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An electrochemical model for the leaching kinetics of gold ore in cyanide solutions

Conradie, Petrus Jacobus

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Run 22.

Liquid fraction of Kloof pulp only
Volume of pulp: 15 liters
Sparging medium: air
Temperature: 17 °C
NaCN added: 9.00 g
Airated for 45 min before NaCN addition

Time(min)	E_{Pt}(mV)	E_{Au}(mV)	E_{Au-Ag}(mV)	$[Au]_1$(ppm)	[CN]mmol/l
0	-	-	-	0.00	-
1	-	-	-525	0.098	13.107
2	-	-445	-	-	-
3	-92	-	-	-	-
4	-	-	-539	-	-
5	-	-435	-	-	-
6	-105	-	-	-	-
8	-	-	-555	-	-
10	-	-447	-	-	-
12	-133	-	-	-	-
15	-93	-	-	0.098	13.130
20	-	-	-530	-	-
30	-	-	-540	0.195	13.062
40	-	-395	-	-	-
50	-55	-	-	-	-
60	-	-	-513	0.244	12.566
75	-	-388	-	-	-
90	0	-350	-460	0.342	12.205
120	+18	-340	-452	0.342	11.776
180	+43	-320	-442	0.488	11.280
270	0	-362	-505	0.585	9.926
360	+74	-289	-440	0.683	8.686
390	+69	-295	-450	-	-

Run 23.

Potential measurements in distilled water
Volume of water: 15 liters
Sparging medium: air
Temperature: 20 °C
NaCN added: 9.00 g
Airated for 45 min before NaCN addition

Time(min)	E_{Pt}(mV)	E_{Au}(mV)	E_{Au-Ag}(mV)	$[Au]_1$(ppm)	[CN]mmol/l
0	-	-	-	0.000	0.00
1	-	-	-473	-	-
2	-	-310	-	-	-
3	-94	-	-	0.049	12.002
4	-	-	-481	-	-
5	-	-307	-	-	-
6	-93	-	-	-	-
8	-	-	-482	-	-
10	-	-302	-	-	-
12	-93	-	-	-	-
15	-87	-	-	0.049	11.979
20	-	-301	-	-	-
25	-	-	-465	-	-
30	-	-	-461	0.122	12.024
40	-	-298	-	-	-
50	-47	-	-	-	-
60	-	-	-447	0.195	11.844
75	-	-324	-	-	-
90	-78	-357	-494	0.293	11.957
120	-25	-324	-457	0.293	11.934
180	+17	-309	-432	0.390	11.438
240	-17	-362	-488	0.5126	11.280
300	+36	-331	-444	0.561	11.032
360	+65	-330	-439	-	10.716
∞	-	-	-	26.689	-

Run 24.

Kloof pulp
Volume of pulp: 15 liters
Sparging medium: air
Temperature: 17 ^{o}C
NaCN added: 4.50 g
Agitation speed: 300 rpm (it was 600 rpm in all the previous runs)

Time(min)	E_{Pt}(mV)	$[Au]_l$(ppm)	$[Au]_s$(g/t)
0	-	0.000	10.8
1	-125	-	-
2	-129	-	-
3	-128	1.346	8.65
5	-129	-	-
8	-129	-	-
16	-125	5.513	5.92
20	-122	-	-
24	-120	-	-
30	-120	8.056	4.32
40	-121	-	-
45	-120	9.979	2.77
60	-115	11.004	2.30
90	-109	12.222	1.16
120	-107	12.842	0.92
180	-107	13.077	0.83
240	-104	13.248	0.40
305	-102	13.526	0.46
360	-102	13.568	0.45
∞	-33	14.103	-

Run 25.

Kloof pulp
Volume of pulp: 15 liters
Sparging medium: air
Temperature: 17 °C
NaCN added: 4.50 g
Agitation speed: 450 rpm (it was 600 rpm in all the previous runs)

Time(min)	E_{Pt}(mV)	$[Au]_l$(ppm)	$[Au]_s$(g/t)
0	-	0.128	11.5
1	-86	-	-
2	-92	-	-
3	-86	1.410	9.36
5	-82	-	-
8	-78	-	-
15	-72	5.406	7.47
20	-67	-	-
24	-64	-	-
30	-63	8.355	4.54
40	-59	-	-
45	-58	10.278	3.26
60	-52	11.325	2.71
90	-44	12.714	1.87
120	-39	13.162	1.31
180	-106	13.397	1.00
195	-54	-	-
240	-39	13.697	1.12
300	-33	13.504	1.09
305	-104	-	-
360	-40	13.632	0.91
∞	-33	14.103	1.22

Run 26.

Kloof pulp
Volume of pulp: 15 liters
Sparging medium: air
Temperature: 17 °C
NaCN added: 4.50 g
Agitation speed: 600 rpm add 0.24 g thallium(I)chloride

Time(min)	E_{Pt}(mV)	$[Au]_l$(ppm)	$[Au]_s$(g/t)
0	-	0.000	11.8
1	-98	-	-
2	-115	-	-
3	-112	2.726	7.94
5	-108	-	-
8	-104	-	-
15	-99	7.76	4.93
20	-98	-	-
24	-70	-	-
30	-65	10.55	2.94
40	-61	-	-
45	-60	12.54	2.44
60	-59	13.604	1.83
90	-55	14.312	0.88
120	-60	14.532	0.60
175	-59	14.837	0.98
240	-66	14.778	0.77
300	-73	14.956	0.96

Experiment A1

400 ml water
Test the effect of cyanide on the potential
No copper added
pH ≈ 10
Concentration of the cyanide solution which was added: 0.6703 mol/l

