

A computer oriented algorithm to determine the raw-mixture composition for sintering

* S. C. Maulik and ** N. Chakravorty

INTRODUCTION :

Sintering is an agglomeration process of fine particles and widely used as a standard method for preparation of blast furnace-feed. In iron-ore sintering, iron ore fines viz. iron ore crushed to -10 mm size, classifier fines, cyclone underflow, blue-dust etc. together with other iron-bearing waste materials viz. mill-scale, flue dust etc. are mixed with fluxing materials like limestone, dolomite etc. and sintered in a continuously operated sinter strand or a bench-scale sinter pot. The sintering of fine particles results from incipient fusion of materials due to heat liberated by combustion of coke-breeze incorporated in the raw mixture and also exothermic heat liberated through complex chemical reactions taking place during the process of sintering. Water added during mixing helps to maintain a proper permeability and return fines act as a supporting structure for the mixture.

Object :

Ingredients of sintering mixture are mixed in a definite pre-calculated proportion so as to meet certain chemical composition of finished sinter and certain other fixed technical conditions. Calculation of raw mixture composition is tedious and for arriving at a optimum testing condition a large number of experiments are usually carried out and this calculation has to be repeated for each experiment as the composition of each mixture is different from other. Thereby for optimizing the tests, time consuming, voluminous and repetitive calculations are to be performed. To avoid this once the mathematical formulae are developed and its programming is done with the help of any high-level computer

language, just by changing the input values, we can obtain the outputs i. e. composition of raw mixture for different experiments easily and quickly.

The conditions

- (1) $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + Y_1 + Y_2 + Y_3 = 100.00$
- (2) Basicity = H, in finished sinter
 $(CaO\% + MgO\%) / (SiO_2\% + Al_2O_3\%) = H$
- (3) $MgO\%$ in sinter = P
- (4) Lime/t sinter = Q
- (5) $Mn\%$ in sinter = RR
- (6) Mill scale/t. sinter = S
- (7) Flue dust/t. sinter = T

For each experiment, values of P, Q, RR, S, T are known.

Now we can develop 7 equations from 7 conditions.

From condition (1)

$$\sum_{i=1}^7 x_i = 100 - \sum_{i=1}^3 Y_i \quad \text{EQN (1)}$$

Now Quantities of

$$CaO \text{ is } 1/100 \left[\left(\sum_{i=1}^7 x_{ie} \right) + Y_{1e} \right]$$

$$MgO \text{ is } 1/100 \left[\left(\sum_{i=1}^7 x_{if} \right) + Y_{1f} \right]$$

$$SiO_2 \text{ is } 1/100 \left[\left(\sum_{i=1}^7 x_{ic} \right) + Y_{1c} \right]$$

* Scientist, Ore-Dressing Division, National Metallurgical Laboratory, Jamshedpur-7.

** Head, Ore-Dressing Division, National Metallurgical Laboratory Jamshedpur-7.

and Al_2O_3 is $1/100$ $[(\sum_{i=1}^7 xidi) + Y1d8]$

Condition (2) i.e. Basicity = H leads to

$$\sum_{i=1}^7 xi (ei + fi - Hci - Hdi) = Y1 (Hc8 + Hd8 - e8 - f8) \quad \dots \text{EQN (2)}$$

Now sintered weight

$$Z = (\sum_{i=1}^7 xiqi) + Y1a8$$

From condition (3) i.e. $MgO\% = P$

$$\frac{[(\sum_{i=1}^7 xifi) + Y1f8]}{Z} = P$$

leads to

$$\sum_{i=1}^7 xi (fi - aiP) = Y1 (a8P - f8) \quad \dots \text{EQN (3)}$$

Condition (4), i.e. Lime/t sinter = Q

$$\frac{X4}{Z} \times 1000 = Q \text{ leads to}$$

$$\frac{(\sum_{i=1}^3 xiai) + X4 (a4 - \frac{1000}{Q})}{Z} = -Y1a8 \quad \dots \text{EQN (4)}$$

Where A is the following matrix :

