 5.3x10-12 0.093 0.008 0.47 0.30

1290 5.69 4.5x1ff12 0.097 0.0086 0.57 Saturated with 0.76

1280 5.36 3.8x10-12

~1O wt% Melilite

0.096 0.0086 0.65 Saturated with

1.76

~16 wt% Melilite 1260 **4.64** 2.9x1□-12 0.093 0.0086 0.89 Saturated with 1000+

~38 wt% Melilite

The above calculations suggest that without changing the slag chemistry, the minimum operating temperature to avoid solid phase formation may be 1300°C.

In real operations, the prevailing oxidation state in the slag will be considerably different from iron saturation. The equilibrium zinc partial pressure in the gas is therefore to be lower than plotted in Figure 1, for any given zinc level in the slag, approximately in proportion to the CO/CO2 ratio *in equilibrium* with the slag. For example, for a slag with 2.5% Zn in equilibrium with an oxygen potential equivalent to CO/C02=1, pZn would be about 0.08 atm.

1. **SIMULATION OF CONTINUOUS SMELTING**
   1. **Modelling of Zone 1** - **the zinc fuming zone**

The simulation of continuous fuming of the zinc slag was performed using the MPE thermodynamic package. Five input streams were used in the thermodynamic calculations and the species and concentrations used are given in Table 2. The composition of the feed slag was based on the chemistry reported to Ongopolo Mining [1] and converted to a dry basis. The Feed Moisture stream simulates the water content of the moist feed slag. The Lance Air stream was assumed to be the only source of air into Zone 1, and only the oxygen and nitrogen components of air were used. The simulation of the Fuel oil and Coal streams assumed that the carbon, hydrogen and oxygen were distributed between the species CH20, CH4 and

C. The ash composition of the Coal stream was assumed to be similar to a typical coal that may be used in a coal gasifier[2]. The stoichiometric quantities of Air required to combust the oil and coal are given in Table 3 along with the calculated thermal energy from combustion and compared with the values previously used [1].

**Table 2.** Feed Streams used in the simulations of continuous smelting of the most feed sla9. !neut feed temeeratures were 25°C.

Feed (wt%) Feed (wt%) Lance (Vol%) Fuel (wt%) Coal (wt%)

Slag Moisture Air Oil

Al2O3 4.2 H2O 100 N2 79 C 51.05. C 44.7

As2O3 0.42 02 21 CH4 45.4 CH2O 15.75

Cao 23.2 CH2O 0.75 N 1.2

Cu2O 0.42 s 2.8 s 1.7

Fe2O3 2.1 Al2O3 1.6

FeO 21.1 cao 3.2

MgO 5.3 Fe2O3 0.8

PbO 2.5 SiO2 2.4

SiO2 27.4 H2O 18

ZnO 12.45

**Table 3.** Combustion air volumes, and heats of combustion of fuel oil and coal from the MPE model.

Stoichiometric combustion air

Calculated

Heat of Combustion (GJ f1)

Gross calorific value (GJ f1)

volume (Nm3.f1)

Trnputs=1300°C T

tnputs

=25°C (15°C)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Fuel Oil | 10690 | 40.0 | 16.7 | **42.9[1]** |
| Coal | 5170 | 19.8 | **8.1** | **23.9[1]** |

In the MPE simulations, there is no distinction between lance oil and reduction oil. The partition between lance oil and reduction oil is determined by the desire to have the lance operating at stoichiometric combustion. On that basis, for 1 ton of oil, 10690 Nm3 of Air is required for stoichiometric combustion. The reduction oil is therefore the excess oil required to make the bath more reducing. The logic of this separation becomes more apparent when a mixture of fuel oil and coal are used in the feed streams. In practice, the lance is operated under slightly reducing conditions with combustion stoichiometry between 90 and 95%, and so the amount of lance oil would be slightly higher and the amount of reduction oil slightly lower.

The feed rates .used in the simulations were calculated on an annualised basis for dry slag assuming a furnace availability of 85%[1]. The feed rate per hour is the·n calculated for example as,

55000/365/24\*0.85 = 7.39 t h.1

The Feed moisture rate is then 5/95x(slag feed rate) or 0.39 t h"1.