Vol CN added	Time (min)	E_{Pt} (mV)	Time (min)	E_{Pt} (mV)
1 ml	0 1 2 3 4 5 6 7	-24 -31 -38 -42 -45 -48 -50 -52	8 9 10 12 14 16 18	-53 -54 -55 -56 -58 -58 -58
2 ml	0 1 2 4	-59 -60 -61 -63	8 10 12	-66 -67 -67
3 ml	0 1 4	-67 -67 -70	10 17	-72 -75
5 ml	1 2 3 4 6	-75 -78 -79 -81 -82	8 10 14 20	-84 -85 -87 -90

Experiment A2

Test the effect of gold ions on the potential
Copper concentration = 3.5 ppm
Cyanide concentration = 0.0084 mol/l
pH ≈ 10
Concentration of the gold solution which was added: 0.0025 mol/l

Vol gold sol. added(ml)	Pt redox pot.(mV)
0	-194
1	-190
2	-188
3	-184
4	-182
5	-180
7	-178
10	-176
11	-173

Experiment A3

Test the effect of copper on the potential
Cyanide concentration = 0.0084 mol/l
pH ≈ 10
Concentration of the copper solution which was added: 0.00446 mol/l

Vol Cu added	Time (min)	E_{Pt} (mV)	Time (min)	E_{Pt} (mV)
2 ml	0 1 2 3	-89 -76 -73 -71	10 20 31	-66 -82 -80
3 ml	0 1 2	-80 -72 -70	3 8 10 28	-68 -65 -65 -67
4 ml	0 1 2 3	-67 -59 -57 -56	6 10 14	-55 -55 -57

Experiment A4

Test the effect of silver on the potential
No copper added
Cyanide concentration = 0.75 mmol/l
pH ≈ 10
Concentration of the silver solution which was added: 0.0282 mol/l

Vol Ag added	Time (min)	E_{Pt} (mV)	Time (min)	E_{Pt} (mV)
1 ml	0 1	-67 -66	2 3	-66 -67
2 ml	0 1	-67 -66	2	-66
3 ml	0 1 2	-66 -64 -64	3 4	-63 -63
4 ml	0 1	-63 -60	4 6	-58 -57
4.5 ml	0 1 2	-56 -52 -51	3 14	-50 -43
5 ml	0 1	-43 +51		