1	1	1	1	1	1	1
W1	W2	W3	W4	W5	W6	W7
f1-a1P	f2-a2P	f3-a3P	f4-a4P	f5-a5P	f6-a6P	f7-a7P
a1	a2	a3	$a4 - \frac{1000}{Q}$	a5	a6	a7
gi-a1RR	g2-a2RR	g3-a3RR	g4-a4RR	g5-a5RR	g6-a6RR	g7-a7RR
a1	a2	a3	a4	a5	$a6 - 1000/S$	a7
a1	a2	a3	a4	a5	a6	$a7 - 1000/T$

Where $W_1 = (e_1 + f_1 - Hc1 - Hd1)$; $W_2 = (e_2 + f_2 - Hc2 - Hd2)$... $W_7 = (e_7 + f_7 - Hc7 - Hd7)$

Condition (5) $Mn\%$ in sinter = RR

$$\frac{[(\sum_{i=1}^7 xigi) + Y1g8]}{Z} = RR \text{ leads to}$$

$$\sum_{i=1}^7 xi (gi - aiRR) = Y1 (RRa8 - g8) \quad \dots \text{EQN (5)}$$

Condition (6) M Scale/t. Sinter = S

$$\frac{X6 (1000)}{Z} = S \text{ leads to}$$

$$\frac{(\sum_{i=1}^5 xiai) + x6 (a6 - \frac{1000}{S}) + X7a7}{Z} = -Y1a8 \quad \dots \text{EQN (6)}$$

Condition (7) F. Dust/t. Sinter = T

$$\frac{X7 (1000)}{Z} = T \text{ leads to}$$

$$\frac{(\sum_{i=1}^6 xiai) + X7 (a7 - \frac{1000}{T})}{Z} = -Y1a8 \quad \dots \text{EQN (7)}$$

The above seven equations can be represented by matrix notation as $AX = V$

and X is the following Matrix :

$$X = \begin{pmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \\ X6 \\ X7 \end{pmatrix}$$

$$\text{and } V = \begin{pmatrix} 100-Y1-Y2-Y3 \\ Y1 (Hc8 + Hd8 - e8 - f8) \\ Y1 (a8P - f8) \\ -Y1 a8 \\ Y1 (a8RR - g8) \\ -Y1 a8 \\ -Y1 a8 \end{pmatrix}$$

$$\text{Now } A \times = V$$

$$\text{or } A^{-1} A \times = A^{-1} V$$

$$\text{or } X = A^{-1} V$$

Hence inversion of the matrix A followed by multiplication by column matrix V leads to the solution of x i. e. x1...x7

So essentially the problem can be divided into the following parts :

- (i) Formation of Matrix A from the analysis values
- (ii) Formation of column matrix V from analysis values
- (iii) Inversion of matrix A

- (iv) Multiplication of Inverted Matrix A^{-1} by matrix V

Computer programming

On the basis of above algorithm, computer programme was written in FORTRAN IV. The programme was compiled in UNIVAC-V-77 mini computer in Indian Statistical Institute, Calcutta and the error free programme has been effectively utilised in the current research programme of the laboratory.

The flow diagram of the programme is given in Appendix 1.

The programme written in FORTRAN IV is given in Appendix 2.

Summary and conclusions :

The voluminous and time consuming calculations for determining the raw mixture compositions for iron-ore sintering experiments particularly when they are to be carried out in large numbers to select the most optimum condition can be avoided with the help of development of formulae and subsequent computer programming and running the compiled programme with the data. The general programme written in the above way would be of very much use to research workers dealing with sintering experiments with different types of iron ores.

Acknowledgements

Our sincere thanks are due to Prof. V. A. Altekar, Director, National Metallurgical Laboratory for his kind permission to present this paper in National Seminar on Mineral Processing and Ninth Annual Technical Convention of I. I. M. E. held in National Metallurgical Laboratory, Jamshedpur.

Development of mathematical formulae

Table 1 lists the inputs and variables. The conditions are written next.

TABLE—1 Inputs and variables.