The MPE calculates that the amount of thermal energy required to heat 1 ton of zinc slag from 25°C to 1300°C is 0.975 GJ r1 (dry basis) and 1.08 GJ r1 (damp basis). For an annual through-put of 55, 000 tons (dry basis), the heat load placed on the furnace from feeding the cold and wet slag is 8.4 GJ h.1.

The heat losses from the furnace were taken from Table 4.2 of the Ongopolo report [1, page 17}. The heat losses from the furnace shell were 1.96 GJ h·1 and sundry heat losses were 1.46 GJ h·1; giving a total heat loss of 3.42 GJ h"1. This value was

used for heat losses in the furnace in evaluating the total heat requirement. (Based on our estimate, heat loss of 1.96 GJ h.1 from the furnace walls may be a 2-3 times over estimate.)

Table 4 presents the results for zinc fuming of the slag at an annual rate of 55,000 tons with the estimated heat losses of 3.4 GJ h"1. These calculations were performed to benchmark the simulations. The amount of Fuel Oil and Air was varied to match the heat load (3.4 GJ h"1) and to produce a low zinc slag. The table shows that as the zinc content in the slag is reduced and the recovery increased, the amount of fuel and air required increases. To decrease the Zn content in the slag from 3 to 2% requires a 13% increase in the amount of oil and 10% increase in the volume of air required. The zinc partial pressure in the offgas of the simulations does not vary greatly with final content in the slag and is around 1.6 volume percent.

It is important to note that the equilibrium calculations predict that to produce a slag containing 3% Zn, the equilibrium CO/CO2 ratio is 0.16. This is considerably more oxidizing that the conditions assumed in the previous work[1] where it was assumed the CO/CO2 ratio was 0.6. If one ton of oil is heated to 1300°C with cold air and combusted to a CO/CO2 ratio of 0.16, 14.5 GJ of heat is evolved, however if the fuel

is combusted to a CO/CO2 ratio of 0.6, only 10.4 GJ of heat is liberated, and consequently 1.4 times more oil and air is required to yield the same amount of heat.

Table 5 shows the results of a simulation smelting hot liquid slag instead of cold slag. The amount of fuel oil and air required decreases substantially (by about 55%), and the Zn tenor in the offgas is around 4.5%, significantly higher than the results of cold slag feeding. If there is waste heat available on the plant to at least dry or preheat the slag, there may be significant energy savings. The fuel use per ton of zinc fumed for the simulation in

Table 5, (0.87) is comparable to that of plant data [3] where hot slag was continuously fed to a zinc fuming furnace and liquid oil (Mazut} and air were combusted to reduce the slag. For a slag contaning 12-14%Zn and reduced to 2% Zn, the use of Mazut was between 11 and 16% by weight per ton of slag or equivalent to 1 to 1.3 ton of oil per ton of zinc fumed.

Table 6 presents the results of simulations where coal is added as reductant and fuel oil is used with the lance. The outcomes of the simulations are very similar to that presented in Table 4, with roughly double the amount of reductant coal compared with "reductant oil". The Zn partial pressure in the offgas is the same and the off gas volumes have not changed greatly. The mass of discard slag produced is slightly greater due.to the ash content of the coal.

In

Table 7, coal is used as both fuel and reductant and the results are directly comparable to that presented in Table 4. On a tonnage basis, twice as much coal as fuel oil is required to achieve the same zinc recovery, however the amount of air required is roughly the same and the zinc content of the gas phase is not significantly different.

ln Tables 8 and 9, the effect of slag feed rate are investigated for- the cases where fuel oil in the lance with reductant coal (Table 7} and coal only(Table 8) are used. For a given slag feed rate and target recovery, the offgas volumes and zinc concentrations are similar, although the H2O/CO2 ratios in the off gas are higher in the fuel oil simulation. Twice as much coal in weight is required to smelt the zinc slag when compared with fuel oil.

The above simulations are for equilibrium. One question to ask is whether there is enough time for the reaction to closely approach the equilibrium. Based on a slag feed rate of 7.4 t h-1 (dry bases, 55 ktpa}, a furnace capacity of 50 t, the residence time of the slag in the furnace is 6.8 hr. This is perhaps unnecessarily long. Doubling the throughput to about 100 ktpa will see the residence time drops to 3.5 hr. As will be seen later in discussions on batch operation, this time is probably still sufficient to achieve over 80% recovery of zinc.