Appendix B

The computer program used to fit the model to the experimental data

```
PROGRAM MODRUN11 (INPUT,OUTPUT);
{**************************************************************
 *   PROGRAM TO DETERMINE THE CONSTANTS K1 AND K2 SO THAT THE BEST  *
 *   POSSIBLE FIT OF THE MODEL ON THE EXPERIMENTAL DATA IS OBTAINED.*
 *                                                                  *
 *  THE PROGRAM DETERMINES THE SUM OF THE SQUARE OF THE DIFFERENCES *
 *  AND MINIMISES IT.                                               *
 **************************************************************}
VAR
OUTERM : TEXT;
K1,K2: {COORDINATES OF THE INITIAL SIMPLEX}   ARRAY(.1..3.) OF REAL;
SOMM: {SUM OF SQUERED DIFFERENCES} REAL;
KK1,KK2: {VARIABLES USED FOR K1 AND K2 IN THE OPTIMIZATION} REAL;
AIN1: {GOLD CONC. AT TIME IN1. } ARRAY(.1..10.) OF REAL;
II,Z,J,I: {COUNTERS} INTEGER;
NN :{MAXIMUM NUMBER OF ITERATIONS ALLOWED} INTEGER;
N : {NUMBER OF CONCENTRATION MEASUREMENTS} ARRAY(.1..10.) OF INTEGER;
NU : {NUMBER OF POTENTIAL MEASUREMENTS} ARRAY(.1..10.) OF INTEGER;
P,T: {P=AU CONC AS MEASURED IN EXP. AT T} ARRAY(.1..10,1..30.) OF REAL;
U0,TU: {E0=POTENTIAL AT TIME=IN} ARRAY(.1..10,1..30.) OF REAL;
X:{THE A T VALUES USED IN GUASS INTG} ARRAY(.1..10,1..30,1..4.) OF REAL;
Y:{FUNCTIONAL VALUES AT EACH X} ARRAY(.1..10,1..30,1..4.) OF REAL;
EUX: {INTERPOLATED POTENTIAL VALUE} ARRAY(.1..10,1..30,1..4.) OF REAL;
INT:{ANTI-IN OF GUASS INTEGRAL} ARRAY(.1..10,1..30.) OF REAL;
CONC:{CALCULATED AU CONCENTRATION} ARRAY(.1..10,1..30.) OF REAL;
SOM: {SUM OF SQUARED DIFFERENCES AT EACH} ARRAY(.1..3.) OF REAL;
     {COORD. OF THE SIMPLEX}

{THE FOLLOWING VARIABLES ARE ALL USED IN THE OPTIMIZATION PROCEDURE}

K1REF,K2REF: {REFLECTED POINT IN THE NELDER ALGORITHM} REAL;
K1EXP,K2EXP: {EXPANDED POINT IN THE NELDER ALGORITHM} REAL;
K1CONT,K2CONT: {CONTRACTED POINT IN THE NELDER ALGORITHM} REAL;
CENTK1,CENTK2: {CENTROID OF COORD. OF THE SIMPLEX EXCEPT WORST} REAL;
DIS11:{DIFFERENCE BETWEEN K1 VALUES OF TWO COORD OF SIMPLEX} REAL;
DIS12:{DIFFERENCE BETWEEN K2 VALUES OF TWO COORD OF SIMPLEX} REAL;
DIST:{DISTANCE BETWEEN TWO COORD OF THE SIMPLEX} REAL;
SOMREF: {SUM OF SQUARED DIFFERENCES AT THE REFLECTED POINT} REAL;
SOMEXP: {SUM OF SQUARED DIFFERENCES AT THE EXPANDED POINT} REAL;
SOMCONT: {SUM OF SQUARED DIFFERENCES AT THE CONTRACTED POINT} REAL;
TOP,TOPK1,TOPK2: {USED TO ARRANGE SUM TERMS IN DESCENDING ORDER} REAL;
ALPHA,BETA: REAL;
NUM :{NUMBER OF RUNS} INTEGER;
}-----------------------------------------------------------------}
PROCEDURE EX;

{THIS PROCEDURE DETERMINES THE FOUR TIME VALUES NEEDED FOR THE
       NUMERICAL INTEGRATION BY MEANS THE GUASS METHOD          }

VAR
JJ,JJ: INTEGER;
BEGIN
```

```
VS PASCAL RELEASE 1.0        MODRUNT1:EX                                    12/09/88 13:57:04

 B P C I  SIMI #                          S O U R C E   P R O G R A M

                  V---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----V
   1   1       1  |FOR J1 := 1 TO NUM DO
   1   1          |BEGIN
 1 1   2       2  |  FOR JJ := 1 TO N(.J1.) DO
 1 1   2          |  BEGIN
 2 1   2       3  |    X(.J1,JJ,1.):= 0.06945*T(.J1,1.)+0.93055*T(.J1,JJ.);
 2 1   2       4  |    X(.J1,JJ,2.):= 0.33*T(.J1,1.)+0.67*T(.J1,JJ.);
 2 1   2       5  |    X(.J1,JJ,3.):= 0.67*T(.J1,1.)+0.33*T(.J1,JJ.);
 2 1   2       6  |    X(.J1,JJ,4.):= 0.06945*T(.J1,JJ.)+0.93055*T(.J1,1.);
 1 1   2          |  END
   1   1          |END
                  |END;
                  |{-----------------------------------------------------------------------}
   1              |PROCEDURE POTEN;
   1              |
   1              |{THIS PROCEDURE DETERMINES THE POTENTIAL AT THE SPECIFIC TIMES
   1              | BY MEANS OF INTERPOLATION  OF THE EXPERIMENTAL VALUES                 }
   1              |
   1              |VAR
   1              |BB,J1,JJ : INTEGER;
   1              |L,K,J,NPT : INTEGER;
   1              |P,ZBAR,B : REAL;
   1              |BEGIN
   1   1       1  |FOR J1 := 1 TO NUM DO
   1   1          |BEGIN
 1 1   2       2  | FOR JJ := 1 TO N(.J1.) DO
 1 1   2          | BEGIN
 2 1   3       3  |  FOR BB:= 1 TO 4 DO
 2 1   3          |  BEGIN
 3 1   3       4  |    NPT := NN(.J1.);
 3 1   3       5  |    ZBAR := X(.J1,JJ,BB.);
 3 1   3       6  |    EHX(.J1,JJ,BB.) := 0 ;
 3 1   3       7  |    L:= 1;
 3 1   3       8  |    P:= 1;
 3 1   4       9  |    WHILE P>0 DO
 3 1   4          |    BEGIN
 4 1   4      10  |      P := P * ( ZBAR - TH(.J1,L.));
 4 1   4      11  |      L := L + 1 ;
 3 1   3          |    END ;
 3 1   3      12  |    IF (L= 2 ) OR ( L = 3 ) THEN L := 4 ;
 3 1   3      14  |    IF L > NPT THEN L:= NPT ;
 3 1   4      16  |    FOR K := (L-3) TO L DO
 3 1   4          |    BEGIN
 4 1   4      17  |      B := 1;
 4 1   5      18  |      FOR J := (L-3) TO L DO
 4 1   5          |      BEGIN