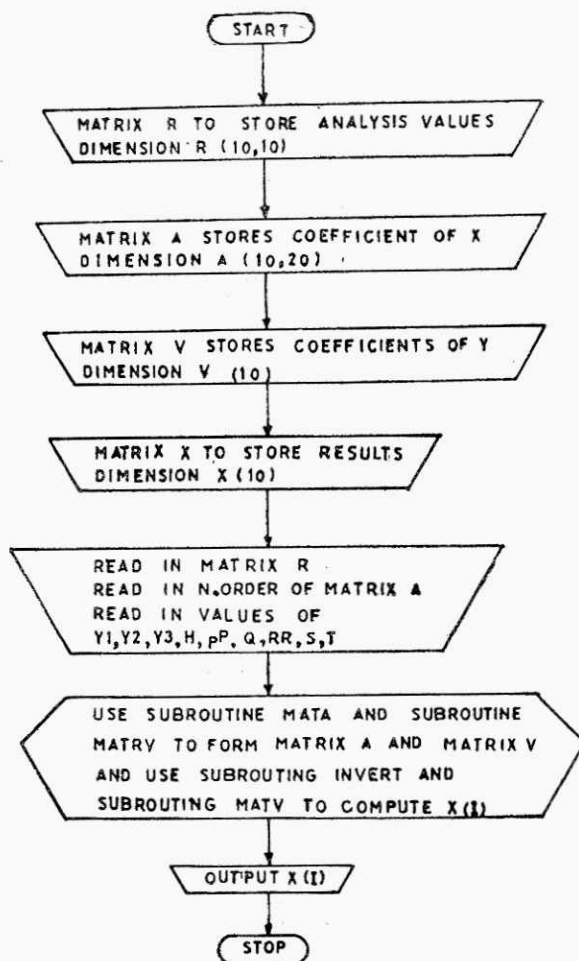
Ingredients	WT%	CF	ANALYSIS					
			Fe%	SiO ₂ %	Al ₂ O ₃ %	CaO%	MgO%	Mn%
Iron ore	X1	a1	b1	c1	d1	e1	f1	g1
Lime stone	X2	a2	b2	c2	d2	e2	f2	g2
Dolomite	X3	a3	b3	c3	d3	e3	f3	g3
Lime	X4	a4	b4	c4	d4	e4	f4	g4
Mn ore	X5	a5	b5	c5	d5	e5	f5	g5
Mill scale	X6	a6	b6	c6	d6	e6	f6	g6
Flue dust	X7	a7	b7	c7	d7	e7	f7	g7
Coke breeze	Y1	a8	b8	c8	d8	e8	f8	g8
Moisture	Y2	—	—	—	—	—	—	—
Return fines	Y3	—	—	—	—	—	—	—