 5 1 1 5      19  |        IF (J - K) <> 0 THEN
 5 1   5      20  |        B := B*(ZBAR - TH(.J1,J.))/(TH(.J1,K.)-TH(.J1,J.));
 4 1   4          |      END;
 4 1   4      21  |      EHX(.J1,JJ,BB.) := EHX(.J1,JJ,BB.) + B*TH(.J1,K.);
 3 1   3          |    END;
 2 1   3          |  END
 1 1   2          | END
   1   1          |END
```

```
VS PASCAL RELEASE 1.0        MODRUN11:                                          12/09/88 13:57:04
 D P C I  SIMI //                          S O U R C E   P R O G R A M

                  V---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----V
                  |END;
                  |{-----------------------------------------------------------------}
   1              |PROCEDURE EIS;
   1              |
   1              |{THIS PROCEDURE DETERMINES THE FOUR Y VALUES AT EACH OF THE TIME
   1              | VALUES.                                                          }
   1              |
   1              |VAR
   1              |POT: {SOLUTION POTENTIAL} REAL;
   1              |II,II,KK: INTEGER;
   1              |BEGIN
   1   1       1  |FOR II := 1 TO NUM DO
   1   1          |BEGIN
 1 1   2       2  |  FOR II:= 1 TO N(.II.) DO
 1 1   2          |  BEGIN
 2 1   3       3  |     FOR KK := 1 TO 4 DO
 2 1   3          |     BEGIN
 3 1   3       4  |     POT:= EHX(.II,II,KK.);
 3 1   3       5  |     Y(.II,II,KK.):= EXP(POT*KK2)*KK1;
 2 1   3          |     END
 1 1   2          |  END
   1   1          |END
                  |END;
                  |{-----------------------------------------------------------------}
   1              |PROCEDURE INTEG;
   1              |
   1              |{THIS PROCEDURE DETERMINES THE INTEGRAL NUMERICALLY BY MEANS OF THE
   1              | GUASS METHOD                                                     }
   1              |
   1              |VAR
   1              |J1,IJ: INTEGER;
   1              |AA,BB: REAL;
   1              |BEGIN
   1   1       1  |FOR J1 := 1 TO NUM DO
   1   1          |BEGIN
 1 1   2       2  |  FOR IJ:= 1 TO N(.J1.) DO
 1 1   2          |  BEGIN
 2 1   2       3  |    AA := 0.1739*(Y(.J1,IJ,1.)+Y(.J1,IJ,4.));
 2 1   2       4  |    BB := 0.3261*(Y(.J1,IJ,2.)+Y(.J1,IJ,3.)),
 2 1   2       5  |    INT(.J1,IJ.) := EXP((I(.J1,1.)-I(.J1,IJ.))*(AA+BB));
 1 1   2          |  END
   1   1          |END
                  |END;
                  |{-----------------------------------------------------------------}
   1              |PROCEDURE KONS;
   1              |
   1              |{THIS PROCEDURE DETERMINES THE CONCENTRATION AS PREDICTED BY THE MODEL}
   1              |
   1              |VAR
   1              |M1,MM: INTEGER;
   1              |BEGIN
   1   1       1  |FOR M1 := 1 TO NUM DO
   1   1          |BEGIN
```

```
VS PASCAL RELEASE 1.0        MODRUN11:KONS                                    12/09/88 13:57:04

 B P C I  SIMF #                          S O U R C E   P R O G R A M

                  V---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----V
 1 1   2       2 |  FOR MM := 1 TO N(.M1.) DO
 1 1   2         |  BEGIN
 2 1   2       3 |  CONC(.M1,MM.) := (P(.M1,1.)-ainf(.M1.)) *INT(.M1,MM.) + AINF(.M1.);
 1 1   2         |  END
   1   1         |END
                 |END;
                 |{-----------------------------------------------------------------}
   1             |PROCEDURE SUM;
   1             |
   1             |{THIS PROCEDURE DETERMINES THE SUM OF SQUARED DIFFERENCES BETWEEN THE
   1             | PREDICTED VALUES AND THE EXPERIMENTAL VALUES                      }
   1             |
   1             |VAR
   1             |M2,MMM: INTEGER;
   1             |DIFF: REAL;
   1             |BEGIN
   1           1 |SOMM := 0 ;
   1   1       2 |FOR M2 := 1 TO NUM DO
   1   1         |BEGIN
 1 1   2       3 |  FOR MMM:= 1 TO N(.M2.)  DO
 1 1   2         |  BEGIN
 2 1   2       4 |    DIFF:= (P(.M2,MMM.)-CONC(.M2,MMM.));
 2 1   2       5 |    SOMM:= SOMM + ABS(DIFF*DIFF)        ;
 1 1   2         |  END
   1   1         |END
                 |END;
                 |{-----------------------------------------------------------------}
                 |
                 |{-----------------------------------------------------------------}
                 |BEGIN
               1 |READLN(NUM,NN);
       1       2 |FOR TT := 1 TO NUM DO
       1         |BEGIN
 1     1       3 |  READLN(N(.TT.),AINF(.TT.),NH(.TT.));
 1     2       4 |  FOR I := 1 TO N(.TT.) DO
 1     2         |  BEGIN
 2     2       5 |    READLN(T(.TT,I.),P(.TT,I.));
 1     1         |  END;
 1     2       6 |  FOR I:= 1 TO NH(.TT.) DO
 1     2         |    BEGIN
 2     2       7 |    READLN(TH(.TT,I.),EH(.TT,I.));
 1     2         |END
                 |END;
       1       8 |FOR I := 1 TO 3 DO
               9 |   READLN(K1(.I.),K2(.I.));
              10 |ALPHA := 2.00;
              11 |BETA := 0.50;
              12 |EX;
              13 |POTEN;
       1      14 |FOR I := 1 TO 3 DO   |DETERMINES THE SUM OF SQUARED DIFFERENCES AT|
       1         |BEGIN                |THE INITIAL 3 COORD. OF THE SIMPLEX         |
 1     1      15 |  KK1 := K1(.I.);
 1     1      16 |  KK2 := K2(.I.);
```

```
VS PASCAL RELEASE 1.0          MODRUN11:<MAIN>                                    12/09/88 13:57:04
 B P C I  SIMT //                                  S O U R C E   P R O G R A M
                  V---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----V
 1     1      17 |  EIS;
 1     1      18 |  INTEG;
 1     1      19 |  KONS;
 1     1      20 |  SUM;
 1     1      21 |  SOM(.I.) := SOMM;
                 |END;
              22 |Z:= 1 ;
       1      23 |WHILE Z < NN DO
       1         |BEGIN
 1     2      24 |FOR I := 1 TO 2 DO                  |ARRANGE SUM OF SQUARED DIFFERENCES |
 1     2         |BEGIN                               |IN DESCENDING ORDER                |
 2     3      25 | FOR J := I+ 1 TO 3 DO
 2     3         | BEGIN
 3   1 3      26 |   IF SOM(.I.) < SOM(.J.) THEN
 3   1 3         |   BEGIN
 4   1 3      27 |   TOP:= SOM(.I.);
 4   1 3      28 |   TOPK1 := K1(.I.);
 4   1 3      29 |   TOPK2 := K2(.I.);
 4   1 3      30 |   SOM(.I.) := SOM(.J.);
 4   1 3      31 |   K1(.I.) := K1(.J.);
 4   1 3      32 |   K2(.I.) := K2(.J.);
 4   1 3      33 |   SOM(.J.) := TOP;
 4   1 3      34 |   K1(.J.) := TOPK1;
 4   1 3      35 |   K2(.J.) := TOPK2;
 3   1 3         |   END
 2     3         | END
 1     1         |END;
 1     1      36 |CENTK1 := (K1(.2.) + K1(.3.))/2;
 1     1      37 |CENTK2 := (K2(.2.) + K2(.3.))/2;
 1     1      38 |DIST1 := K1(.2.) - K1(.3.);                  |CHECK FOR CONVERGENCE |
 1     1      39 |DIST2 := K2(.2.) - K2(.3.);
 1     1      40 |DIST := SQRT(DIST1*DIST1 + DIST2*DIST2);
 1     1      41 |IF DIST < 0.000000001 THEN Z:= 100000;
 1     1      43 |K1REF := CENTK1 + (CENTK1 - K1(.1.));       |CALCULATE REFLECTED POINT|
 1     1      44 |K2REF := CENTK2 + (CENTK2 - K2(.1.));
 1     1      45 |KK1 := K1REF;
 1     1      46 |KK2 := K2REF;
 1     1      47 |EIS;
 1     1      48 |INTEG;
 1     1      49 |KONS;
 1     1      50 |SUM;
 1     1      51 |SOMREF := SOMM;
 1   1 1      52 |IF SOMREF < SOM(.3.) THEN
 1   1 1         |BEGIN
 2   1 1      53 |  K1EXP := CENTK1 + ALPHA*(CENTK1 - K1(.1.)); |CALCULATE EXPANDED POINT|
 2   1 1      54 |  K2EXP := CENTK2 + ALPHA*(CENTK2 - K2(.1.));
 2   1 1      55 |  KK1 := K1EXP;
 2   1 1      56 |  KK2 := K2EXP;
 2   1 1      57 |  EIS;
 2   1 1      58 |  INTEG;
 2   1 1      59 |  KONS;
 2   1 1      60 |  SUM ;
 2   1 1      61 |  SOMEXP := SOMM;
```

```
VS PASCAL RELEASE 1.0        MODRUN11:<MAIN>                                    12/09/88 13:57:04
 B P C I  STMT #                                  S O U R C E   P R O G R A M
                  V---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----V
 2   2 1      62 |  IF SOMEXP < SOMREF THEN
 2   2 1         |  BEGIN
 3   2 1      63 |    K1(.1.) := K1EXP;
 3   2 1      64 |    K2(.1.) := K2EXP;
 3   2 1      65 |    SOM(.1.) := SOMEXP;
 2   2 1         |  END
 2   2 1         |  ELSE
 2   2 1         |  BEGIN
 3   2 1      66 |    K1(.1.) := K1REF;
 3   2 1      67 |    K2(.1.) := K2REF;
 3   2 1      68 |    SOM(.1.) := SOMREF;
 2   2 1         |  END
 1   1 1         |END
 1   1 1         |ELSE
 1   1 1         |BEGIN
 2   2 1      69 |  IF SOMREF > SOM(.1.) THEN
 2   2 1         |  BEGIN
 3   2 1      70 |    K1REF := K1(.1.) ;
 3   2 1      71 |    K2REF := K2(.1.) ;
 2   1 1         |  END;
 2   1 1      72 |  K1CONT := CENTK1 - BETA*(CENTK1 - K1REF); {CALCULATE CONTRACTED POINT}
 2   1 1      73 |  K2CONT := CENTK2 - BETA*(CENTK2 - K2REF);
 2   1 1      74 |  KK1 := K1CONT ;
 2   1 1      75 |  KK2 := K2CONT ;
 2   1 1      76 |  EIS;
 2   1 1      77 |  INTEG;
 2   1 1      78 |  KONS;
 2   1 1      79 |  SUM;
 2   1 1      80 |  SOMCONT := SOMM;
 2   2 1      81 |  IF SOMCONT < SOM(.1.) THEN
 2   2 1         |  BEGIN
 3   2 1      82 |    SOM(.1.) := SOMCONT;
 3   2 1      83 |    K1(.1.) := K1CONT;
 3   2 1      84 |    K2(.1.) := K2CONT;
 2   2 1         |  END
 2   2 1         |  ELSE
 2   2 1         |  BEGIN
 3   2 1      85 |    K1(.2.) := CENTK1;
 3   2 1      86 |    K2(.2.) := CENTK2;
 3   2 1      87 |    KK1 := K1(.2.);
 3   2 1      88 |    KK2 := K2(.2.);
 3   2 1      89 |    EIS;
 3   2 1      90 |    INTEG;
 3   2 1      91 |    KONS;
 3   2 1      92 |    SUM;
 3   2 1      93 |    SOM(.2.) := SOMM;
 3   2 1      94 |    K1(.1.) := (K1(.1.) + K1(.3.))/2;
 3   2 1      95 |    K2(.1.) := (K2(.1.) + K2(.3.))/2;
 3   2 1      96 |    KK1 := K1(.1.);
 3   2 1      97 |    KK2 := K2(.1.);
 3   2 1      98 |    EIS;
 3   2 1      99 |    INTEG;
 3   2 1     100 |    KONS;
```