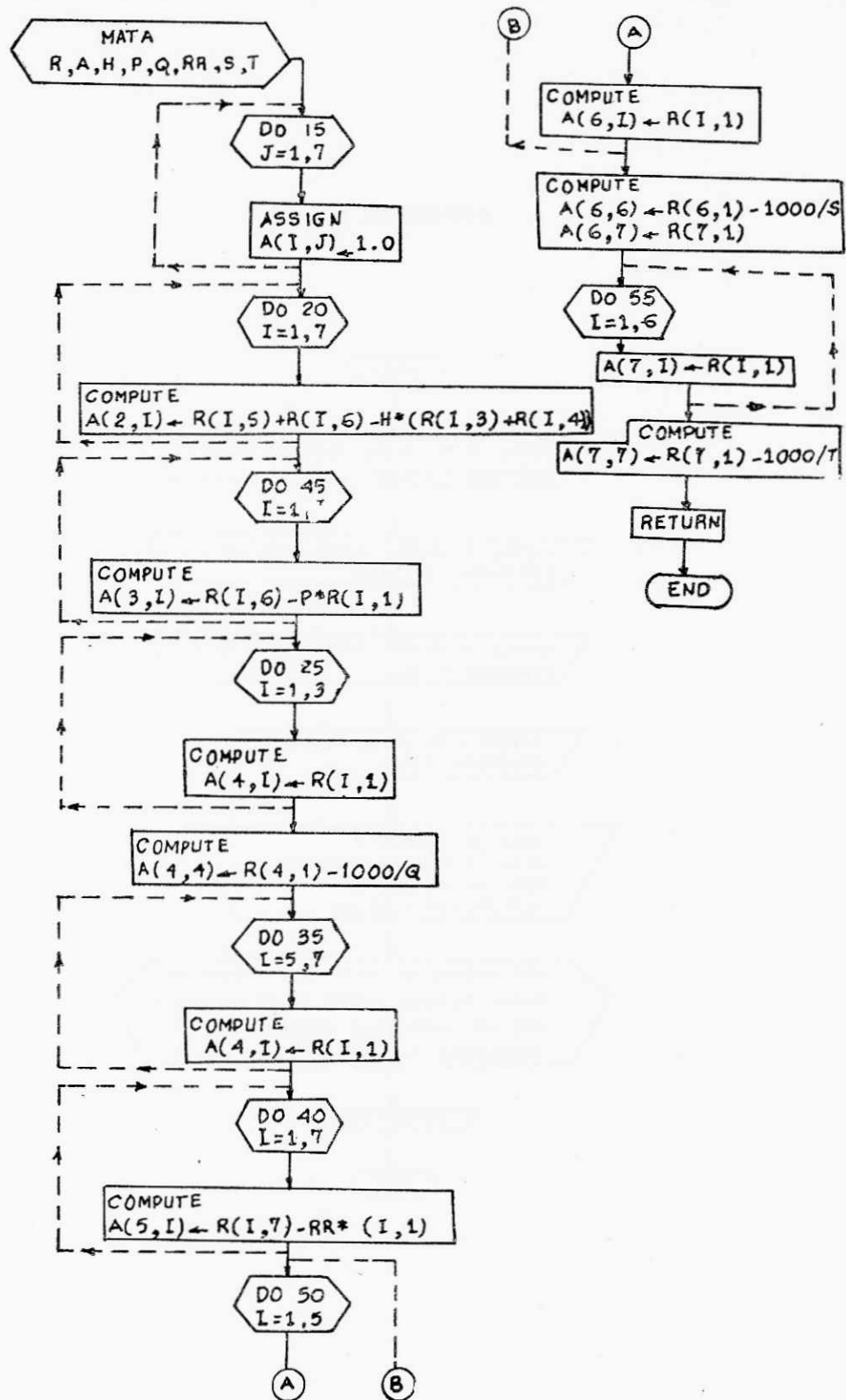
NOTE : (1) Inputs are all the a, b, c, d, e, f and g values