B P C I SIMT # S O U R C E P R O G R A M

```
                 V---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----V
3   2 1     101 |     SUM;
3   2 1     102 |     SOM(.1.) := SOMM;
2   2 1         |   END
1     1         |END;
1     1     103 |Z := Z+ 1;
                |END;
                |WRITELN(OUTERM,Z);
                |WRITELN('-------------------------------------');
                |WRITELN('    ' );
                |WRITELN('K1 =  ',K1(.3.):12,' K2 =  ',K2(.3.):10:7);
        1   108 |FOR II := 1 TO NUM DO
        1       |BEGIN
1       2   109 |  FOR J :=1 TO N(.II.) DO
1       1   110 |    WRITELN(I(.II,J.):10:2,P(.II,J.):10:4,CONC(.II,J.):10:4);
                |END;
                |WRITELN('R*R =  ',SOM(.3.):7:3);
                |END.
```

NO COMPILER DETECTED ERRORS

PARAMETERS PASSED: MAR (1 80) DEBUG NOX NOOPT NOPXREF LANGLVL (STANDARD)

OPTIONS IN EFFECT: MARGINS(1,80), NOSEQUENCE, NOXREF, LANGLVL(EXTENDED), DDNAME(COMPAT), FLAG(I), STDFLAG(E), LI
PAGEWIDTH(120), CHECK, DEBUG, GOSIMT, SOURCE

SOURCE LINES: 335; COMPILE TIME: 0.28 SECONDS, COMPILE RATE: 71786 LPM

Appendix C

The model predicted leaching kinetics

The predicted leaching kinetics for experiments 1, 2 and 3 (See figure 6.3)

An average redox potential measurement, determined from the three experiments, was used. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 1.242*10^{-4}$ $k_2 = -0.0409334$

Time (min)	$[Au]_1$(ppm) experimental	$[Au]_1$(ppm) predicted
2	0.873	0.6367
3	1.368	0.8777
5	1.625	1.2641
13	2.213	2.2227
13	2.217	2.2227
17	2.400	2.5593
20	2.783	2.7816
23	2.783	2.9741
30	3.000	3.3155
30	3.302	3.3155
45	3.525	3.7040
45	3.797	3.7040
45	3.774	3.7040
60	3.800	4.0304
60	4.104	4.0304
60	3.962	4.0304
90	4.025	4.3064
90	4.599	4.3064
90	4.339	4.3064
120	4.300	4.4924
120	4.811	4.4924
120	4.627	4.4924
180	4.500	4.7582
180	5.187	4.7582
180	4.906	4.7582
240	5.189	4.8991
300	4.850	4.9646
360	4.850	4.9849

The sum of squared differences = 1.407

The predicted leaching kinetics for experiment 4 (See figure 6.6)

The constants were optimized for experiment 4 individually. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 7.013*10^{-4}$ $k_2 = -0.0473214$

Time (min)	$[Au]_1$(ppm) experimental	$[Au]_1$(ppm) predicted
0	0.000	0.0000
2	2.063	1.8351
7	3.228	3.4796
13	3.762	3.7589
20	4.053	4.1727
30	4.369	4.5434
45	4.515	4.7988
60	4.903	4.9808
90	4.903	5.1493
120	4.976	5.2150
200	5.000	5.2401
250	5.243	5.2427
300	5.243	5.2430

The sum of squared differences = 0.855

The predicted leaching kinetics for experiment 5 (See figure C3)

The constants were optimized for experiment 5 individually. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 2.599*10^{-4}$ $k_2 = -0.0686404$

Time (min)	$[Au]_1$(ppm) experimental	$[Au]_1$(ppm) predicted
0	0.000	0.0000
2	5.944	6.1680
10	12.908	12.8019
15	14.617	13.9556
25	15.306	15.4897
30	15.306	15.7619
47	15.510	16.3238
60	15.561	16.4133
90	15.944	16.4895
120	16.020	16.4989
180	16.122	16.5000
240	16.122	16.5000

The sum of squared differences = 2.942

The predicted leaching kinetics for experiment 6 (See figure C4)

The constants were optimized for experiment 6 individually. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 1.778*10^{-3}$ $k_2 = -0.0408394$

Time (min)	$[Au]_1$(ppm) experimental	$[Au]_1$(ppm) predicted
0	0.300	0.3000
1	3.125	3.3479
8	11.750	11.5014
18	14.275	14.3730
39	15.175	15.5472
45	15.175	15.6138
60	15.175	15.6702
90	15.300	15.6795
120	14.675	15.6800
180	14.500	15.6800
240	15.675	15.6800
300	15.675	15.6800
360	15.675	15.6800

The sum of squared differences = 3.244

The predicted leaching kinetics for experiment 4, 5 and 6

The constants were optimized for experiment 4, 5 and 6 simultaneously; in other words, the constants were forced to be the same for the three experiments. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 5.864*10^{-2}$ $k_2 = -0.0098954$

The sum of squared differences = 14.060

(continues on the next page)

Time (min)	$[Au]_1$(ppm) experimental	$[Au]_1$(ppm) predicted
Experiment no 4		
0	0.000	0.0000
2	2.063	1.6756
7	3.228	4.2410
13	3.762	4.6011
20	4.053	5.0076
30	4.369	5.1856
45	4.515	5.2351
60	4.903	5.2419
90	4.903	5.2430
120	4.976	5.2430
200	5.000	5.2430
250	5.243	5.2430
300	5.243	5.2430
Experiment no 5		
0	0.000	0.0000
2	5.944	4.4058
10	12.908	12.6638
15	14.617	14.5423
25	15.306	16.0027
30	15.306	16.2403
47	15.510	16.4737
60	15.561	16.4951
90	15.944	16.4999
120	16.020	16.5000
180	16.122	16.5000
240	16.122	16.5000
Experiment no 6		
0	0.300	0.3000
1	3.125	2.9423
8	11.750	11.8811
18	14.275	14.9245
39	15.175	15.6532
45	15.175	15.6698
60	15.175	15.6791
90	15.300	15.6800
120	14.675	15.6800
180	14.500	15.6800
240	15 675	15.6800
300	15.675	15.6800
360	15.675	15.6800

The predicted leaching kinetics for experiment 8 (See figure 6.5)

The constants were optimized for experiment 8 individually. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 4.612*10^{-2}$ $k_2 = +0.0023231$

Time (min)	$[Au]_s$(ppm) experimental	$[Au]_s$(ppm) predicted
0	11.1	11.1000
3	10.39	10.1281
8	8.78	8.6796
13	7.30	7.4283
20	5.98	5.9714
30	4.31	4.3795
45	2.72	2.7714
60	1.84	1.7939
120	0.70	0.4874
180	0.59	0.3158
240	0.69	0.2933
300	0.44	0.2904

The sum of squared differences = 0.336

The predicted leaching kinetics for experiment 9 (See figure C1)

The constants were optimized for experiment 9 individually. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 8.659*10^{-2}$ $k_2 = +0.0088893$

Time (min)	$[Au]_s$(ppm) experimental	$[Au]_s$(ppm) predicted
0	10.8	10.8000
3	10.1	10.1100
10	8.84	8.5624
20	6.54	6.6381
30	5.03	5.1225
45	3.33	3.4773
70	1.91	1.9167
90	1.48	1.2657
120	0.98	0.7943
180	0.69	0.5264
240	0.57	0.4866
300	0.49	0.4810

The sum of squared differences = 0.231

The predicted leaching kinetics for experiment 12 (See figure C2)

The constants were optimized for experiment 12 individually. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 5.880*10^{-6}$ $k_2 = -0.0709691$

Time (min)	$[Au]_s$(ppm) experimental	$[Au]_s$(ppm) predicted
0	11.4	11.4000
5	7.97	8.5813
20	4.78	4.2181
40	2.27	2.4899
60	1.53	1.6150
90	0.92	0.9289
120	0.70	0.5587
170	0.55	0.3717
240	0.44	0.3026
300	0.44	0.2919
360	0.45	0.2904

The sum of squared differences = 0.231

The predicted leaching kinetics for experiments 8,9 and 12(See figure 6.5)

The constants were optimized for experiment 8, 9 and 12 simultaneously, in other words the constants were forced to be the same in all three experiments. The optimum constants where the sum of squared differences was a minimum were:

$k_1 = 6.027*10^{-2}$ $k_2 = +0.0043686$

The sum of squared differences = 8.485

(continues on the next page)

Time (min)	$[Au]_s$(ppm) experimental	$[Au]_s$(ppm) predicted
Experiment no 8		
0	11.1	11.1000
3	10.39	10.1917
8	8.78	8.8104
13	7.30	7.5925
20	5.98	6.1514
30	4.31	4.5511
45	2.72	2.9000
60	1.84	1.8852
120	0.70	0.5016
180	0.59	0.3178
240	0.69	0.2935
300	0.44	0.2904
Experiment no 9		
0	10.8	10.8000
3	10.1	9.8750
10	8.84	7.9471
20	6.54	5.7890
30	5.03	4.2302
45	3.33	2.6882
70	1.91	1.3901
90	1.48	0.9238
120	0.98	0.6301
180	0.69	0.4964
240	0.57	0.4818
300	0.49	0.4802
Experiment no 12		
0	11.4	11.4000
5	7.97	9.6535
20	4.78	5.8631
40	2.27	3.0202
60	1.53	1.6178
90	0.92	0.7368
120	0.70	0.4425
170	0.55	0.3151
240	0.44	0.2921
300	0.44	0.2902
360	0.45	0.2900

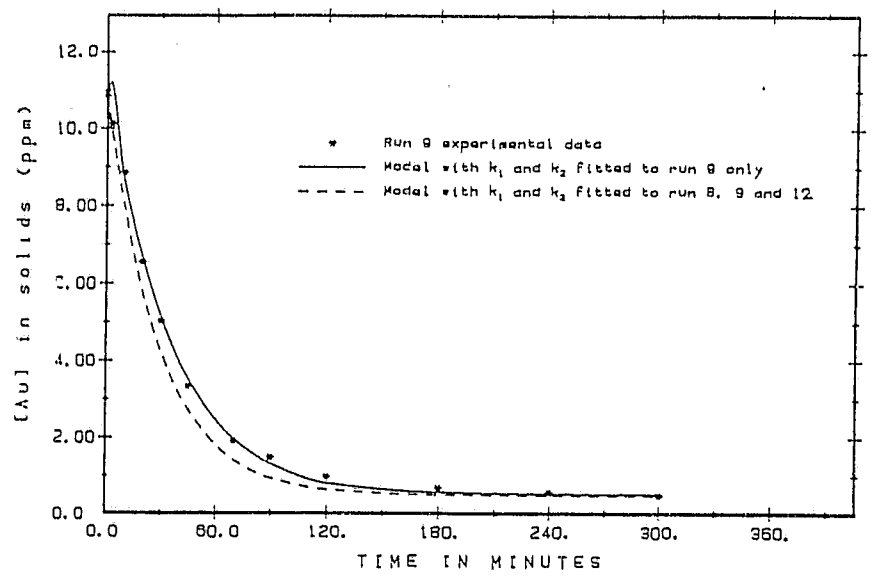

Figure C1: Model prediction of leaching kinetics vs. the experimental results of experiment no. 9.
Fitted to run 9 only: $k_1 = 8.659*10^{-2}$ and $k_2 = +0.0088893$
Fitted to 8,9 and 12 simult.: $k_1 = 6.027*10^{-2}$ and $k_2 = +0.0043686$