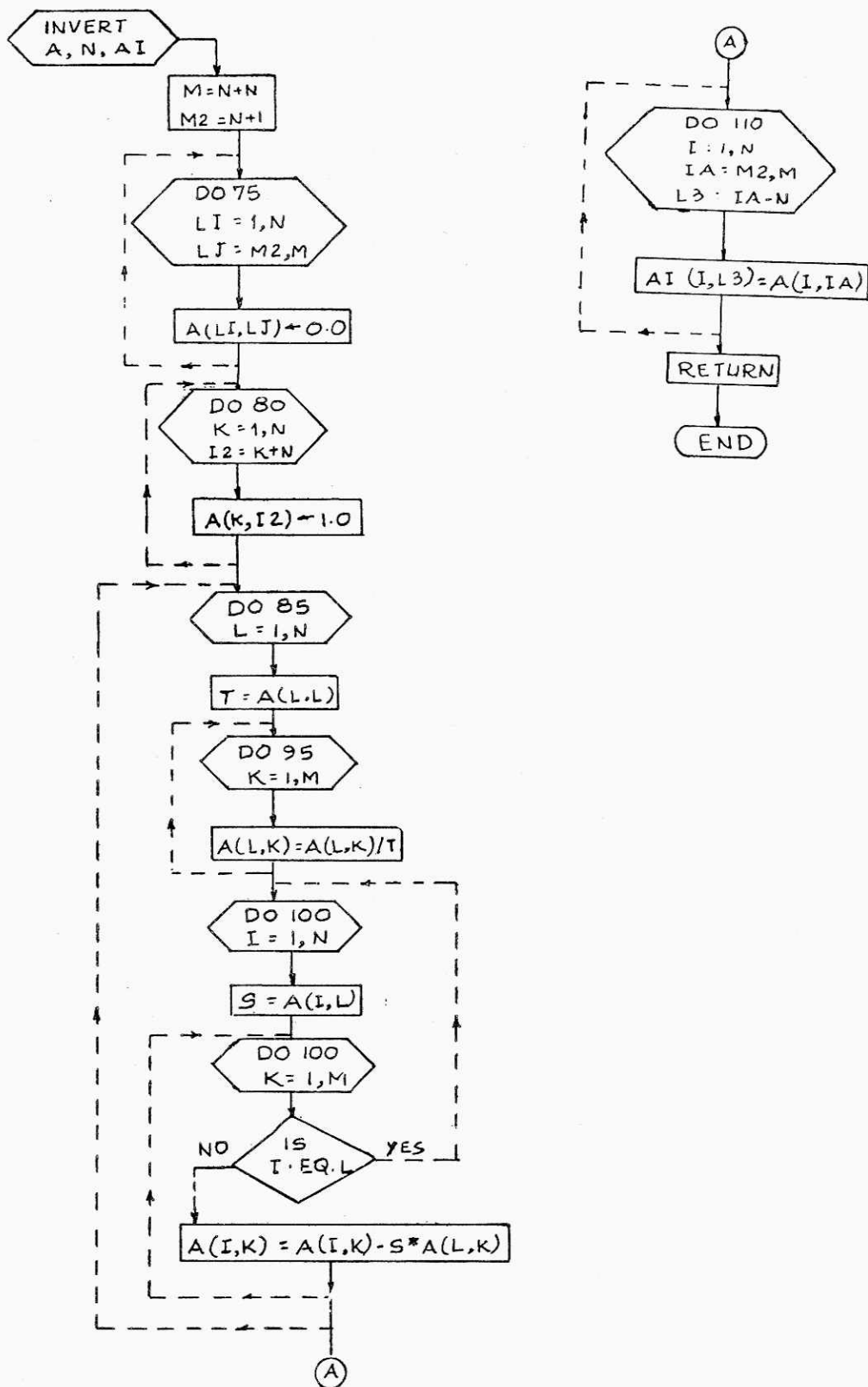
(2) Variables are X and Y values of which Y values are known for each experiment.

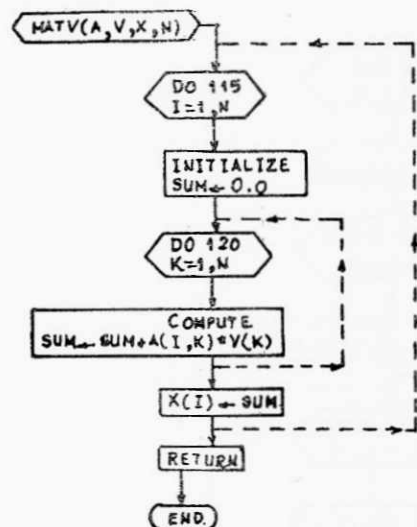
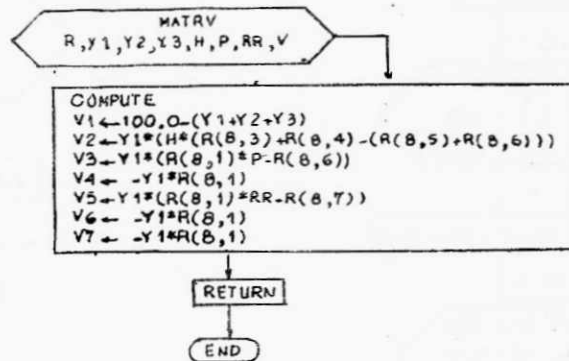
(3) CF = Calcination factor.