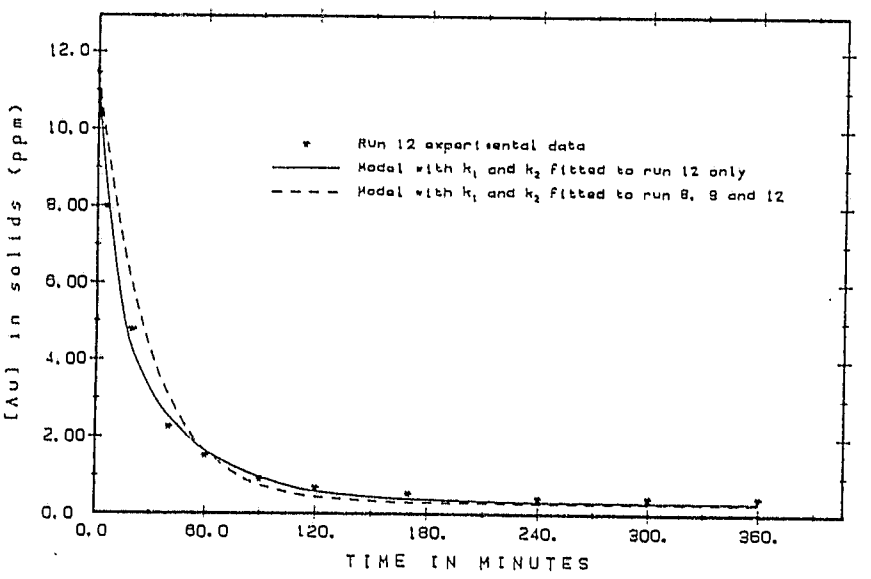

Figure C2: Model prediction of leaching kinetics vs. the experimental results of experiment no. 12.
Fitted to run 12 only: $k_1 = 5.880*10^{-6}$ and $k_2 = -0.0709691$
Fitted to 8,9 and 12 simult.: $k_1 = 6.027*10^{-2}$ and $k_2 = +0.0043686$

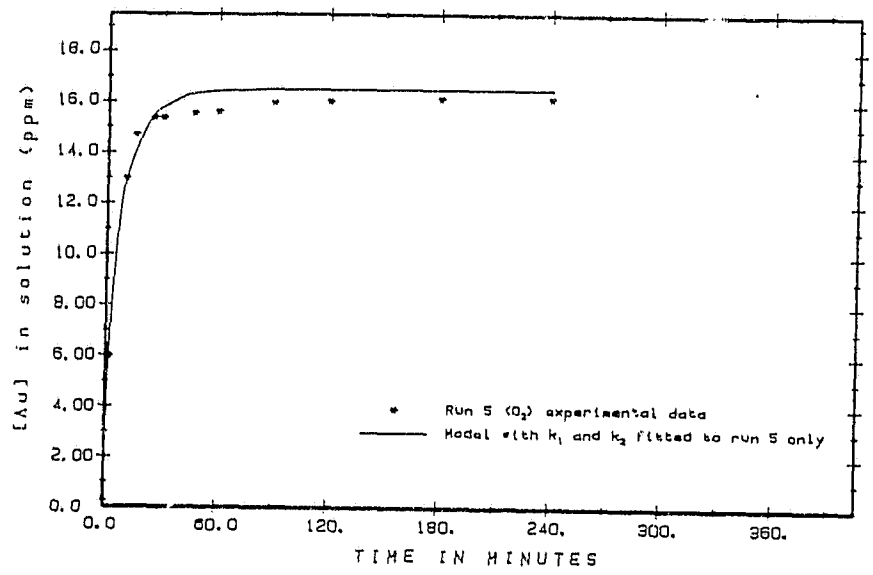

*Figure C3: Model prediction of leaching kinetics vs. the experimental results of experiment no. 5 (k_1 = 2.599*10^{-4} and k_2 = -0.068640).*

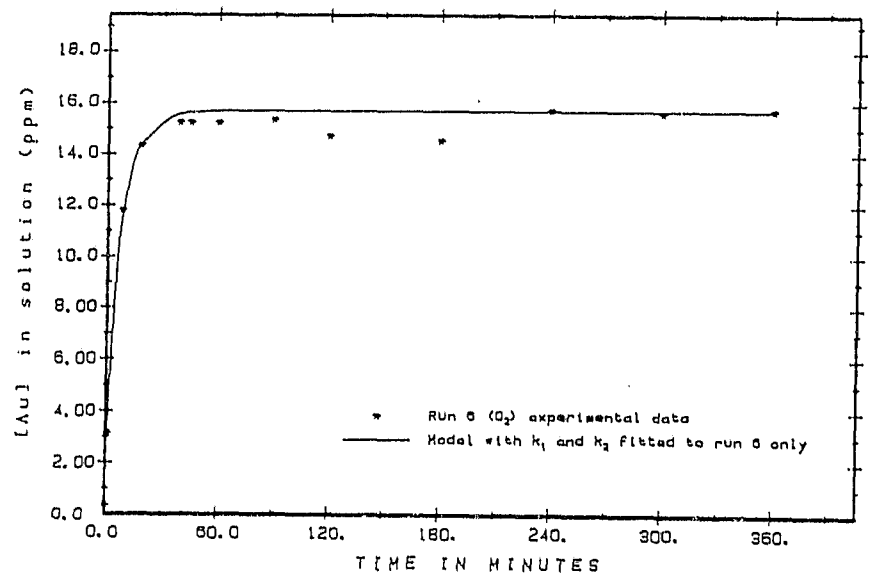

*Figure C4: Model prediction of leaching kinetics vs. the experimental results of experiment no. 6 (k_1 = 1.778*10^{-3} and k_2 = -0.040839).*

Author Conradie P J
Name of thesis An Electrochemical model for the leaching Kinetics of gold ore in Cyanide solutions 1988

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