APPENDIX — I









APPENDIX - II

```

C PROGRAMMER S.C.MAULIK,SCT,N.M.L.,JAMSHEDPUR
C CALCULATION OF RAW MIXTURE COMPOSITION FOR SINTERING
C INGR WT% CALCF FE% SIO2% AL2O3% CAO% MGO% MN%
C I/ORE X1 R(1,1) R(1,2) R(1,3) R(1,4) R(1,5) R(1,6) R(1,7)
C L/ST. X2 R(2,1) R(2,2) R(2,3) R(2,4) R(2,5) R(2,6) R(2,7)
C DOLO. X3 R(3,1) R(3,2) R(3,3) R(3,4) R(3,5) R(3,6) R(3,7)
C LIME X4 R(4,1) R(4,2) R(4,3) R(4,4) R(4,5) R(4,6) R(4,7)
C MN.ORE X5 R(5,1) R(5,2) R(5,3) R(5,4) R(5,5) R(5,6) R(5,7)
C M/SCL. X6 R(6,1) R(6,2) R(6,3) R(6,4) R(6,5) R(6,6) R(6,7)
C F/DST. X7 R(7,1) R(7,2) R(7,3) R(7,4) R(7,5) R(7,6) R(7,7)
C C/BRZ. Y1 R(8,1) R(8,2) R(8,3) R(8,4) R(8,5) R(8,6) R(8,7)
C Y2=MOIST%;Y3=R/FINES%;H=BASICITY(CAO+MGO/(SIO2+AL2O3))
C P=MGO%;Q=LIME(KG/T),RR=MN%,S=M/SCALE(KG/T),T=F/DUST(KG/T) IN
C SINTER.R=ANALYSIS MATRIX,A AND V MATRICES ARE FORMED THRO'
C CO-EFFICIENTS OF X AND Y RESPECTIVELY.N=NO.OF X VARIABLES,
C AI= INVERSE OF MATRIX A,NO=NO. OF EXPERIMENTS.
C DIMENSION R(10,10),A(10,20),AI(10,10),X(10),V(10)
C READ (1,5)N,NO,P,Q,RR,S,T
5 FORMAT(2I2,5F5.2)
C READ(1,10)((R(I,J),I=1,8),J=1,7)
10 FORMAT(8F7.3)
C WRITE(2,6)
6 FORMAT(5X,'ANALYSIS OF RAW MATERIALS ARE GIVEN BELOW')
C WRITE(2,7)
7 FORMAT(5X,' INGR',3X,' CALCF',3X,' FE%',3X,' SIO2%',3X,' AL2O3%',2X,' CA
10%',3X,' MGO%',3X,' MN%')
C WRITE(2,8)((R(I,J),J=1,7),I=1,8)
8 FORMAT(5X,' I/ORE',2X,7(F5.2,2X)/5X,' L/ST.',2X,7(F5.2,2X)/5X,' DOLO'
1,3X,7(F5.2,2X)/5X,' LIME'3X,7(F5.2,2X)/5X,' MN.ORE',1X,7(F5.2,2X)/5X
2,' M.SCL',2X,7(F5.2,2X)/5X,' F/DUST',1X,7(F5.2,2X)/5X,' C/BRZ',2X,7(F
35.2,2X))
C WRITE(2,222)N,P,Q,RR,S,T
222 FORMAT(/5X,' N=',I2/5X,' TECHNICAL CONDITIONS'/5X,' MGO%=',F5.2,2X,'
1LM KG/T',F5.2,2X,' MN%=',F5.2,2X,' M.SCALE KG/T',F5.2,2X,' F.DUST KG/
2T=',F5.2)
C DO 9 KK=1,NO
C READ (1,13,END=200)Y1,Y2,Y3,H
13 FORMAT(4F5.2)
C CALL MATA(R,A,H,P,Q,RR,S,T)
C CALL MATRV(R,Y1,Y2,Y3,H,P,RR,V)
C CALL INVERT(A,N,AI)
C CALL MATV(AI,V,X,N)
C WRITE(2,57)Y1,Y2,Y3,H
57 FORMAT(/5X,' RAW MIXTURE COMPOSITION FOR C/BRZ%=',F5.2,2X,' MST%',F
15.2,2X,' R/FINES%=',F5.2,2X,' BASICITY=',F5.2)
C WRITE(2,66)
66 FORMAT(5X,' INGREDIENTS',10X,' WEIGH PERCENT')
C WRITE (2,70)(X(I),I=1,N),Y1,Y2,Y3
70 FORMAT(5X,' IRON ORE',17X,F6.3/5X,' LIME STONE',14X,F6.3/5X,' DOLOMIT
1E',16X,F6.3/5X,' LIME',20X,F6.3/5X,' MN ORE',18X,F6.3/5X,' MILL SCAL
2E',14X,F6.3/5X,' FLUE DUST',15X,F6.3/5X,' COKE BREEZE',13X,F6.3/5X,'
3MOISTURE',16X,F6.3/5X,' RETURN FINES',12X,F6.3)
9 CONTINUE
200 STOP
END

```

```

SUBROUTINE MATA(R,A,H,P,Q,RR,S,T)
  DIMENSION R(10,10),A(10,10)
  DO 15 J=1,7
    A(1,J)=1.0
15  CONTINUE
    DO 20 I=1,7
      A(2,I)=R(I,5)+R(I,6)-H*(R(I,3)+R(I,4))
20  CONTINUE
      DO 45 I=1,7
        A(3,I)=R(I,6)-P*R(I,1)
45  CONTINUE
        DO 25 I=1,3
          A(4,I)=R(I,1)
25  CONTINUE
          A(4,4)=R(4,1)-1000.0/Q
          DO 35 I=5,7
            A(4,I)=R(I,1)
35  CONTINUE
            DO 40 I=1,7
              A(5,I)=R(I,7)-RR*R(I,1)
40  CONTINUE
              DO 50 I=1,5
                A(6,I)=R(I,1)
50  CONTINUE
                A(6,6)=R(6,1)-1000.0/S
                A(6,7)=R(7,1)
                DO 55 I=1,6
                  A(7,I)=R(I,1)
55  CONTINUE
                  A(7,7)=R(7,1)-1000.0/T
                RETURN
              END
C    SUBROUTINE SUBPROGRAM TO FORM MATRIX V
      SUBROUTINE MATRV(R,Y1,Y2,Y3,H,P,RR,V)
        DIMENSION R(10,10),V(10)
        V(1)=100.0-(Y1+Y2+Y3)
        V(2)=Y1*(H*(R(8,3)+R(8,4))-(R(8,5)+R(8,6)))
        V(3)=Y1*(R(8,1)*P-R(8,6))
        V(4)=-Y1*R(8,1)
        V(5)=Y1*(R(8,1)*RR-R(8,7))
        V(6)=-Y1*R(8,1)
        V(7)=-Y1*R(8,1)
        RETURN
      END
C    SUBROUTINE FOR INVERSION OF THE MATRIX
      SUBROUTINE INVERT(A,N,AI)
        DIMENSION A(10,20),AI(10,10)
        M=N+N
        M2=N+1
        DO 75 LI=1,N
          DO 75 LJ=M2,M
            A(LI,LJ)=0.0
75  CONTINUE
            DO 80 K=1,N
              I2=K+N
              A(K,I2)=1.0
80  CONTINUE

```

```

      T=A(L,L)
      DO 95 K=1,M
      A(L,K)=A(L,K)/T
95    CONTINUE
      DO 100 I=1,N
      S=A(I,L)
      DO 100 K=1,M
      IF(I.EQ.L)GO TO 100
      A(I,K)=A(I,K)-S*A(L,K)
100   CONTINUE
85    CONTINUE
      DO 110 I=1,N
      DO 110 IA=M2,M
      L3=IA-N
      AI(I,L3)=A(I,IA)
110   CONTINUE
      RETURN
      END
C     SUB ROUTINE TO MULTIPLY A MATRIX BY A VECTOR
      SUBROUTINE MATV(A,V,X,N)
      DIMENSION A(10,10),V(10),X(10)
      DO 115 I=1,N
      SUM=0.0
      DO 120 K=1,N
120   SUM=SUM+A(I,K)*V(K)
115   X(I)=SUM
      RETURN
      END

```